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CALCULATIONS OF SHIPBOARD HEAT EXCHANGERS,(U)
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FOREIGN TECHNOLOGY DIVISION

CALCULATIONS OF SHIPBOARD HEAT EXCHANGERS

by

A. S. Tsygankov

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By: A. S. Tsygankov

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

Page 1.

CALCULATIONS OF SHIPBOARD HEAT EXCHANGERS.

Reference textbook.

A. S. Tsygankov.

Page 2.

In the book is generalized and systematized the calculated material, accumulated in the process of designing the heat exchangers. The book is a reference textbook of practical nature and does not contain theoretical linings/calculations and substantiation. The systematization of the given material allows with the minimum expenditure of time sufficient to full-valued produce the necessary linings/calculations and calculations.

The book is intended for the technical-engineering workers (designers and builder-heat technicians) can also serve as textbook for the students of ship-building and energy call and students of technical schools.

Page 3.

Preface.

Heat exchangers are the composite/compound equipment component of the power plants, which have extensive application in the industry, and also on the vessels of civil/civilian and serviceman of fleets.

The creation of the ideal and reliable equipment, which corresponds to the contemporary level of development of technology, requires the thorough study of occurring in the apparatuses processes and technology of their production on the basis of experimental investigations and production experiment.

In the past postwar years is carried out the series/row of scientific research and experimental works on heat engineering, which contributed to accumulation of considerable experience according to the design, to production and testing of heat exchangers and served as basis for writing of this book.

This edition of the book differs from the publication 1948 [1] of the more detailed treatment of the questions, connected with the heat

transfer, hydraulic resistance and structural strength of heat exchangers.

FOOTNOTE [1]. A. S. Tsygankov. Calculations of shipboard heat exchangers. Sudpromgiz, 1948. ENDFOOTNOTE.

The obsolete calculation formulas are replaced here by modern ones. During the treatment/processing of the book is taken into consideration also the majority of observations and wishes of the reviewers and readers.

Page 4.

For the purpose of warning/prevention of the errors and for the savings of time with the execution of calculations in the book are given typical examples of the thermal designs of the most widely used apparatuses and examples of the calculations of hydraulic resistances for different working media, which take place in their cavities.

In the book is given the single procedure of calculation of different tube plates and are given examples of the calculation of the strength of the basic parts of apparatuses.

The section of applications/appendices is renovated and

supplemented by new tabulated data of the physical parameters of the working media of heat exchangers.

A. Tsygankov.

Page 5.

Chapter I.

THERMAL DESIGNS.

§1. Pressures and rarefaction/evacuation.

By the pressure is understood the force, which acts per unit of surface. Working standard of pressure is called technical atmosphere, i.e., the pressure, produced by force in 1 kg to 1 cm^2 of surface.

In the rarefaction/evacuation, or the vacuum, is understood the difference between the pressure of the external atmosphere and the absolute pressure in the place of measurement, while by the overpressure - a difference between the absolute and atmospheric pressures. Absolute pressure is expressed in the absolute atmospheres, and vacuum - in the millimeters of mercury or water column, and also in the percentages.

Normal barometric pressure, or physical atmosphere:

$B=760$ mm Hg $=1.033$ kg/cm^2.

The technical atmosphere:

p =1 at=1 kg/cm²=735.6 mm Hg with 0°C;

p=737.4 mm Hg with 15°C;

p~~10 m H_2O with 4°C.

Absolute, either real, pressure:

$$\left.\begin{aligned} p_a &= p_b + p \\ p_a &= p_b - p_h \end{aligned}\right\} \qquad (1)$$

where p_b - atmospheric, or barometric, pressure, mm Hg;

p - overpressure (reading manometer), mm Hg.

p_h - vacuum, or rarefaction/evacuation (reading vacuum gauge), mm Hg.

Page 6.

Pressure at any point within the liquid:

$$p = p_0 + \gamma z \text{ kg/m}^2, \qquad (2)$$

where p_0 - pressure above the surface of liquid, kg/m²;

γ - the specific gravity/weight of liquid, kg/m³;

z - submersion depth of point under the surface of liquid, m.

The force of pressure of liquid on the flat/plane vertical wall:

$$P = (p_0 + \gamma z_{cr}) F \text{ kg}, \qquad (3)$$

where z_{cr} - height/altitude, equal to the submersion depth of the geometric center of wall, m;

F - area of wall, m².

The force of pressure of liquid on the inclined wall:

$$P = (p_0 + \gamma z_{cr}) F \cos\alpha \text{ kg}, \qquad (4)$$

where α - angle of component with the normal to the wall.

During the determination of force of pressure on the curved

surface of wall into formula (4) instead of F cos α is substituted the projection of surface, perpendicular to force direction

The pressure of vapor or gas (characteristic equation):

$$p = \frac{RT}{v} \text{ kg/m}^2, \qquad (5)$$

where R - gas constant, kg-m/kg °K: for the saturated water vapor R=47.05, for air R=29.27;

T=273.2+t°C - absolute temperature, °K;

v - specific volume, m³/kg.

Absolute condenser backpressure:

$$\left.\begin{aligned} p_к &= b - h \text{ мм рт. ст.}^{(1)} \\ p_к &= \frac{b-h}{735{,}6} \text{ ата}^{(2)} \\ p_к &= \left(1 - \frac{p_h}{100}\right) 735{,}6 \text{ мм рт. ст.}^{(3)} \end{aligned}\right\} \qquad (6)$$

Key: (1). mm Hg. (2). atm(abs.).

where b - reading barometer, mm Hg;

h - reading vacuum gauge, mm Hg;

p_h - vacuum in the capacitor/condenser, c/c.

Rarefaction/evacuation in the capacitor/condenser:

$$p_h = \frac{735{,}6 - p_к}{735{,}6} 100, \%, \qquad (7)$$

where $p_к$ - the same as in formula (6).

Page 7.

The pressure of mixture in the capacitor/condenser:

$$p_{см} = p_п + p_в \text{ мм Hg} \qquad (8)$$

where $p_п$ - partial pressure of vapor, мм Hg;

$p_в$ - partial air pressure, мм Hg.

Partial pressure of vapor can be determined according to tables 1 and 2 for the water vapor (see applications/appendices) in depending on the temperature of mixture.

Partial pressure of vapor in the air-steam mixture:

$$p_п = \frac{p_{см}}{1 + 0.622 \frac{G}{D}} \text{ мм Hg} \qquad (9)$$

Partial air pressure in the air-steam mixture:

$$p_в = \frac{p_{см}}{1+1{,}61\,\frac{D}{G}}, \text{ мм Hg} \qquad (10)$$

Here $p_{см}$ - pressure of mixture in capacitor/condenser, мм Hg;

D - quantity of that entering capacitor/condenser of vapor, kg/h;

G - quantity of air, kg/h.

Critical pressure of vapor (atm(abs.)):

$$\left.\begin{array}{l}(1)\ \text{насыщенного}\ p_{кр} = 0{,}577\ p_0 \\ (2)\ \text{перегретого}\ p_{кр} = 0{,}574\ p_0\end{array}\right\}, \qquad (11)$$

Key: (1). saturated. (2). overheated.

where p_0 - initial pressure of vapor, atm(abs.).

Water vapor pressure - see applications/appendices, Table 1 and 2.

Selection of design pressures.

The pressure of cooling water in the branch pipes of pumps for the capacitors/condensers, the oil coolers, the coolants of condensate and other similar to them apparatuses and the pressure of the preheated feed outboard water in the preheaters for the vaporizers/evaporators is accepted from the conditions of overcoming the losses of head in the system of this conduit/manifold, in the established/installed on it apparatuses and the accessories, and also in depending on final counterpressure.

Usually the calculated water pressure p is:

1) for the capacitors/condensers and the oil coolers 8-25 m H_2O;

2) for the vaporizers/evaporators 15-40 m water column.

Page 8.

Vapor pressure p of the heating for feed heaters of first stage usually is approximately 1.5-2.5 atm(abs.), since in essence for preheating water in the preheaters is utilized the exhaust steam from the auxiliary mechanisms of a machine-boiler installation.

Vapor pressure p of the heating for feed heaters of the second and third steps/stages is 5 atm(abs.) and it is above. For this

purpose is utilized the exhaust steam from the group of the auxiliary mechanisms, which work to the increased counterpressure, or the vapors from main turbines.

Vapor pressure p of the heating in oil heaters usually is accepted on 3-5 atm(abs.) higher than pressure of petroleum and in the majority of the cases is 20-25 atm(abs.).

For some types of injectors the pressure of petroleum can reach 40 atm(abs.). In this case, and also at the pressures of petroleum, which exceed pressure of vapor it is expedient to apply oil heaters with the dual tube plates or sectional oil heaters which work on the high parameters of vapor.

Pressure p of that heating (primary) vapor in the vaporizers/evaporators is recommended the accepting of:

1) for the vacuum evaporators 1.5-2.5 atm(abs.) (usually as heating steam is utilized the exhaust steam from the auxiliary mechanisms);

2) for the vaporizers/evaporators, which work under the positive pressure, 3-5 atm(abs.) (is applied also the mastered or throttled live steam).

During the pollution/contamination of the heating coils the vapor pressure of the heating for the purpose of the maintenance of productivity, can be increased to 8 atm(abs.).

Pressure p_2 of the secondary steam in the vaporizers/evaporators, as a rule, is accepted:

	(1) ата
(2) Для вакуумных одноступенчатых	0,5—0,8
(3) Для вакуумных циркуляционных	0,3—0,7
(4) Для вакуумных двухступенчатых:	
(4a) в первой ступени	0,6—0,8
(4b) во второй ступени	0,2—0,4
(5) Для атмосферных, а также для испарителей с давлением выше атмосферы	1,0—2,0

Key: (1). atm(abs.). (2). For vacuum single-stage ones. (3). For vacuum circulation ones. (4). For vacuum two-stage ones. (4a). in first stage. (4b). in the second step/stage. (5). For atmospheric ones, and also for vaporizers/evaporators with pressure higher than atmosphere.

Vapor pressure p of the heating for the atmospheric and vacuum deaerators is received as 1.2-2.0 atm(abs.) (usually is utilized the exhaust steam).

Operating pressure in the housings of deaerators is accepted:

1) in vacuum 0.1-0.9 atm(abs.);

2) in atmospheric 1.1-1.4 atm(abs.).

Vapor pressure p of working in the steam-air ejectors is usually received as 10 atm(abs.) and it is above.

Page 9.

Vacuum in the capacitors/condensers depends on a number of factors (principal of them are temperature and quantity of cooling water) and is usually within the limits:

1) for the shipboard turbine plants from $p_k = 95\%$ with $t_1 = 15°C$ to $p_k = 90\%$ with $t_1 = 30°C$;

2) for stationary installations $p_k = 96 - 97{,}5\%$ with $t_1 = 10-15°C$ or during the cooling by river water in the unlimited quantity;

3) for installation with steam engines vacuum p_k in essence is limited by the sizes/dimensions of low-pressure cylinder and it usually composes 85-87c/c.

Absolute condenser backpressure near the place of air exhaust

(to avoid the overexperditure of energy to the exhaust device/equipment and an increase in its dimension) must be not less than 25 mm Hg:

$$p_к' = p_к - \Delta p,$$

where $p_к$ - absolute condenser backpressure, mm Hg;

Δp - steam resistance of capacitor/condenser, mm Hg.

§2. Temperatures and their difference.

Temperature characterizes the degree of the warmth of body. Temperature is measured in the degrees according to international thermometric scale, according to which temperature of the fusion of ice at the normal atmospheric pressure is designated through 0°C, while the boiling point of water - through 100°C. The temperature, measured according to the international scale, is designated by letter t, and its scale - °C.

Temperaure counted off from the absolute of zero temperatures, is called the absolute temperature:

$$T = 273{,}2 + t, \text{°K}, \qquad (12)$$

where t - temperature, °C.

Mean temperature of the heat-transfer agent:

$$t_{ср} = 0{,}5\,(t_1 + t_2)\,\text{°C}, \qquad (13)$$

where t_1 - initial temperature of heat-transfer agent, °C;

t_2 - final temperature of heat-transfer agent, °C.

Mean temperature of the mixture:

$$t_{cm} = \frac{G_1c_1t_1 + G_2c_2t_2 + \dots}{G_1c_1 + G_2c_2 + \dots} \text{°C}, \qquad (14)$$

where G_1, G_2 - weights of the components, entering the mixture, kg;

c_1, c_2 - average/mean heat capacities of components, kcal/kg°C;

t_1, t_2 - temperature of components, °C.

Page 10.

Mean temperature of the wall, which divides two heat-transfer agents:

$$t_{cr}^{cp} = 0{,}5\left(\frac{t_1 + t_2}{2} + \frac{t_1' + t_2'}{2}\right) \text{°C}, \qquad (15)$$

where t_1, t'_1 - initial temperatures of heat-transfer agents, °C;

t_2, t'_2 - final temperatures of heat-transfer agents, °C.

Mean temperature of the surface of the wall:

$$t \approx 0{,}5(t_{cp} + t_{ст}^{cp})\,^{\circ}C, \qquad (16)$$

where t_{cp} - mean temperature of heat-transfer agent, °C;

$t_{ст}^{cp}$ - mean temperature of wall, °C.

Formulas (15) and (16) it is possible to use also for determining approximate value of the temperature of the surface of wall with small differences in the temperatures of heat-transfer agents.

Temperature of the surface of single-layer wall [1]:

1) internal

$$t_{ст_1} = \frac{\alpha_1 t_1 + A t_2}{\alpha_1 + A}\,^{\circ}C, \qquad (17)$$

$$t_{ст_1} = t_{ст_2} + q\frac{s}{\lambda}\,^{\circ}C; \qquad (18)$$

2) external

$$t_{ст_1} = \frac{t_1 + \alpha_2 B t_2}{1 + \alpha_2 B}\,^{\circ}C, \qquad (19)$$

$$t_{ст_2} = t_{ст_1} - q\frac{s}{\lambda}\,^{\circ}C, \qquad (20)$$

where t_1 - temperature of medium from inside of wall, °C;

t_2 - temperature of medium from the face of wall, °C;

α_1 - heat-transfer coefficient of medium from inside of wall, kcal/m²h °C;

α_2 - heat-transfer coefficient of medium from the face of wall, kcal/m²h °C;

q - quantity of heat, transferred of 1 m² of the surface of wall, kcal/m²h;

s - wall thickness, m;

λ - coefficient of the thermal conductivity of wall, kcal/m-hour °C;

A and B - values, determined according to the formulas:

$$A = \frac{1}{\frac{s}{\lambda} + \frac{1}{\alpha_2}}; \quad B = \frac{1}{\alpha_1} + \frac{s}{\lambda}.$$

FOOTNOTE [1]. For calculating the temperatures of the surface of wall the heat-transfer coefficients of medium α_1 and α_2 in the first calculation are received tentatively according by this on page 74, and then, according to the determination of their values, in that produced the calculation again is done the refined calculation of

these temperatures. ENDECCINCIE.

Page 11.

The temperatures of the surface of walls $t_{ст1}$ and $t_{ст2}$ can be determined graphically (Fig. 1) as follows.

On the x axis plot/deposit value s/λ, and on both sides from it the cuts, equal to $1/\alpha_1$ and $1/\alpha_2$ from ends/leads of which are established the perpendiculars.

At a distance of t_1 and t_2 from the axis/axle x-оß and in parallel to it draw a line of temperatures, which intersect with the perpendiculars at points a and в. Straight line, which connects these points, intersects the surface of wall at points c and d and gives unknown temperatures $t_{ст1}$ and $t_{ст2}$.

Mean temperature of the boundary layer:

$$t_{гр} = 0{,}5\,(t_{ср} + t_{ст})\,°C. \qquad (21)$$

where $t_{ср}$ - mean temperature of medium, °C;

$t_{ст}$ - temperature of wall, determined according to formulas (17)-(20) or by graphic method, °C.

By formulas (15) -(21) used during the calculation of heat transfer and hydraulic resistance.

During the derivation of calculation formulas on heat exchange and hydraulic resistance from conducted experiments the individual authors applied the different methods of calculating the determining temperature in order to consider the effect of heat flux. Some of them as the determining temperature accepted the temperature of wall t_{cr}, determined according to formulas (17)-(20), others - mean temperature of medium t_{cp}, determined according to formula (13), the third - different combinations, the fourth - mean temperature of boundary layer t_{rp}, determined according to formula (21) and, etc.

Using calculation formulas on heat exchange and hydraulic resistance, it is necessary the determining temperature to calculate by that method which was used with the derivation of calculation formula.

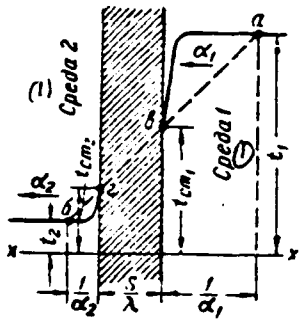

Fig. 1.

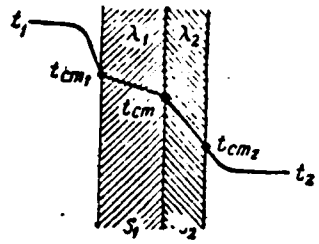

Fig. 2.

Fig. 1. Graph/curve of determination of temperature of surface of wall.

Key: (1). Medium.

Fig. 2. Graph/curve of determination of temperature of surface of two-layered wall.

Page 12.

Temperature of the surface of two-layered wall (Fig. 2):

1) the external surface of the first layer of the wall

$$t_{ст_1} = \frac{\left(\alpha_1 C + \frac{\alpha_1}{\alpha_2} D\right) t_1 + D t_2}{\alpha_1 C + \frac{\alpha_1}{\alpha_2} D + D} \text{ °C;} \qquad (22)$$

2) the external surface of the second layer of the wall

$$t_{ст_2} = \frac{\alpha_1 D t_1 + (\alpha_2 D + \alpha_1 \alpha_2 C) t_2}{(\alpha_1 + \alpha_2) D + \alpha_1 \alpha_2 C} \text{ °C;} \qquad (23)$$

3) on the boundary between the layers of the walls

$$t'_{ст} = t_{ст_1} - q \frac{s_1}{\lambda_1} = t_{ст_2} + q \frac{s_2}{\lambda_2} \text{ °C.} \qquad (24)$$

Here α_1 - heat-transfer coefficient of the first layer, kcal/m²h °C;

α_2 - heat-transfer coefficient of the second layer, kcal/m²h °C;

t_1 - temperature of medium from the side of the first layer, °C;

t_2 - temperature of medium from the side of the second layer, °C;

s_1 - the wall thickness of the first layer, m;

s_2 - the wall thickness of the second layer, m;

λ_1 - coefficient of the thermal conductivity of the first layer of wall, kcal/m-hour C;

λ_2 - coefficient of the thermal conductivity of the second layer of wall, kcal/m-hour °C;

q - quantity of heat, transferred of 1 m² of the surface of wall, kcal/m²h;

C and D - value, they are determined according to the formulas:

$$C = \frac{\lambda_1}{s_1} + \frac{\lambda_2}{s_2}; \; D = \frac{\lambda_1}{s_1}\frac{\lambda_2}{s_2}.$$

The temperature of the air, driven out from the capacitor/condenser, is accepted:

1) according to data of the experiments

$$t_n = t_1 + 4 + 0{,}1\,(t_2 - t_1)\ ^\circ\mathrm{C}; \qquad (25)$$

2) according to the data of the practice

$$t_n = t_1 + (3 \div 5)\ ^\circ\mathrm{C}, \qquad (26)$$

where t_1 - temperature of cooling water upon the entrance into the capacitor/condenser, °C;

t_2 - temperature of cooling water on leaving from the capacitor/condenser, °C.

Calculations according to formulas (25) and (26) give close results.

Page 13.

The temperature of the superheated steam which at the saturation pressure is condensed as the saturated steam:

$$t_{пп} = t_п + 0{,}0001515\, \alpha_в\, (t_п - t_в)\ ^\circ\mathrm{C}, \qquad (27)$$

where $t_п$ - saturation temperature, which corresponds to condenser backpressure, °C;

$\alpha_в$ - heat-transfer coefficient of water, kcal/m²h °C;

$t_в$ - temperature of cooling water upon the entrance into the capacitor/condenser, °C.

Formula (27) is applied during the determination of the cooling surface of capacitor/condenser, if it is necessary to lower the temperature of the superheated steam before its condensation.

The temperature of the saturated water vapor tentatively can be

determined according to the following approximated formulas:

$$t_н \approx 100\sqrt[4]{p_н}\ °C\ \text{при}\ p_н = 1{,}0-25\ ama; \quad (28)$$

$$t_н \approx 100\sqrt[3]{p_н}\ °C\ \text{при}\ p_н = 0{,}1-1{,}0\ ama; \quad (29)$$

$$t_н \approx 145\sqrt{p_н}\ °C\ \text{при}\ p_н = 0{,}03-0{,}1\ ama, \quad (30)$$

Key: (1). with. (2). atm(abs.).

where $p_н$ - pressure of saturated steam, atm(abs.).

The temperature of water vapors - see appendices table 1 and 2.

Difference in the temperatures.

By a difference in the temperatures is understood the heat drop between the final and initial temperatures, while by the average/mean difference - an heat drop between mean temperatures of heat-transfer agents.

Quantity of heat, transferred through the surface during the heat exchange, proportional to an average/mean difference in temperatures.

With a uniform and small temperature drop along the length of surface of heating or cooling) an average/mean difference in the

temperatures will be aritnmetical, which is changed on the straight line from the initial tc final difference.

With the more interse heat exchange and large differences in the temperatures, which usually is cbserved in the heat exchangers, a temperature drop along the length cf surface is uneven; in this case an average/mean difference in the temperatures will be logarithmic, which is changed on the curve from the initial tc a finite difference in the temperatures of heat-transfer agents.

Page 14.

If relation $\frac{t_2-t_1}{t_2-t_1'}<2$, then a difference in the temperatures between the average/mean logarithmic and arithmetic mean does not exceed 4o/o. In this case it is possible tc use fcrmulas (32) and (33) arithmetic mean differences in the temperatures.

The value of an average/mean difference in the temperatures depends not only on the values cf the initial and final temperatures of heat-transfer agents, but alsc cn the directicn of the motion of their flow.

The schematics cf the directicn of the mcticn of heat-transfer agents, which are usually enccuntered during the calculation cf an

average/mean difference in the temperatures in the apparatuses, are given in Fig. 3.

A difference in the temperatures of the heat-transfer agents

$$\delta t = t_2 - t_1 \,^\circ\mathrm{C}, \qquad (31)$$

where t_2 - the greatest temperature of heat-transfer agent, °C;

t_1 - the minimum temperature of heat-transfer agent, °C.

Arithmetic mean difference in the temperatures:

1) for the unidirectional flow

$$\delta t = 0{,}5\,[(t_1 - t_1') + (t_2 - t_2')]\ ^\circ\mathrm{C}; \qquad (32)$$

2) for the countercurrent

$$\delta t = 0{,}5\,[(t_1 - t_2') + (t_2 - t_1')]\ ^\circ\mathrm{C}, \qquad (33)$$

where t_1, t'_1 - initial temperatures of heat-transfer agents, °C;

t_2, t'_2 - the final temperatures of heat-transfer agents, °C.

The diagram of a change in the temperatures of heat-transfer agents and arithmetic mean difference in the temperatures in the dependence on the direction of coolant flows is depicted in Fig. 4. Lines AB and CD show a change in the temperatures over surface of F with the countercurrent, lines AB and C'D' - with the unidirectional flow.

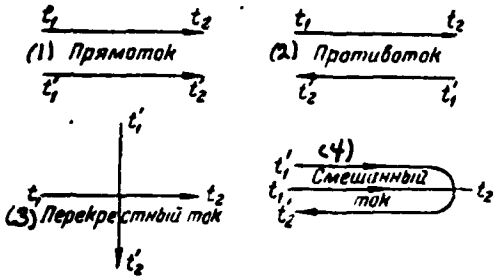

Fig. 3.

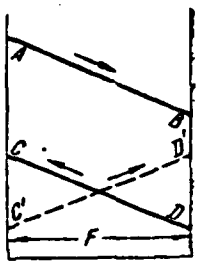

Fig. 4.

Fig. 3. Schematics of direction of motion of heat-transfer agents.

Key: (1). Unidirectional flow. (2). Countercurrent. (3). Crosscurrent. (4). Displaced current.

Fig. 4. Diagrams of change arithmetic mean difference in temperatures.

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Average/mean logarithmic difference in the temperatures:

1) for the unidirectional flow

$$\Delta t = \frac{(t_1 - t_1') - (t_2 - t_2')}{2{,}3 \lg \frac{t_1 - t_1'}{t_2 - t_2'}} \text{ °C.} \qquad (34)$$

The diagram of a change in the temperatures over surface of F with the unidirectional flow is depicted in Fig. 5;

2). for the countercurrent

$$\Delta t = \frac{(t_1 - t_2') - (t_2 - t_1')}{2{,}3 \lg \frac{t_1 - t_2'}{t_2 - t_1'}} \text{ °C.} \qquad (35)$$

The diagram of a change in the temperatures over surface of F with the countercurrent is given in Fig. 6;

3) for mixed and crosscurrent:

$$\Delta t = \frac{(t_1 - t_2') - \left(t_2 - \frac{t_1' + t_2'}{2}\right)}{2{,}3 \lg \frac{t_1 - t_2'}{t_2 - \frac{t_1' + t_2'}{2}}} \text{ °C.} \qquad (36)$$

The diagram of a change in the temperatures over surface of F with the mixed current is represented in Fig. 7;

4) for the case when temperature of one of the heat-transfer agents (for example, condensable vapor) is permanent, the difference between the unidirectional flow and the countercurrent disappears and

the formula of an average/mean logarithmic difference in the temperatures takes the following form:

$$\Delta t = \frac{t_2 - t_1}{2{,}3 \lg \frac{t - t_1}{t - t_2}} \,^{\circ}\mathrm{C}. \qquad (37)$$

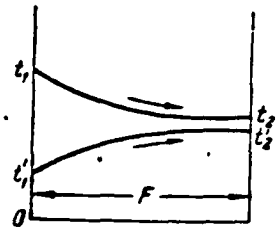

Fig. 5.

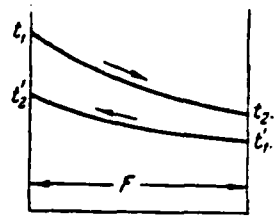

Fig. 6.

Fig. 5. Diagram of change in temperatures with unidirectional flow.

Fig. 6. Diagram of change in temperatures with countercurrent.

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The diagram of a change in the temperatures over surface of F during the heat exchange when one of the heat-transfer agents has permanent temperature, is given in Fig. 8:

5) for single-flow capacitors/condensers with crosscurrent of water and steam according to experimental data:

$$\Delta t = \frac{t_2' - t_1'}{2{,}3 \lg \left[\frac{1}{1 - 2{,}3 \frac{t_2' - t_1'}{t_1 - t_2} \lg \frac{t_1 - t_1'}{t_2 - t_1'}} \right]} \text{°C.} \qquad (38)$$

6) for the capacitors/condensers of two-flowing ones and more:

$$\Delta t = \frac{(t_2 - t_1') - (t_1 - t_2')}{2{,}3 \lg \frac{t_2 - t_1'}{t_1 - t_2'}} \text{ °C} / \qquad (39)$$

Here t - permanent temperature of heat-transfer agent, °C;

t_1, t'_1 - initial temperatures of heat-transfer agents, °C;

t_2, t'_2 - the final temperatures of heat-transfer agents, °C.

In formulas (38) and (39) as the initial temperature of vapor t_1 is accepted saturation temperature of vapor which corresponds to absolute condenser backpressure, and for the final - saturation temperature of vapor t_2, which corresponds to absolute condenser backpressure about the place of air exhaust.

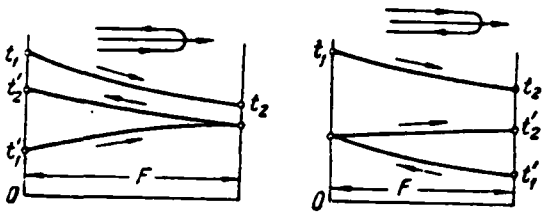

Fig. 7.

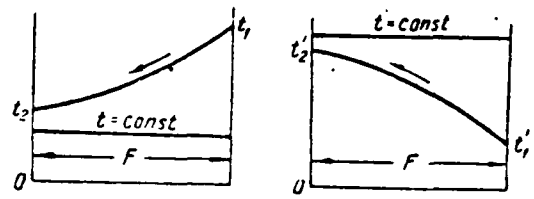

Fig. 8.

Fig. 7. Diagram of change in temperatures with mixed current.

Fig. 8. Diagram of change in temperatures during heat exchange when one of heat-transfer agents has permanent temperature.

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If heat-transfer agent is the superheated steam and if the temperature of the walls of the tubes lower than temperature of its saturation, then in formula (34) of an average/mean logarithmic difference in the temperatures is substituted the temperature of saturation, and not superheated steam, which corresponds to its pressure.

For the apparatuses with the more complicated crossed and mixed current the calculation of average/mean differences in the

temperatures becomes complicated by mathematical calculations. In this case their calculation can be produced according to formula (35) with the subsequent multiplication of result for correction factor ε, determined on the graphs/curves of Fig. 9-12, given for different flow charts of heat-transfer agents.

On these graphs/curves the value of coefficient ε is given as the function of two dimensionless quantities $\varepsilon = f(P,R)$, equal to:

$$P = \frac{t_2' - t_1'}{t_1 - t_1'}; \qquad R = \frac{t_1 - t_2}{t_2' - t_1'}.$$

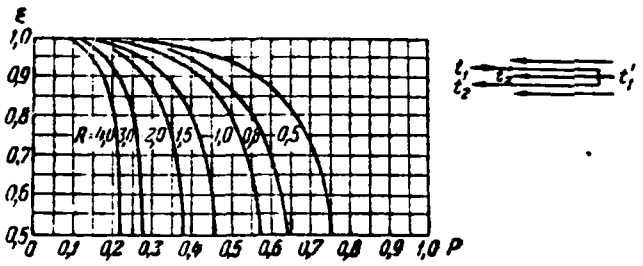

Fig. 9. Values of correction factor $\varepsilon = f(P,R)$ for determining the average/mean logarithmic difference in the temperatures in the compound circuit of the motion of liquids.

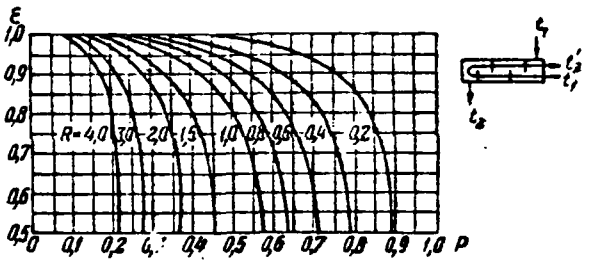

Fig. 10. Values of correction factor $\varepsilon = f(P,R)$ for determining average/mean logarithmic difference in temperatures in compound circuit of motion of liquid.

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The relationship/ratio of average/mean differences in the temperatures in the two-stage evaporator with the equal heating

surfaces in each step/stage

$$\frac{\Delta t_1}{\Delta t_2} = \frac{Q_1}{k_1} : \frac{Q_2}{k_2}, \qquad (40)$$

where Δt_1 - an average/mean difference in the temperatures in first stage, °C;

Δt_2 - average/mean difference in the temperatures in the second step/stage, °C;

Q_1 - rate of heat transmission in first stage of vaporizer/evaporator, kcal/h;

Q_2 - rate of heat transmission in second step/stage, kcal/h;

k_1 - coefficient of heat transfer in first stage, kcal/m²h °C;

k_2 - coefficient of heat transfer in second stage, kcal/m²h °C.

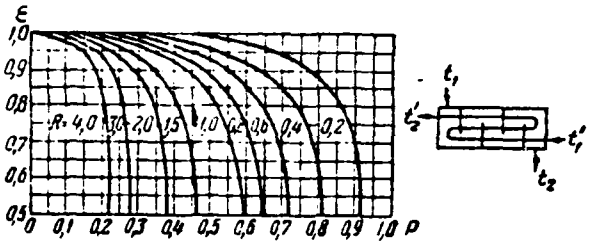

Fig. 11. Values of correction factor $\varepsilon = f(P,R)$ for determining the average/mean logarithmic difference in the temperatures in the compound circuit of the motion of liquid.

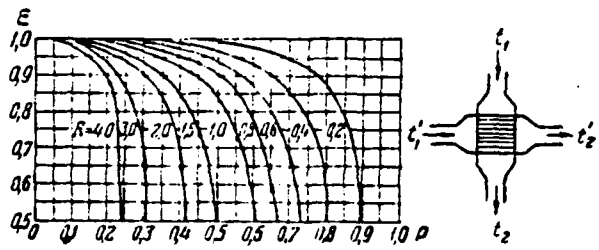

Fig. 12. Values of correction factor $\varepsilon = f(P,R)$ for determining average/mean logarithmic difference in temperatures in compound circuit of motion of liquid.

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Selection of calculated temperatures.

The temperature of the outboard water: 1) the initial calculated

temperature t_1 of the cooling or preheated outboard water is equal to approximately/exemplarily 15-20°C;

2) the final calculated temperature t_2 of the cooling outboard water:

In the oil coolers ... 20-25°C.

In the capacitors/condensers ... 23-32°C.

Increase in the temperature Δt of cooling water in the capacitors/condensers:

Two-pass and more than ... 8-11°C.

Single-pass ... 6-8°C.

For the capacitors/condensers, which work with $p \geqslant 0.1$ atm(abs.), $\Delta t = 13-17$°C.

The final calculated temperature t_2 of the preheated outboard water in the preheaters of vaporizers/evaporators is usually received as 60-90°C; in the preheaters of the circulation vaporizers/evaporators:

At a pressure in housing of the vaporizer/evaporator 0.7 atm(abs.) ... 104-106°C.

At a pressure in the housing of the vaporizer/evaporator 0.3 atm(abs.) ... 85°C.

Temperature of feed water. The initial temperature of feed water in the preheaters is usually the temperature of the condensate, which enters from the capacitor/condenser, taking into account its increase in steam-jet airs ejector, mixers and other apparatuses, if they are established/installed on the way from capacitor/condenser to the preheater, or the temperature of condensate in by heat box.

Initial calculated temperature t_1 of feed water usually lies/rests within limits of 36-50°C.

Final temperature t_2 of feed water in the preheaters is selected in depending on the thermal circuit of installation and number of steps/stages of preheaters in it, and also on the construction/design of boiler, and usually it is accepted:

	°C
(1) При одноступенчатом подогреве	95—115
(2) При двухступенчатом подогреве	120—170
(3) При трехступенчатом подогреве	170—220

Key: (1). With the single-stage of preheating. (2). With two-stage preheating. (3). During three-stage preheating.

Temperature t of the heated water in the atmospheric deaerators is received as 102-104°C, and in the vacuum ones - corresponding to the boiling point with this working pressure in the housing of deaerator.

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The temperature of heating steam: 1) for the vaporizers/evaporators minimum temperature t of the saturation higher than temperature of the secondary steam on 15-20°C, but maximum (with the superheated steam) is not higher than 200-230°C;

2) for the deaerators (with the mastered superheated steam) t=180-230°C;

3) for feed heaters and preheaters of the circulation vaporizers/evaporators, which work on the exhaust steam, t≤230°C;

4) for the preheaters of usual evaporative installations (vacuum or working under the pressure) preheating water is conducted by the secondary steam of vaporizers/evaporators or by condensate of heating steam.

The temperature of the petroleum: 1) the initial calculated temperature t_1 of petroleum in heaters of fuel/propellant is received as 10-15°C;

2) the final calculated temperature t_2 of petroleum usually is taken within limits of 90-95°C;

The temperature of oil: 1) the initial temperature t_1 of oil upon the entrance in oil coolers usually is approximately 55-60°C;

2) final temperature t_2 of oil, which emerges from the oil cooler:

For the lubrication of the bearings of shafting, turbines, reducer, etc. ... 45-55°C.

For the lubrication of the teeth of reducer and automatic

control ... 35-45°C.

The selection of the calculated temperatures of oil is conducted in the dependence on the viscosity of oil used: the less the viscosity of oil, the is accepted below the temperature of lubrication and vice versa.

A difference in the temperatures Δt between the initial temperature of the heating (cooling) medium and the final temperature of heated (cooled) medium must comprise not less than 8-10°C.

A difference in the temperatures in the capacitor/condenser between the condensable vapor and the cooling water on leaving on the average comprises:

	°C
(1) Для стационарных турбин	4,5—6,5
(2) Для поршневых паровых машин	8,5—11
(3) Для корабельных турбоустановок средней мощности (18—35 тыс. л. с.)	22—28
(4) Для корабельных турбоустановок большой мощности (50—65 тыс. л. с.)	8,5—11
(5) Для коммерческих судов с паровыми турбинами	6,5—8,5
(6) Для коммерческих судов с паровыми машинами	14—16,5

Key: (1). For the stationary turbines. (2). For piston steam machines. (3). For ship turboinstallations of average/mean power (18-35 thousand hp). (4). For ship turboinstallations of large power (50-65 thousand hp). (5). For commercial vessels with steam turbines. (6). For commercial vessels with steam engines.

A difference in the temperatures Δt between the primary and secondary steam of vaporizers/evaporators it is expedient to assign within limits of 20-30°C.

A difference in the temperatures Δt between the temperature of the entrance of water into the circulation vaporizer/evaporator and the temperature of the output of brine from the vaporizer/evaporator is received as 12-15°C.

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Difference in the temperatures Δt between the temperature of condensation and the temperature of condensate on leaving from the capacitor/condenser:

In the regenerative capacitors/condensers ... 1°C.

In the nonregenerative capacitors/condensers ... 4°C.

A difference in the temperatures between the temperature of the condensable vapor and the temperature of air, i.e., the possible value of supercooling condensate in the condensers of the type O-V for guaranteeing the regeneration

$$\Delta t = t_s - t_n + 3^\circ C,$$

where t_s - condensation temperature of vapor, °C;

t_0 - temperature of the air, driven out from the capacitor/condenser, °C.

§3. Volumes and weights.

By the specific volume of substance is understood the ratio of the volume, occupied by substance, to its weight. Unit the measurement of specific volumes - m^3/kg or cm^3/g.

The value, reciprocal to specific volume, it is the specific gravity/weight of substance and is designated by letter γ. Dimensionality of specific gravity/weight - kg/m^3 or g/cm^3.

The mass of unit volume is called density and is designated by letter ρ.

The specific volume of the medium:

$$v = \frac{V}{G} = \frac{1}{\gamma} \ m^3/kg, \qquad (41)$$

where V - volume, occupied by medium, the m^3;

G - weight of medium, kg;

γ - the specific gravity/weight of medium, kg/m³.

The specific volume of vapors and gases (characteristic equation):

$$v = \frac{RT}{p} \text{ m}^3/\text{kg}, \qquad (42)$$

where T - absolute temperature, °K;

p - pressure of vapor or gas, kg/m²;

R - gas constant, kg-m/kg °K.

The specific volume of the superheated steam:

$$v_n = \frac{47{,}05\,T}{p} - 0{,}016 \text{ m}^3/\text{kg}, \qquad (43)$$

where T - absolute temperature of vapor, °K;

p - pressure of superheated steam, kg/m².

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Specific volume of wet steam:

$$v_x = xv_s \ m^3/kg, \qquad (44)$$

where x - a degree of dryness of steam; pair;

v_s - the specific volume of dry saturated steam, m^3/kg.

The specific volume of the mixture:

$$v_{см} = \frac{G_1 v_1 + G_2 v_2 + \dots}{G_1 + G_2 + \dots} \ м^3/кg, \qquad (45)$$

where G_1, G_2 - weights of the components, entering the mixture, kg;

v_1, v_2 - the specific volumes of the components, entering mixture, m^3/kg.

The volume of mixture in the capacitor/condenser (according to the law of Dalton):

$$V_{см} = V_п + V_в \ м^3, \qquad (46)$$

where V_n - volume, occupied by vapor, m^3;

$V_в$ - volume, occupied by air, m^3.

The volume of the air, exhausted from the capacitor/condenser:

$$V_в = \frac{29.27\,(273 + t_в)\,G_в}{p_в}\ м^3/h \qquad (47)$$

where $t_в$ - temperature of air, °C;

$G_в$ - weight of the exhausted air, kg/h;

$p_в$ - partial air pressure, kg/m^2.

The volume of dry air in depending on the temperature:

$$V_t = V_0\left(1 + \frac{1}{273}t\right) м^3, \qquad (48)$$

where V_0 - a volume of dry air at temperature of 0°C and barometric pressure 760 mm Hg, m^3;

t - temperature of air, °C.

The volume of water in the deaerating tank for the shipboard

installations is selected from the conditions for a 3-4-minute water supply and is determined

$$V = \frac{Wv}{15 \div 20}\ м^3, \qquad (49)$$

where W - a quantity of deaerated water (productivity), t/h;

v - the specific volume of the deaerated water, m^3/t.

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The specific weight of the humid air

$$\gamma_{вл} = \gamma_{сух} - 0{,}176\frac{\varphi h_s}{T}\ кг/м^3, \qquad (50)$$

where $\gamma_{сух}$ - the specific weight of dry air (it is found through tables 5 of applications/appendices), of kg/m^3; h_s - water vapor pressure upon the complete saturation of air, mm, Hg;

T - absolute temperature of humid air, °K;

φ - relative air humidity:

$$\varphi = \frac{h_п}{h_s}100 = \frac{d}{d_s}100\%,$$

where $h_п$ - partial water vapor pressure mm Hg;

d - moisture content of air with this temperature and upon

this saturation:

$$d = 622 \frac{h_n}{B - h_n} \text{ g/kg dry air,}$$

d_s - a moisture content of air with this temperature and upon complete saturation, the g/kg;

B - barometric pressure of atmospheric air as the gas mixture:

$$B = h_c + h_n \text{ mm Hg,}$$

where h_c - partial pressure of dry air, mm Hg.

The weight of the humid air

$$G_{вл} = G_{сух} + G_п \text{ кг,} \qquad (51)$$

where $G_{сух} = \frac{B - h_п}{2,153\,T}$ - weight of dry air, kg;

$G_п = \frac{h_п}{3,461\,T}$ - weight of water vapors, kg.

Here B - barometric pressure of atmospheric air, mm Hg;

$h_п$ - partial water vapor pressure of the atmosphere, mm Hg;

T - absolute temperature of air, °K;

number 2.153 - the gas constant of dry air in the measurement of pressure in kg/m²;

number 3.461 - gas constant water vapors in the measurement of pressure in kg/m².

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The specific gravity/weight of oil-products with different temperatures

$$\gamma_t = \gamma_{20} - \beta(t - 20) \ t/m^3, \qquad (52)$$

where γ_{20} - the specific gravity/weight of oil-product with 20°C, t/m³;

β - temperature correction for 1°C (it is determined on Tables 1);

t - temperature of oil-product, °C.

The graph/diagram of the dependence of the specific gravity/weight of different oil-products on the temperature is given in Fig. 13.

Specific volumes and weights of water vapors, air and liquids - see applications/appendices, Table 1-14.

The enthalpy (enthalpy) of the humid air:

$$i_{вл} = 0{,}24t + (0{,}46t + 595)\,d\,10^{-3} \text{ kcal/kg dry air,} \quad (53)$$

where 0.24t - enthalpy of dry air, kcal/kg;

$0.46td\,10^{-3}$ - heat of superheat of the water vapors, which contain in the air, kcal/kg the dry air;

$595d\,10^{-3}$ - heat of vaporization with 0°C, kcal/kg dry air.

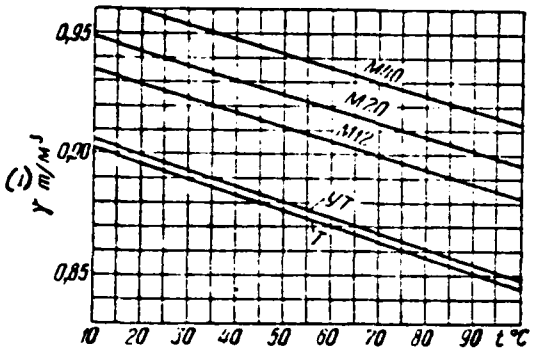

Fig. 13. Graph/diagram of the dependence of the specific gravity/weight of oil-products on the temperature. M12 - petroleum residue the sailor; M120 - petroleum residue naval; M40 - petroleum residue furnace; UT and T - lubricating oils.

Key: (1). t/m³.

Table 1. Values of temperature correction β.

(1) Удельный вес при $t = 20°$ C	β
0,90	0,000633
0,91	0,000620
0,92	0,000607
0,93	0,000594
0,94	0,000581
0,95	0,000567
0,96	0,000554
0,97	0,000541

Key: (1). Specific gravity/weight with.

§ 4. Heat capacities.

Heat capacity, or weight specific heat, is called a quantity of heat, necessary for the heating 1 kg substances on 1°C. With an increase in the temperature the heat capacity increases (for mercury it decreases).

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The heat capacity of imperfect gases depends not only on temperature, but also on the pressure, and it is subdivided into the heat capacity at constant pressure c_p and the heat capacity at a constant volume c_v.

Is distinguished heat capacity weight, volumetric and molar in depending on that, to what quantitative unit it is related.

Weight heat capacity c, c_p or c_v is measured in kcal/kg °C; volumetric $c_{об}$ - in kcal/m³ °C and molar μc - in kcal/mole °C.

The heat capacity of the water:

$$c = 0{,}9983 - 0{,}005184\, t\, 10^{-2} + 0{,}006912\, t^2\, 10^{-4} \text{ kcal/kg °C}, \quad (54)$$

where t - temperature of water, °C.

Thermal capacity of water vapor:

$$c_p = c_{p_0} + 0{,}5311\frac{p}{p_{кр}}\left(\frac{T_{кр}}{T}\right)^{3,5} + 1{,}1991\left(\frac{p}{p_{кр}}\right)^{3}\left(\frac{T_{кр}}{T}\right)^{18} \text{kcal/kg} \quad °C, \quad (55)$$

where c_{p_0} = 0.3613+0.00017361+ $\frac{9.0}{T}$, - heat capacity with p=0;

p - absolute pressure, kg/m²;

$p_{кр}$ = 225.05•10⁴ - critical pressure, kg/m²;

$T_{кр}$ = 273.2+374=647.2 - critical temperature, °K;

T - absolute temperature, °K.

The heat capacity of overheated water vapor in depending on temperature and pressure of steam - see applications/appendices, Fig. 1.

The heat capacity of the oil-products:

$$c_p = (0{,}403 + 0{,}00081t)\frac{1}{\sqrt{\gamma_{15}}} \text{ kcal/kg} \quad °C, \quad (56)$$

where t - temperature of oil-products, °C;

γ_{15} - the specific gravity/weight of oil-products with 15°C, t/m³.

The graph/diagram of the dependence of the heat capacity of oil-products on the temperature and the specific gravity/weight is represented in Fig. 14.

Heat capacity of the air:

$$c_p = 0{,}2404 + 0{,}0000843\,t \text{ kcal/kg °C}, \qquad (57)$$

where t - temperature of air, °C.

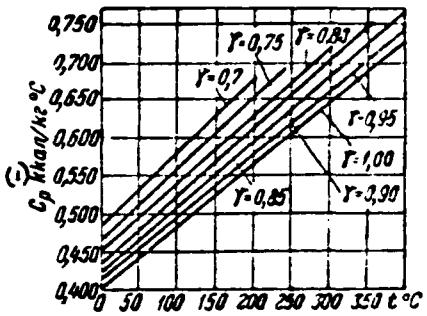

Fig. 14. Graph/curve of a change of the heat capacity of oil-products in the dependence on the temperature and the specific gravity/weight.

Key: (1). kcal/kg.

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The graph/curve of a change in the heat capacity of the air, calculated according to formula (57), in the dependence on the temperature is given in Fig. 15, and in the dependence on the temperature and the pressure - 16.

The heat capacity of the humid air:

$$c_x = 0{,}242 + 0{,}47 d\, 10^{-3}$$

kcal/kg dry air °C, (58)

where d - a moisture content of air, g/kg.

The heat capacity of the mixture:

$$c = \frac{G_1 t_1 c_1 + G_2 t_2 c_2 + \ldots}{G_1 t_1 + G_2 t_2 + \ldots}$$

kcal/kg °C, (59)

where G_1, G_2 - weights of blending agents kg;

t_1, t_2, temperature of the blending agents, °C;

c_1, c_2 - heat capacity of the blending agents, kcal/kg °C.

The expression of the dependence between the molar heat capacity:

$$\mu c_p = \mu c_v + \mu AR = \mu c_v + 1{,}985, \qquad (60)$$

where $\mu AR = 1.985$ - the gas constant of 1 moles in the thermal units.

Translation/conversion of molar heat capacity μc into weight c:

$$c = \frac{(\mu c)}{\mu}. \qquad (61)$$

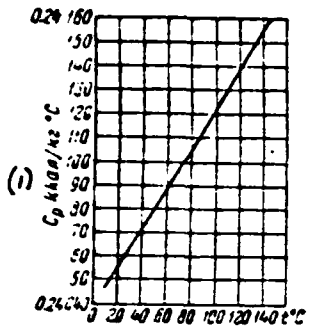

Fig. 15.

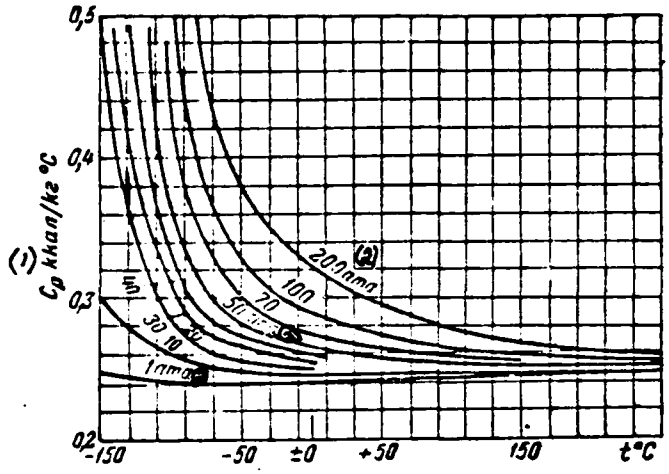

Fig. 16.

Fig. 15. Graph/curve of change of heat capacity of the air in dependence on temperature.

Key: (1). kcal/kg.

Fig. 16. Graph/curve of change of heat capacity of the air in dependence on temperature and pressure.

Key: (1). kcal/kg. (2). atm(abs.).

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The translation/conversion of the weight heat capacity c into

volumetric $c_{об}$:

$$c_{об} = c\gamma. \qquad (62)$$

The value of heat capacities for different bodies are given in appendices (Table 4-14 and Fig. 1-3).

§ 5. Coefficients of thermal conductivity.

The coefficient of thermal conductivity indicates the ability of substance to carry out heat. The value of this coefficient determines a quantity of heat which is passed per unit time through the unit of the surface of wall with a temperature drop on 1°C per the unit of length, and it is measured in kcal/m-hour °C.

The coefficient of the thermal conductivity of water in depending on temperature is shown graphically in Fig. 17 and Table 6 of applications/appendices.

The coefficient of the thermal conductivity of the water vapor:

$$\lambda = \frac{0{,}00578\, c_v \sqrt{T}}{1 + \frac{321}{T}} \text{ kcal/m-hour °C}, \qquad (63)$$

where c_v - thermal capacity of water vapor at a constant volume, equal to

$$c_v = 0{,}259 + 0{,}000111T \text{ kcal/kg} \quad {}^{\circ}\text{C},$$

T - absolute temperature, °K.

The coefficient of the thermal conductivity of water and water vapor in depending on temperature and pressure is represented curves in Fig. 18.

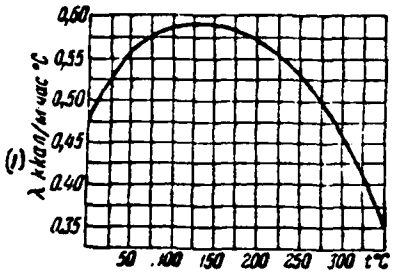

Fig. 17.

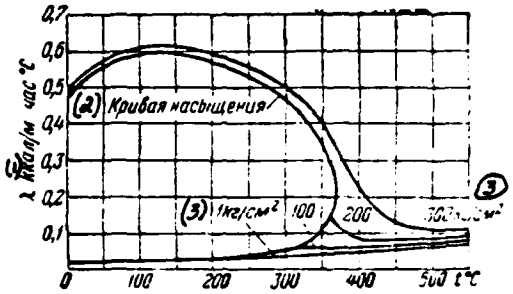

Fig. 18.

Fig. 17. Coefficient of thermal conductivity of water in depending on temperature.

Key: (1). kcal/m-hour.

Fig. 18. Coefficient of thermal conductivity of water and water vapor in depending on temperature and pressure.

Key: (1). kcal/m-hour. (2). Saturation curve. (3). kg/cm².

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The coefficient of thermal conductivity for the overheated water vapor in depending on temperature and pressure - see applications/appendices, Fig. 2.

The coefficient of the thermal conductivity of the air:

$$\lambda = \frac{0{,}00167\,(1 + 0{,}0001947)\,\sqrt{T}}{1 + \frac{117}{T}} \text{ kcal/m-hour } ^\circ\text{C}, \qquad (64)$$

where T - absolute temperature, °K.

The curve of the dependence of the coefficient of the thermal conductivity of air on the temperature is given in Fig. 19, and 20 are depicted the curves of the coefficient of the thermal conductivity of different gases at pressure 760 mm Hg and different temperatures.

The coefficient of the thermal conductivity of oil in the range of temperatures of 20-100°C for the approximate computations can be accepted

$$\lambda = 0{,}10 \div 0{,}11 \text{ kcal/m-hour } ^\circ\text{C}. \qquad (65)$$

The coefficient of the thermal conductivity of oil-products can be determined according to the empirical formula

$$\lambda = \frac{0{,}101}{\gamma_{15}}\,(1 - 0{,}00054t) \text{ kcal/m-hour } ^\circ\text{C}, \qquad (66)$$

where γ_{15} - is specific weight of oil-products at temperature of 15°C, t/m³;

t - mean temperature, °C.

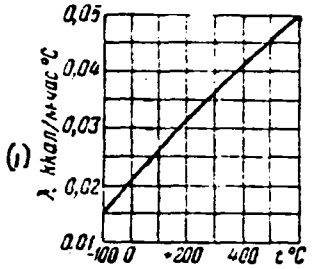

Fig. 19.

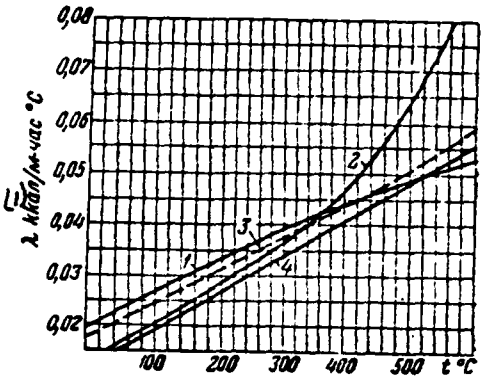

Fig. 20.

Fig. 19. Coefficient of thermal conductivity of air in depending on temperature.

Key: (1). kcal/m-hour.

Fig. 20. Coefficient of thermal conductivity of different gases at pressure 760 mm Hg and different temperatures. 1 - oxygen, nitrogen, air; 2 - water vapor; 3 - flue gases; 4 - carbonic acid.

Key: (1). kcal/m-hour.

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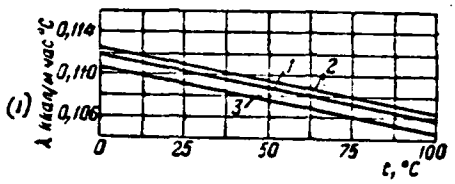
This formula is applied to the oil-products with the specific

gravity/weight, equal to 0.78-0.95 t/m³, in the range of temperatures of 0-200°C.

Fig. 21 depicts the coefficients of the thermal conductivity of different brands of oils in depending on the temperatures, calculated according to formula (66).

It should be noted that in the literary sources occur and other formulas of the definition of the coefficients of the thermal conductivity of oil-products, which give contradictory results, in consequence of which formula (66), and also existing up to now formulas, which differ from formula (66), it is possible to examine only as those approximated.

Fig. 22 gives the curves of the coefficients of the thermal conductivity of different metals in the dependence on the temperature. The value of the coefficients of thermal conductivity for different bodies - see applications/appendices, Table 4-12.



21.

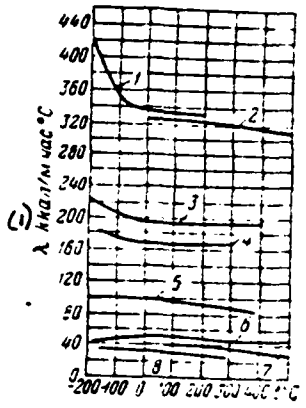


Fig. 22.

Fig. 21. Coefficients of thermal conductivity of oil-products in depending on temperature. 1 - oil turbine UT; 2 - oil turbine T; 3 - oil diesel.

Key: (1). kcal/m-hour.

Fig. 22. Coefficients of thermal conductivity of metals in depending on temperature. 1 - copper is pure/clean; 2 - copper 99.9o/o; 3 - aluminum 99.7o/o; 4 - aluminum 99.0o/o; 5 - zinc 99.8o/o; 6 - nickel 99.0o/o; 7 - iron 99.8o/o; 8 - lead pure/clean technical.

Key: (1). kcal/m-hour.

§ 6. Viscosities/ductilities/toughness.

Viscosity/ductility/toughness characterizes the value of the molecular cohesion/coupling of particles and depends on the force of the internal friction, which appears between two layers of liquid during their motion.

Viscosity/ductility/toughness is determined by the speed of the displacement/movement of layers and by the properties of liquid. The viscosity of liquids with an increase in the temperature decreases, and with the pressure increase insignificantly it increases; however, at high pressures - 100 atm(ats.) and more - viscosity change becomes perceptible.

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The unit of absolute viscosity represents the force (tangent), necessary for the mutual displacement at a rate of 1 cm/s of two layers of liquid in area 1 cm^2 each, located at a distance 1 cm one relative to another, and it is expressed in the poises.

The ratio of absolute viscosity to the density at the same temperature is called kinematic viscosity.

In the system of practical units is dynamic, or absolute, viscosity is expressed in kg•s/m², and kinematic - in m²/s. Viscosity in the Engler degrees is ratio of the time of the discharge 200 cm³ of product to the time of the discharge of the same volume of water from Engler's instrument with 20°C and is designated °E.

The dynamic viscosity of the water:

$$\mu_p = \frac{0{,}0178}{1 + 0{,}0337t + 0{,}000221t^2} \text{ poises,} \qquad (67)$$

where t - temperature of water, °C.

The dynamic viscosity of water in depending on temperature is represented curve in Fig. 23.

The dynamic viscosity of gases and water vapor

$$\mu 10^6 = \frac{2{,}766T}{821 + t}\sqrt{\frac{T}{273}} \text{ kg•s/m}^2, \qquad (68)$$

where t - temperature of gas or vapor, °C;

T - absolute temperature of gas or vapor, °K.

For the overheated water vapor dynamic viscosity in depending on

temperature and pressure is represented curves - see applications/appendices, Fig. 3.

Dynamic viscosity of the air:

$$\mu 10^6 = 1{,}712 \sqrt{1 + 0{,}003665\,t}\,(1 + 0{,}0008\,t)^2 \text{ kg}\cdot\text{s/m}^2, \quad (69)$$

t - temperature of air, °C.

Fig. 24 and 25 give the respectively curved of the dynamic and kinematic viscosity of air in the dependence on the temperature and the pressure.

The dynamic viscosity of air, water vapor, oxygen, nitrogen, and also the kinematic viscosity of flue gases in depending on temperature are represented in Fig. 26.

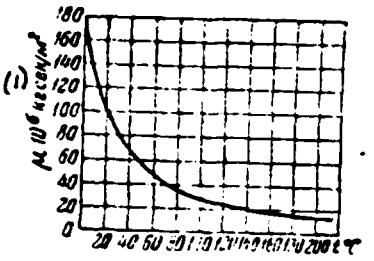

Fig. 23. Dynamic viscosity of water in depending on temperature.

Key: (1). kg s/m².

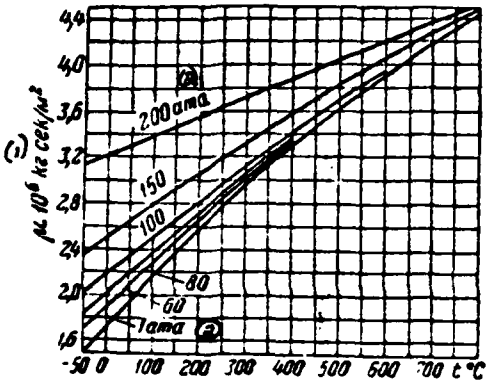

Fig. 24.

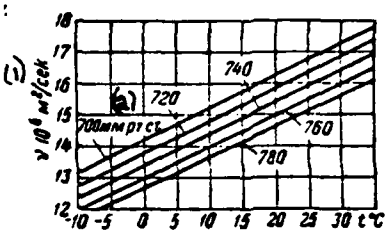

Fig. 25.

Fig. 24. Dynamic viscosity of air in depending on temperature and pressure.

Key: (1). kg s/m². (2). atm(abs.).

Fig. 25. Kinematic viscosity of air in depending on temperature and pressure.

Key: (1). m²/s. (2). mm Hg.

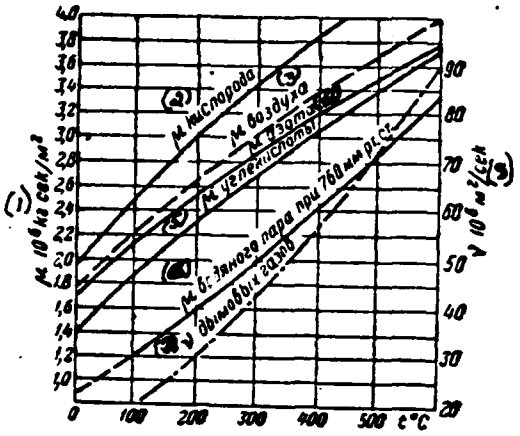

Fig. 26. Dynamic viscosity of air, oxygen, nitrogen, of carbon dioxide, water vapor and kinematic viscosity of flue gases in depending on temperature.

Key: (1). kg s/m². (2). oxygen. (3). air. (4). nitrogen. (5). carbonic acid. (6). water vapor with 760 mm Hg. (7). flue gases. (8). m²/s

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The effect of pressure on the viscosity of gases to p=10 atm(abs.) can be disregarded/neglected.

The kinematic viscosity of the mixture of gases in the engineering is computed according to the formula:

$$\nu_{см} = \frac{100}{\frac{v_1}{\nu_1} + \frac{v_2}{\nu_2} + \frac{v_3}{\nu_3} + \ldots} \text{ м}^2/\text{s},$$

where ν_1, ν_2, ν_3 - kinematic viscosity of separate components, m^2/s;

v_1, v_2, v_3 - volumetric contents of separate blending agents, o/o.

The dynamic viscosity of the oil-products:

$$\lg \mu_p = -3 + \frac{0.211}{0.968 - \gamma}$$

poises, (70)

where γ - specific gravity/weight of oil-product at appropriate temperature, g/cm^3.

For the most commonly used lubricating oils and the petroleum residue Fig. 27 depicts their kinematic viscosities and viscosity in the Engler degrees in depending on the temperatures, obtained according to the data of tests.

For determining the viscosity of oil-product at prescribed/assigned temperature it is possible to use the following approximation formula of recalculation:

$$^{\circ}E_t = \frac{^{\circ}E_{50}\, 50^n}{t^n} \quad \text{or} \quad \nu_t = \frac{\nu_{50}\, 50^n}{t^n}, \qquad (71)$$

where $^{o}E_{50}$ - viscosity (^{o}E) or kinematic viscosity ν_{50} at 50°C, indicated in the standards for the oil-products;

t - temperature at which it is necessary to determine viscosity, by °C;

n - exponent, it is selected on Tables 2.

Formula (71) is applied in the range of temperatures from 30 to 150°C for the viscosity of oil-products, which does not exceed 16°E, but in the range of temperatures from 40 to 110°C - for the viscosity of oil-products more 16°E.

Table 2. Values of exponent n.

$°E_{50}$	1,2	1,5	1,8	2,0	3,0	4,0	5,0	6,0	7,0	8,0
n	1,39	1,59	1,72	1,79	1,99	2,19	2,24	2,32	2,42	2,49
$°E_{50}$	9,0	10	15	20	25	30	35	50	65	—
n	2,52	2,56	2,75	2,86	2,96	3,06	3,10	3,17	3,32	—

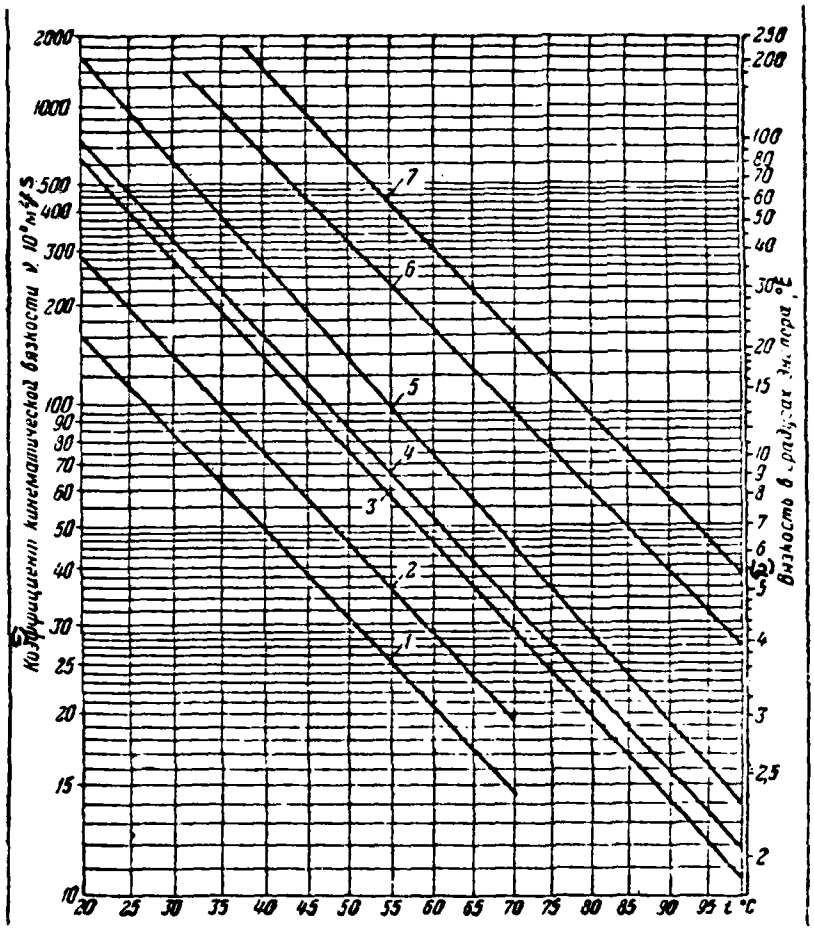
Коэффициент кинематической вязкости ν, 10⁻⁶ м²/с
Вязкость в градусах Энглера, °Е
t °C
1
2
3
4
5
6
7

Fig. 27.

Fig. 27. Dependence of viscosity of lubricating oils and petroleum residue on temperature. 1 - oil turbine UT; 2 - oil turbine T; 3 - oil diesel; 4 - petroleum residue the sailor M12; 5 - petroleum residue the sailor M20; 6 - petroleum residue furnace M40; 7 - petroleum residue furnace M80.

Key: (1). Kinematic viscosity coefficient. (2). Viscosity in Engler degrees.

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Transfer equations from some ones of viscosity to others:

1) from the dynamic viscosity, expressed in poises μ_p, to the dynamic viscosity μ, expressed in working standards:

$$1 \text{ poise} = 1 \text{ dynes. s./cm}^2 = 1/98.1 \text{ kg}^o\text{s/m}^2; \quad (72)$$

2) from the dynamic viscosity, expressed in the poises, μ_p to kinematic viscosity

$$1 \text{ poise} = 1/962.36 \text{ m}^2/\text{s}; \quad (73)$$

3) from the dynamic viscosity μ to the kinematic ν:

$$\nu = \frac{\mu}{\rho} = \frac{\mu g}{\gamma} \ m^2/s; \qquad (74)$$

4) from kinematic viscosity ν to the dyramic μ:

$$\mu = \nu\rho = \nu\frac{\gamma}{g} \ kg \cdot s/m^2; \qquad (75)$$

5) from the viscosity, expressed in the Engler degrees (°E), to the dynamic viscosity μ:

$$\mu 10^6 = \left(0{,}746\,°E - \frac{0{,}643}{°E}\right)\gamma \ kg \cdot s/m^2; \qquad (76)$$

6) from the viscosity, expressed in the Engler degrees (°E), to kinematic viscosity ν:

$$\nu 10^6 = \left(7{,}31\,°E - \frac{6{,}31}{°E}\right) m^2/s. \qquad (77)$$

Here ρ - density, $kg \cdot s/m^4$;

γ - specific gravity/weight, kg/m^3;

g - acceleration of gravity m/s^2.

The graph/curve of the recalculation of viscosity from the Engler degrees into the dynamic and kinematic viscosity in depending on the specific gravity/weight of liquid γ (t/m^3) is represented in Fig. 28.

The values of the coefficients of viscosity for different media are given in appendices (Table 4-14).

§ 7. Speeds.

Under the average speed of the motion of medium or flow is understood the path, passed by the moving medium for the time unit. The speed, at which occurs the transition of stream-line conditions into the turbulent with the constant/invariable viscosity and the given diameter of duct, is called critical speed.

Unit speed measurement of flow - m/s.

The determination of turbulent and stream-line conditions see § 22.

The speed of medium according to the equation of the continuity:

$$v = \frac{G}{\gamma F} \text{ m/s}, \qquad (78)$$

where G - expenditure/consumption of medium, kg/s;

γ - the specific gravity/weight of medium, kg/m³;

F - sectional area of opening/aperture, m².

Discharge velocity through the opening/aperture:

$$v = \varphi \sqrt{2gH \frac{\gamma_1}{\gamma_2}} \text{ m/s}, \qquad (79)$$

where ϕ - velocity coefficient (see § 25);

g - acceleration of gravity of m/s²;

H - velocity head, m;

γ_1 - the specific gravity/weight of medium under standard conditions, kg/m³;

γ_2 - the specific gravity/weight of medium at its mean temperature, kg/m³.

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The speed of mixture in the section:

$$v_{см} = \frac{G_1 v_1 + G_2 v_2 + \ldots}{G_1 + G_2 + \ldots} \text{ m/s}, \qquad (80)$$

where G_1, G_2 - weights of the components, entering the mixture, kg;

v_1, v_2 - speed of the components, entering the mixture, m/s.

The critical speed of the water:

$$v_{кр} = \frac{p}{Bd} \text{ m/s}, \qquad (81)$$

where p - Poisson ratio of viscosity to the density:

$$p = \frac{1}{1 + 0{,}0337 t_1 + 0{,}000221 t_1^2};$$

B=43.79 - constant;

d - inner diameter, m;

t_1 - initial temperature of water, °C.

Discharge velocity of steam behind the nozzle:

$$v = 91{,}53\,\varphi\sqrt{h}\ \text{m/s}, \qquad (82)$$

where φ - velocity coefficient (see § 25);

h - adiabatic drop/jump in the heat:

$$h = i_0 - i_d\ \text{kcal/kg};$$

i_0 - enthalpy of steam with nozzle entry, kcal/kg;

i_d - enthalpy of steam on leaving from the nozzle, kcal/kg.

The critical speed or discharge of steam (gas):

$$v_{кр} = \sqrt{2gp_1v_1\frac{k}{k+1}}\ \text{m/s}, \qquad (83)$$

where g - acceleration of gravity m/s²; 91 p_1 - a pressure of vapor or gas, kg/m²;

v_1 - the specific volume of vapor or gas, m³/kg;

k - adiabatic index: k=1.4 - for the air and the diatomic gases; k=1.3 - for the superheated steam; k=1.135 - for the dry saturated steam; k=1.035+0.1x - for wet steam;

x - degree of dryness of steam.

Speed of sound in the gases:

$$v = \sqrt{gkp_1v_1} \text{ m/s}, \qquad (84)$$

where g, k, p_1 and v_1 - the same as in formula (83).

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The average speed of liquid in the cylindrical housing with the transverse bulkheads:

$$v_{cp} = \frac{Lv_1 + (N-1)Av_2}{L + (N-1)A} \text{ m/s}, \qquad (85)$$

where L - distance between centers of input and exhaust ducts, m;

v_1 - speed of the liquid above the partition/baffle, m/s;

v_2 - speed of the liquid between the partitions/baffles in the central series/row, m/s;

N - number of partitions/baffles;

N-1 - number of gaps/intervals between the partitions/baffles (input and exit sections are not considered);

$A=\frac{s}{8f}$ - average/mean length of the gaps/intervals between the partitions/baffles, equal to distance between centers of gravity of the areas of the segments (cut off by partitions/baffles), confined by chord s, m;

f - area of the segment above the partition/baffle, m².

The speed of the condensed steam in the capacitor/condenser:

$$v=\frac{Gv_n}{3600\,LD\left(1-\frac{d_n}{t}\sqrt{\eta_{np}}\right)}\ \text{m/s}, \qquad (86)$$

where G - a quantity of condensed steam, kg/h;

v_n - specific volume of steam, m³/kg;

L - length of steam housing, m;

D - outside diameter of the arrangement/position of the beam of tubes, m;

d_n - outside diameter of tubes, mm;

t - space of the laying out of tubes, mm;

$\eta_{тр}$ - solidity/loading factor of the tube plate, see formula (175).

The maximal allowable speeds of steam in the upper series/row of the tubes of capacitor/condenser. The values of allowable speeds of steam upon the entrance into the capacitor/condenser in depending on vacuum in the capacitor/condenser are given in Fig. 29 and Table 3.

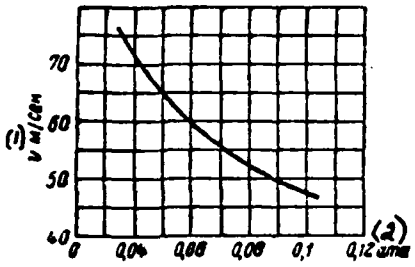

Fig. 29. Dependence of the maximum permissible speed of steam upon the entrance into the capacitor/condenser on the vacuum.

Key: (1). m/s. (2). atm(abs.).

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In the contemporary shipboard capacitors/condensers are accepted the higher speeds, which reach by 80-100 m/s with the vacuum 0.08 atm(abs.).

The speed of steam in the central gangway of capacitor/condenser is usually received as v=3-5 m/s. In the remaining parts of the capacitor/condenser it is necessary to attain the identical speeds, on the basis of the requirement to prevent the possibility of forming air pockets (stagnant places).

Speed of steam which carries along the drops of the water:

$$v > \sqrt{2{,}2gd\frac{\gamma_в}{\gamma_п}} \text{ m/s}, \qquad (87)$$

where g - acceleration of gravity m/s²;

d - diameter of spherical drop, m;

$\gamma_в$ - the specific gravity/weight of water, kg/m³;

$\gamma_п$ - specific gravity/weight of steam, kg/m³.

The values of the speeds at which steam it carries along drops, in depending on the diameter of drop and pressure of steam p, are given in Table 4.

Table 3. Values of speeds steam upon the entrance into the capacitor/condenser.

(1) Давление в конденсаторе, *ата*	0,03	0,04	0,05	0,06	0,07	0,08	0,10
(2) Скорость пара в верхнем ряду трубок, *м/сек*	80	72	65	59	55	52	47

Key: (1). Condenser backpressure, atm(abs.). (2). Speed of steam in upper series/row of tubes, m/s.

Table 4. Values of speeds of steam.

(1) *p*, *ата* \ *d*, *мм*	0,06	0,08	0,1	1,0	2,0	3,0	4,0	5,0
	(2) Скорость, при которой пар увлекает капли, *м/сек*							
0,2	3,2	3,6	4,2	13,0	19,0	23,0	26,0	29,0
0,4	2,3	2,6	3,0	9,5	14,0	17,0	19,0	21,0
0,5	2,1	2,4	2,7	8,4	12,0	15,0	17,0	19,0
0,6	1,9	2,2	2,4	7,6	11,0	13,5	15,5	17,0
0,8	1,7	1,9	2,1	6,7	10,0	12,0	14,0	15,5
1,0	1,5	1,7	1,9	6,1	8,6	11,0	12,0	14,0
1,5	1,3	1,4	1,6	5,0	7,4	9,0	10,0	12,0
2,0	1,1	1,2	1,4	4,4	6,2	7,6	8,8	9,8
2,5	1,0	1,1	1,3	4,0	5,6	6,9	8,0	9,0
3,0	0,9	1,0	1,1	3,6	5,1	6,2	7,2	8,1

Key: (1). atm(abs.). (2). Speed at which steam carries along drops, m/s.

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Selection of rated speeds.

The speeds of steam v in the branch pipes of heat exchangers usually are accepted:

For the saturated steam ... 30-50 m/s.

For the superheated steam ... 50-75 m/s.

For the capacitors/condensers ... 100-150 m/s.

The speed of liquids in the branch pipes of heat exchangers can be accepted in the dependence on the speed in the conduit/manifold and permissible hydraulic resistances in the apparatus; therefore it can be within the limits of 0.4-2.5 m/s.

For the main capacitors/condensers it can be accepted also in the dependence on the expenditure of cooling water, speed of vessel and construction/design of circulation branch pipes and can reach 2.5-7.5 m/s.

Speed of the preheated water in the tubes of preheaters 1-2.5

m/s.

Speed of cooling water in the tubes of capacitors/condensers 1.8-2.4 m/s.

Usually average speeds v accept:

for the single-pass capacitors/condensers with the self-flow system of cooling water ... 1.25-2.0 m/s.

For the single-pass capacitors/condensers during the supplying of cooling water by the pump ... 3.0 m/s.

For the capacitors/condensers of the two-pass and with a large number courses ... 2.4 m/s.

The velocity of cooling water in the oil-cooking pipes in 0.4-1.0 m/s

The speeds of water and especially marine water are limited to the usually indicated limits, on the basis of the conditions of preventing the phenomena of corrosion and erosion which considerably more intensely flow/occur/last at the higher speeds and destructively they act not only to the blacks, but also to the nonferrous metals.

Speed of petroleum in the tubes of fuel heater v=0.5-1.2 m/s.

Speed of oil in the intertube space of oil coolers v=0.4-0.8 m/s.

The exit velocity of condensate from the apparatuses is assigned in depending on diversion conditions for condensate, local resistances and the like and usually are accepted v=0.4-1.0 m/s.

Speed of air-steam mixture in branch pipes v~~15 m/s.

§ 8. Expenditures and quantities.

Under the expenditure is understood the amount of liquid, which takes place per unit time through the "clear opening of its flow".

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Fluid flow rate is determined from the fundamental flow equation - so-called equation of continuity, continuity or continuity of the motion of jet. The measurement of expenditures and quantities is made in the units of weight (t/h, kg/h), volumetric ones (m^3/h, l/s) and thermal (kcal/h).

For the gases and the vapors, i.e., elastic liquid, volumetric flow rate is not characteristic value as a result of the possibility

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of their expansion or compression, and in this case it is necessary to use the weight flow rate, which are a constant value for all sections.

The flow equation:

$$Q = v_1 f_1 = v_2 f_2 = \text{const}, \qquad (88)$$

where v_1, v_2 - speeds of flow, m/s;

f_1, f_2 - sectional area of flow, m^2.

The expenditure of liquid or gaseous substance according to the equation of the continuity:

$$G = \frac{uF}{v} \text{ kg/s}, \qquad (89)$$

where u - speed of medium, m/s;

F - sectional area, m^2;

v - the specific volume of medium, m^3/kg.

Flow of the cooling water:

$$W = \frac{Q}{c(t_2 - t_1)} \text{ kg/h}, \qquad (90)$$

where Q - the quantity of heat, transferred to water, kcal/h;

c — the heat capacity of water, kcal/kg, °C;

t_1 - initial temperature of water, °C;

t_2 - the final temperature of water, °C.

Expenditure is vapor:

$$G = \frac{Q\eta}{i-q} \text{ kg/h}, \qquad (91)$$

where Q - a quantity of heat, kcal/h;

$\eta = 1{,}02$ - coefficient, which considers the heat losses;

i - enthalpy of steam, kcal/kg;

q - enthalpy of liquid, kcal/kg.

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Heat consumption can be determined according to one of the following expressions

$$\left.\begin{aligned} Q &= Dc(t_2 - t_1)\ \text{ккал/час}^{(1)} \\ Q &= D(i - q)\ \text{ккал/час}^{(1)} \\ Q &= \frac{\lambda}{s} F(t_2 - t_1)\ \text{ккал/час}^{(1)} \\ Q &= kF\Delta t\ \text{ккал/час}^{(1)} \end{aligned}\right\} \qquad (92)$$

Key: (1). kcal/h.

where D - a quantity of heated substance, kg/h;

c - heat capacity of substance with mean temperature, kcal/kg °C;

t_1 - initial temperature, °C;

t_2 - final temperature, °C;

i - enthalpy of steam, kcal/kg;

q - enthalpy of liquid, kcal/kg;

λ - coefficient of the thermal conductivity of wall, kcal/m-hour °C;

s - wall thickness, m;

F - surface of heating or cooling, m^2;

k - coefficient of heat transfer, kcal/m^2h °C;

Δt - average/mean logarithmic difference in the temperatures, °C.

A quantity is steam, that is formed by the spontaneous evaporation:

$$G = W\frac{q_1 - q_2}{r} = Wc\frac{t_1 - t_2}{r} \text{ kg/h}, \qquad (93)$$

where W - amount of liquid, which enters the apparatus, kg/h,

q_1 - enthalpy of the liquid, which enters the apparatus, kcal/kg;

q_2 - enthalpy of liquid, which corresponds to pressure of steam in the housing of apparatus, kcal/kg;

r - heat of vaporization, kcal/kg;

c - heat capacity of liquid with mean temperature, kcal/kg °C;

t_1 - temperature of the liquid, which enters the apparatus, °C;

t_2 - temperature of liquid, which corresponds to pressure of steam in the housing of apparatus, °C.

Graph/curve for determining a quantity of steam, generatrix by spontaneous evaporation from 1 m^3 of hot water (having saturation temperature), in depending on lowering in the pressure above the surface of evaporation, is given in Fig. 30.

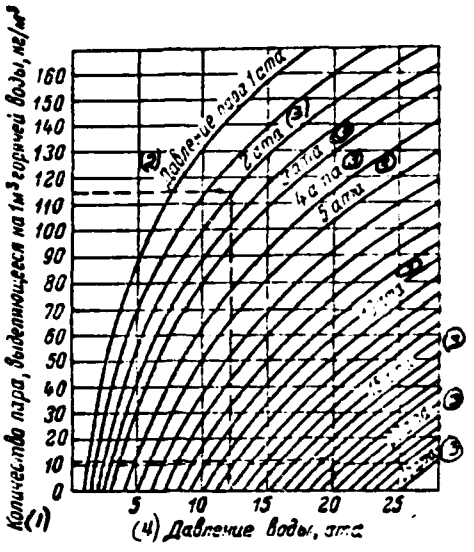

Fig. 30. Graph/curve of the determination of a quantity of steam, the forming with the incidence/drop pressure above the surface of hot water.

Key: (1). The quantity of steam that is isolated to 1 m³ of hot water, kg/m³. (2). Pressure of steam 1 atm(abs.). (3). atm(abs.). (4). Water pressure, atm (abs.).

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The expenditure of water for the vaporizer/evaporator

$$W = \frac{DS_p}{S_p - S_0} \text{ kg/h}, \qquad (94)$$

where D - productivity of vaporizer/evaporator, kg/h;

S_p - salinity of brine in the housing of vaporizer/evaporator, °B (Brandt);

S_0 - salinity of the water, which enters the vaporizer/evaporator, °B.

The additional expenditure of feed water for vaporizer/evaporator with the supply by its blowoff water from the boiler:

$$W = \frac{D(S_p - S_z) - D_{np}(S_p - S_{np})}{S_p - S_0} \text{ kg/h} \qquad (95)$$

where D, S_p, S_0 - the same as in formula (94);

$S_д$ - salinity of the distillate of vaporizer/evaporator, °B;

$D_{пр}$ - quantity of blowoff boiler water, kg/h;

$S_{пр}$ - salinity of blowoff boiler water, °B.

A quantity of circulating water in the circulation vaporizers/evaporators can be determined according to the formula

$$W = \frac{Dr}{24c(t_1 - t_2)} \text{ t/h} \quad (96)$$

where D - productivity of vaporizer/evaporator, tons/day;

r - heat of vaporization at the appropriate pressure in the vaporizer/evaporator, kcal/kg;

c - heat capacity of the entering water evaporator, kcal/kg of °C;

t_1 - temperatures of the entrance of water into the vaporizer/evaporator from the preheater, °C;

t_2 - temperature of the output of brine from the

vaporizer/evaporator, °C.

Consumption curves of water for the circulation vaporizer/evaporator of different productivity in depending on a difference in the temperatures of water with the entrance into the vaporizer/evaporator and the output from it (for the operating pressure in the vaporizer/evaporator p=0.3 atm(abs.)) are given in Fig. 31.

From Fig. 31 it is evident that the consumption of the circulating water grows/rises with a decrease of a difference in the temperatures and an increase in the productivity of vaporizer/evaporator.

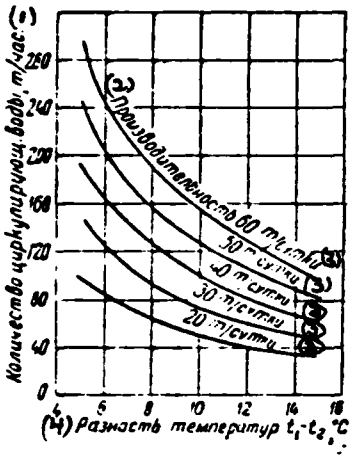

Fig. 31. Curves of the dependence of the consumption of water on the productivity of circulation vaporizer/evaporator and difference in the temperatures of water with the entrance and the output from it.

Key: (1). Quantity of circulating of water t/h. (2). productivity. (3). tons/day. (4). Difference in temperatures.

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A quantity of air-blast brine from the vaporizer/evaporator:

$$W_p = W - D = D\frac{S_n}{S_p - S_0} \text{ kg/h}, \qquad (97)$$

where W, D, S_p, S_0 - the same as in formula (94);

Concentration of brine in the housing of the vaporizer/evaporator:

$$S_p = \frac{WS_0 - DS_\text{д}}{W_p} \text{ °E}, \qquad (98)$$

where W, S_0, D - the same as in formula (94);

$S_\text{д}$ - salinity of the distillate of vaporizer/evaporator, °B;

W_p - quantity of air-blast brine from vaporizer/evaporator, kg/h.

The time, which corresponds to the achievement of the concentration of brine accepted in the housing of the vaporizer/evaporator:

$$t = \frac{S_p - S_0}{S_0} \frac{V_1}{V_2} \text{ hour}, \qquad (99)$$

where S_p, S_0 - the same as in formula (94);

V_1 - volume, occupied by water in the housing of vaporizer/evaporator to the datum level, the m^3;

V_2 - volume of the water, which evaporates during one hour, m^3/h.

The curves of the coefficient of the purging of vaporizer/evaporator in depending on the salinity of feed marine water and brine in the housing of vaporizer/evaporator are represented in Fig. 32.

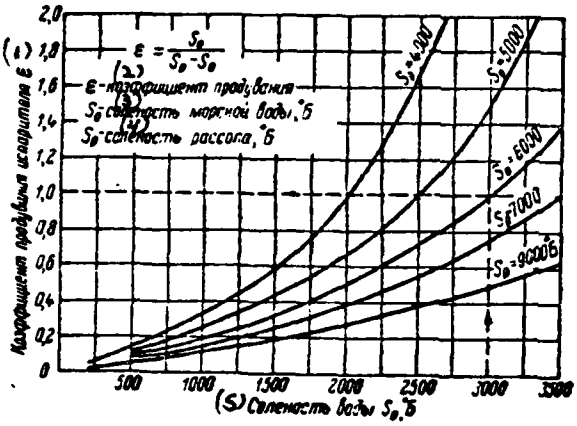

Fig. 32. Coefficient of the purging of vaporizer/evaporator in depending on the salinity of feed marine water and brine.

Key: (1). Coefficient of the purging of vaporizer/evaporator. (2). Coefficient of purging. (3). Salinity of seawater, °B. (4). Salinity of brine, °B. (5). Salinity of water S_0, °B.

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The quantity of oxygen, introduced by the deaerated water into the deaerator:

$$G_к = a_к W 10^{-3} \text{ kg/h}, \qquad (100)$$

where $a_к$ - content of dissolved oxygen in the water, determined on the curve of Fig. 33, in depending on the temperature of water at the

barometric air pressure 760 mm Hg, saturated by water vapor, the mg/ℓ;

W - quantity of deaerated water, t/h.

After the admission into the deaerator of the mixture, which consists of the condensate or different condensates and additions of feed water, quantity of oxygen, introduced by water mixture, it is determined from the formula

$$G_к = (a'_к W' + a''_к W'' + \ldots)\,10^{-3} \quad \text{кг/ч}, \qquad (101)$$

where $a'_к, a''_к$ - content of dissolved oxygen in the water, determined on Fig. 33 for each component, mg/ℓ;

W', W" - a quantity of deaerated water, t/h.

The quantity of dissolved gases of air, introduced by the deaerated water into the deaerator:

$$G_г = a_г W 10^{-3} \quad \text{кг/ч}, \qquad (102)$$

where $a_г$ - content of the dissolved gases of air in the water, determined on the curve of Fig. 33 in depending on the temperature of

water at the barometric air pressure 760 mm Hg, saturated by water vapor, mg/l;

W - quantity of deaerated water, t/h.

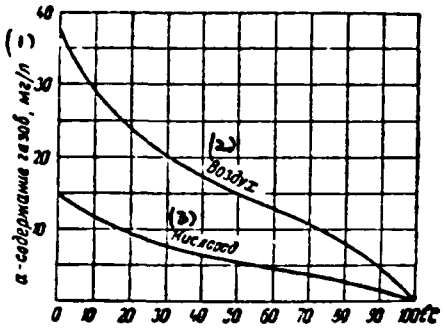

Fig. 33. Oxygen content and air in the water at a barometric pressure 760 mm Hg in depending on the temperature of water.

Key: (1). the content of gases, mg/l. (2). Air. (3). Oxygen.

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A quantity of gases, introduced by water mixture, is determined analogously with a quantity of oxygen [see formula (101)].

A quantity of vapor (steam-gas mixture), driven out from the deaerator, if we disregard/neglect an insignificant residual/remanent quantity of dissolved gases in the deaerated water, is found by the formula

$$G_{см} = G_г\left(1 + 0{,}622\frac{p_п}{p_г}\right) \text{ kg/h}, \qquad (103)$$

where $p_п$ - partial pressure of the vapor [see formula (8)] in the deaerator, atm(abs.);

$p_г$ - partial gas pressure above the surface of water in the deaerator, determined according to the formula

$$p_г = \frac{p_к a_г}{a_к} \text{ atm(abs.)}, \tag{104}$$

where $a_к$, $a_г$ - contents of dissolved oxygen and dissolved gases of air in the water the mg/л [see formulas (100) and (102)];

$p_к$ - partial oxygen pressure above the surface of water in the deaerator, determined according to the formula

$$p_к = \frac{p_0 a_р}{k a_0} \text{ atm(abs.)}, \tag{105}$$

p_0 - physical atmosphere, equal to 1.033 atm(abs.);

$a_р$ - calculated (final) oxygen content in the deaerated water, the mg/л; for the shipboard deaerators usually is accepted $a_р = 0{,}03$ mg/л;

k=2-3 - ratio of equilibrium oxygen pressure in the vapor to partial, necessary for guaranteeing the prescribed/assigned (final) oxygen

content in the deaerated water;

a_0 - constant of the weight solubility of oxygen or solubility of oxygen in the water at its pressure above the water 760 mm Hg, mg/l; it is determined on the curve of Fig. 34 in depending on temperature.

Values a_w, a_r, a_0, p_w and p_r, entering formulas (103)-(105), independent of pressure in the deaerator, they are accepted or are calculated at a pressure of the physical atmosphere how is achieved the retention/preservation/maintaining constant value p_r due to an increase in value p_n, i.e. due to the increase in the vapor, which ensures intensity and high quality of deaeration.

From formula (103) it follows that independent of pressure in the deaerator a quantity of vapor always must be connected with the partial pressure of non-condensable gases p_r, and consequently, with their consumption.

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By a small change in the values of gas constants of the vapor and of the non-condensable gases, entering formula (103) in the form of the permanent relation, equal to 0.622, with a change of the pressure in the deaerator it is possible to disregard.

A quantity is of vapor that contains in the vapor:

$$G_n = G_{см} - G_r \text{ kg/h.} \qquad (106)$$

The effect of the value of vapor on the depth of the deoxygenation of water is shown in Fig. 35, and 36 are given the curves, which show the oxygen content in the water in depending on its underheating to the boiling point.

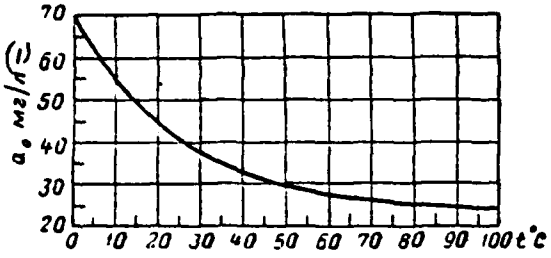
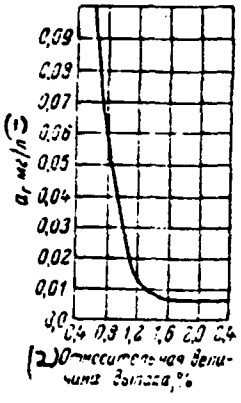


Fig. 34. Weight solubility of oxygen in depending on temperature at its pressure above the water, equal to 760 mm Hg.

Key: (1). mg/l.



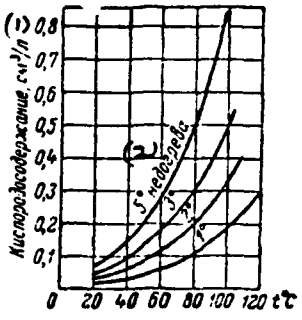


Fig. 35. Fig. 36.

Fig. 35.
Effect of the value of vapor on the depth of the deoxygenation of water.

Key: (1). mg/l. (2). Relative value of evaporation.

Fig. 36. Oxygen content in water in depending on its underheating to boiling point.

Key: (1). Oxygen content, $cm^3/2$. (2). underheating.

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As can be seen from Fig. 35, the value of vapor with respect to the consumption of heating steam for obtaining qualitative deaerated water, it composes altogether only 1.5-2c/o. However, since they are possible: 1) the disturbance/breakdown of the conformity of feed of vapor with the water supply, which unavoidably with the manual control leads to the systematic underheatings and the "breakthroughs" of oxygen into the feed water and, therefore, to an overall increase in the oxygen content in it; 2) the incidence/impingement of gases into the deaerator not only with the deaerated water, but also heating with those condensing by vapor even 3) gas permeation into the deaerator through the leakages/looseresses of apparatuses and conduits/manifolds, that for guaranteeing the qualitative deaeration the value of vapor expedient to support in the limits of 4-6 kg/t of the deaerated water, which composes 3.5-5o/o of the consumption of heating steam.

The expenditure of working vapor for steam-air ejector can be

determined according to of the curves of Fig. 37, refined according to the data of practice, in depending on the degree of rarefaction/evacuation in the capacitor/condenser and on the size/dimension of ejector.

Curve 1 gives relation $G_n:G_в$ (flow rate of working vapor in kg/h to a quantity of air, driven out from the capacitor/condenser in kg/h) for one- and two-stage ejectors of small sizes/dimensions with the consumption of working vapor to 60 kg/h; curve 2 - for two- and three-stage ejectors with the consumption of working vapor from 60 to 100 kg/h; curve 3 - for the same ejectors with the consumption of working vapor from 100 to 300 kg/h and curve 4 - for the large ejectors with the consumption of working vapor is more than 300 kg/h.

The distributions of the total consumption of working vapor according to the steps/stages is expedient to determine of the conditions of the identical initial vapor pressure of working of each step/stage, identical minimum sections of nozzle, but taking into account the pressure in the chamber of mixing. In this case tentatively it is possible to accept the consumption of working vapor on the steps/stages equal ones, since virtually, as a result of different pressures after the nozzle, they will differ little.

The quantity of air entering the Condenser:

1) for high-pressure turbines

$$G_в = \frac{G_п}{2000} + 1{,}36 \text{ kg/h} \qquad (107)$$

2) for medium-and low-pressure turbines

$$G_в = 1{,}5\left(\frac{G_п}{2000} + 1{,}36\right) \text{ kg/h} \qquad (108)$$

3) for piston engines

$$G_в = 2\left(\frac{G_п}{2000} + 1{,}36\right) \text{ kg/h} \qquad (109)$$

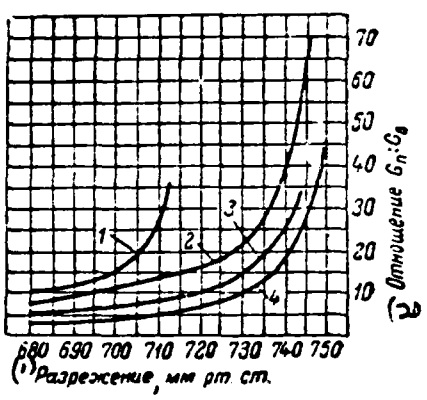

Fig. 37. Expenditure of working vapor for steam-air ejector in depending on rarefaction/evacuation and quantity of air.

Key: (1). Rarefaction/evacuation мм Hg. (2). ratio.

where G_n - quantity of condensed vapor in capacitor/condenser, kg/h.

A quantity of air in the capacitor/condenser with the varying load:

$$G_в = \frac{1}{2000}(0{,}33G_n + 0{,}67G_{nx})\ \text{кг/ч}, \qquad (110)$$

where G_n - quantity of condensed vapor at rated load of capacitor/condenser, kg/h;

$G_{пг}$ - quantity of condensed vapor with this load of capacitor/condenser, kg/h.

Quantity of air-steam mixture, driven out from the capacitor/condenser:

$$G_{см} = G_{в}\left(1 + 0{,}622\frac{p_{п}}{p_{в}}\right) \text{ кг/ч.} \qquad (111)$$

A quantity of vapor that contains in the air-steam mixture:

$$G_{п} = \frac{G_{см}}{1 + 1{,}61\frac{p_{в}}{p_{п}}} \text{ кг/ч,} \qquad (112)$$

where $G_{в}$ - quantity of air, driven out from the capacitor/condenser, kg/h;

$p_{в}$ - partial air pressure, mm Hg;

$p_{п}$ - partial pressure of vapor, mm Hg.

A quantity of air, which is contained in the air-steam mixture, is determined from formula (106).

A quantity of moisture, which evaporates during moistening of the air:

$$W = G_в (d_к - d_н) 10^{-3} \quad \text{kg/h}, \qquad (113)$$

where $G_в$ - quantity of moistered air, kg/h;

$d_н$, $d_к$ - initial and final moisture content of air, g/kg.

Quantity of emitted heat. During the calculation of the heat losses into the surrounding space by the heated surfaces of apparatuses one should consider both the heat loss by convection and by emission.

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The first of these losses can be determined according to formula (92), the second - according to formulas (114) or (115).

The total quantity of given up by wall heat into the surrounding space is determined by the sum of these losses.

A quantity of heat, emitted by hot body into the surrounding space, calculated according to the Stefan-Boltzmann formula:

$$Q_{луч} = C\left[\left(\frac{T_{ст}}{100}\right)^4 - \left(\frac{T_{окр}}{100}\right)^4\right] \text{ kcal/m}^2\text{h} \qquad (114)$$

or according to the formula

$$Q_{луч} = \alpha_{луч}(t_{ст} - t_{окр}) \text{ kcal/m}^2\text{h}, \qquad (115)$$

where $T_{ст} = 273{,}2 + t_{ст}$ - absolute temperature of the wall, heat-radiating, °K;

$T_{окр} = 273{,}2 + t_{окр}$ - absolute temperature of the surrounding space, which obtains heat, °K;

C - radiation factor, depending on surface condition, the kcal/m²h (°K)⁴. (Values of value C they are given in Table 14);

$\alpha_{луч}$ - radiation coefficient from the wall in the surrounding space [see formula (160)].

§9. Coefficients of heat transfer and heat emission.

The heat transfer in the heat exchangers is conducted

simultaneously by the method of the thermal conductivity (transition of energy within the body from its one particle it is direct to another) and by the method of convection (transition of energy in the form of heat together with the single material particles, which contain this heat).

The convective heat exchange can occur both with the free and with the constrained motion of liquid. The motion of liquid, caused on a difference in the densities of the heated and cold particles, is called free. Constrained motion is created by the external exciting forces - pumps, compressors, fans, agitators.

During the heat exchange distinguish the phenomena the heat emissions and heat transfer. Heat emission is characterized by the coefficient, which measures a quantity of heat which is transferred from the heating body to the wall or from the wall to the heating body. Heat transfer is characterized by the coefficient, which measures a quantity of heat which is transferred from the heating body to that heated. Thus, coefficient of heat transfer or heat emission is called the quantity of heat, transferred by the unit of surface for the time unit with a difference in the temperatures of media in 1°C.

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In the metric system the coefficients of heat transfer or heat emission are measured in the kcal/m²h °C.

The equivalent thermal units, mechanical and electrical energy are expressed by the following dependences:

$$1\ \text{ккал}^{(1)} = 427\ \text{кгм}^{(2)};$$
$$1\ \text{л. с.}^{(3)} = 632{,}3\ \text{ккал/час}^{(4)};$$
$$1\ \text{квт}^{(5)} = 860\ \text{ккал/час}.$$

Key: (1). kcal. (2). kg.-m. (3). hp. (4). kcal/h. (5). kW.

The coefficient of heat transfer depends on many factors. Thus, for instance, in the capacitors/condensers it depends:

1) from the side of water on the rate of motion, temperature of water and degree of contamination of the tubes;

2) from the side of steam from the content of air in a steam, steam load on the cooling surface, the formation/educations of water film on the tubes, the location of the cooling tubes and depth of the cooling beam.

In depending on these factors the coefficient of heat transfer

can change in relation 1:3.

Similarity criteria.

For determining the coefficients of heat transfer is been commonly used the law of similitude, which consists in the combination of theoretical and experimental methods.

The application/appendix of the law of similitude to the study of heat transfer made it possible to establish/install the dependence between some dimensionless quantities - similarity criteria. Most commonly used are the following similarity criteria.

Reynolds number characterizes the relation of the forces of inertia and viscous forces in the fluid flow and is expressed by the dependence

$$\mathrm{Re} = \frac{vd}{\nu} = \frac{vd\gamma}{\mu g}. \qquad (116)$$

Nusselt's criterion characterizes the intensity of heat exchange for the boundary liquid - wall and is expressed by the dependence

$$\mathrm{Nu} = \frac{\alpha d}{\lambda}. \qquad (117)$$

Peclet's criterion characterizes heat fluxes during the convective heat exchange and is expressed by the dependence

$$\mathrm{Pe} = 3600\frac{vd}{a} = 3600\frac{vdc\gamma}{\lambda}. \qquad (118)$$

Prandtl number characterizes the physical properties of liquid and is expressed by the dependence

$$Pr = \frac{Pe}{Re} = \frac{3600\nu}{a} = \frac{3600\mu g c}{\lambda}. \qquad (119)$$

Grashof's criterion characterizes interaction of lifts and viscous forces and is expressed by the dependence

$$Gr = \frac{g l^3 \Delta t}{\nu^2}. \qquad (120)$$

Here α - heat-transfer coefficient, kcal/m²h °C;

d, l - linear dimension, diameter of duct or length, m;

λ - coefficient of thermal conductivity, kcal/m-hour °C;

v - rate of motion of liquid or gas, m/s;

μ - coefficient of dynamic viscosity, kg•s/m²;

ν - kinematic viscosity coefficient, m²/s;

c - heat capacity (at a constant pressure), kcal/kg°C;

g - acceleration of gravity m/s²;

γ - specific gravity/weight, kg/m^3;

$a=\lambda/c\gamma$ - coefficient of thermal diffusivity (characterizes the rate of temperature balance in the unevenly heated fluid flow or gas), m^2/h;

β - coefficient of linear expansion of liquid or gas, 1/°C;

Δt - difference in the temperatures, °C.

Over-all heat-transfer coefficients from the heating medium to that heated through the wall.

1. Through single-layer flat/plane wall

$$k=\frac{1}{\frac{1}{\alpha_1}+\frac{s}{\lambda}+\frac{1}{\alpha_2}} \text{ kcal/m}^2\text{h °C}, \qquad (121)$$

where α_1 - heat-transfer coefficient from heating medium to wall, kcal/m^{2}h °C;

s - wall thickness, m;

λ - coefficient of heat conductivity of material of wall, kcal/m-

hour °C;

α_2 - heat-transfer coefficient from wall to heated medium, kcal/m²h °C.

2. Through multilayer flat/plane wall

$$k = \frac{1}{\frac{1}{\alpha_1} + \frac{s_1}{\lambda_1} + \frac{s_2}{\lambda_2} + \ldots + \frac{s_n}{\lambda_n} + \frac{1}{\alpha_2}} \text{ kcal/m}^2\text{h °C}, \quad (122)$$

where $s_1 \div s_n$ - thickness of walls (layers), m;

$\lambda_1 \div \lambda_n$ - coefficient of thermal conductivity of material of walls (layers), kcal/m- hour °C.

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3. Through single-layer cylindrical wall

$$k = \frac{1}{\frac{1}{\alpha_1} + \frac{s}{\lambda} + \frac{1}{\alpha_2}\frac{2d_1}{d_1 + d_2}} \text{ kcal/m}^2\text{h °C} \quad (123)$$

4. Through the multilayer cylindrical wall

$$k = \frac{1}{\left(\frac{1}{\alpha_1 d_i} + \frac{1}{2\lambda_1}\ln\frac{d_1}{d_i} + \frac{1}{2\lambda_2}\ln\frac{d_2}{d_1} + \ldots + \frac{1}{2\lambda_n}\ln\frac{d_n}{d_{n-1}} + \frac{1}{\alpha_2 d_n}\right) d_i}, \quad \text{kcal/m}^2\text{h}\ ^\circ\text{C}, \tag{124}$$

where d_i - cylinder bore, m;

d_1, d_2 - outer diameters of cylinder and layers, m;

d_n - outer diameter of latter/last n layer, m;

ln - natural logarithm.

If the wall thickness of cylinder is insignificant in comparison with the inner diameter and the thickness of the layer (insulation/isolation) and comprises less than 1/20 diameters, then in this case the coefficient of heat transfer can be calculated as for the flat/plane wall.

5. Through finned wall:

1) for unit of smooth surface

$$k = \frac{1}{\frac{1}{\alpha_1} + \frac{s}{\lambda} + \frac{1}{\alpha_2}\frac{F_1}{F_2}} \text{ kcal/m}^2\text{h}\ ^\circ\text{C}; \tag{125}$$

2) for unit of finned surface

$$k = \frac{1}{\frac{1}{\alpha_1}\frac{F_2}{F_1} + \frac{s}{\lambda}\frac{F_2}{F_1} + \frac{1}{\alpha_2}} \text{ kcal/m}^2\text{h } ^\circ\text{C}, \quad (126)$$

where $\frac{F_1}{F_2}$ - ratio of smooth surface to that finned;

$\frac{F_2}{F_1}$ - ratio of finned surface to smooth.

Fig. 38 depicts the finned wall with a thickness of s, the coefficient of thermal conductivity of which is equal to λ. One side of this wall with finneds of the same material. From hair side the surface is equal to F_1, while with that finned - F_2; the latter is comprised from the surface of edges/fins and surface of wall itself between the edges/fins.

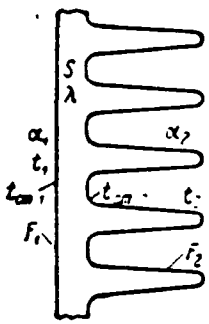

Fig. 38. Coefficient of heat transfer through the finned wall.

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Particular coefficients of heat transfer.

The simplified determination of the coefficients of heat transfer from the vapor to the water for the capacitors/condensers can be recommended according to the following approximation formula resulting data which answer the character of the curves Fig. 39; this formula gives, however, somewhat the higher values

$$k = 942\sqrt{v}\,\sqrt[4]{t_{cp} + 17{,}8} \quad \text{kcal/m}^2\text{h}\ ^\circ\text{C}, \qquad (127)$$

where v - a rate of water in tubes, m/s;

t_{cp} - mean temperature of water, °C.

The curves of the coefficient of heat transfer for the brass tubes with a diameter of 19 mm are given in Fig. 39. The values of coefficient of k of heat transfer are given maximum, attained in the virtually pure/clean capacitors/condensers of good construction/design with certain supply.

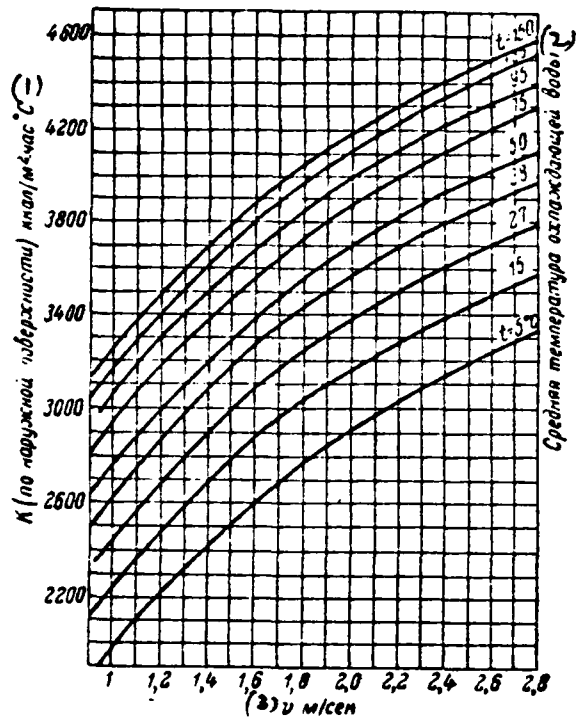

Fig. 39. Coefficient of heat transfer from the vapor to the water depending on the rate and temperature of cooling water for brass tubes with a diameter of 19 mm.

Key: (1). To (over the external surface) kcal/m²h °C. (2). Mean temperature of cooling water. (3). m/s.

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For the tubes with a diameter of 16 mm k it increases by 2o/o. For the tubes with a diameter of 25 mm k it decreases by 3o/c. For

the German silver tubes k it descends to 10c/c and for the steel tubes - by 17-20o/o.

These coefficients of heat transfer are determined for the capacitors/condensers, designed with Δt taking into account the effect of steam resistance.

For obtaining the average/mean value of coefficient of k' the obtained coefficient k in formula (127) or in Fig. 39 should be multiplied by 0.8-0.85 to account for the effect of surface contaminations and inconstancy of other factors, noted on page 50.

The coefficient of heat transfer for the capacitors/condensers according to the data of VTI is determined by the formula

$$k = 3500\left(\frac{1,1v}{\sqrt[4]{d_в}}\right)^x\left[1 - \frac{0,42\sqrt{a}}{1000}(35 - t_в)^2\right]\Phi_2\Phi_6,$$

kcal/m²h °C, (128)

where $x = 0,12a(1 + 0,15)t_в$;

a=0.8-0.85 - the coefficient, which considers surface contamination of the cooling;

v - rate of water in the tubes, m/s;

$d_в$ - inner diameter of tube, mm;

$t_в$ - temperature of cooling water in the capacitor/condenser, °C;

Φ_z - factor, which considers the effect of a number of courses of water in the capacitor/condenser,

$$\Phi_z = 1 + \frac{z-2}{10}\left(1 + \frac{t_в}{35}\right);$$

z - number of courses of water in the capacitor/condenser;

Φ_δ - factor, which considers the effect of the steam load of capacitor/condenser U [see formula (161)]: $\Phi_\delta = 1$ for the nominal steam load or changing within the limits from $U_{ном}$ to $U_{гр} = \delta_{гр} U_{ном}$, where $\delta_{гр} = 0{,}9 - 0{,}012 t_в$; $\Phi_\delta = \delta(2-\delta)$ for $U < U_{гр}$, where $\delta = \frac{U}{U_{гр}}$.

The coefficient of heat transfer for the capacitors/condensers of steam engines:

$$k_0 = 0{,}8k \text{ kcal/m}^2\text{h °C},$$

where k - the coefficient of heat transfer, determined in formula (127) or in of the curves of fig. 39;

number 0.8 - the coefficient, which considers the presence in capacitor/condenser of oil, introduced with the vapor in the dustlike state.

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The coefficient of heat transfer for the vaporizers/evaporators and the distillers (from the vapor to the boiling brine of marine water) is determined on of the curves of Fig. 40 in depending on the temperature of primary (heating) and secondary steam.

During the practical calculations of vaporizers/evaporators should be considered the degree of surface contamination of heat exchange, the effect of air and the nonuniformity of the distribution of heat-transfer agent, which make the coefficient worse of heat transfer against that theoretically calculated. This effect is considered by the correction factor β, which is introduced in the form of factor to the coefficient of heat transfer, found in of the curves of Fig. 40. The value of correction factor β is accepted within the limits from 0.8 to 0.9 in depending on the salinity of marine water and brine in the housing of vaporizer/evaporator. The larger salinity of water and brine answers the smaller value of coefficient and vice versa.

The coefficient of heat transfer from the vapor to the petroleum residue depending on the rate and mean temperature of petroleum residue is determined on the graph/curve Fig. 41.

The curves of graph/curve are constructed according to the data of tests for the course of the admiralty fuel oil M12 in the steel tubes with a diameter of 17/13 mm.

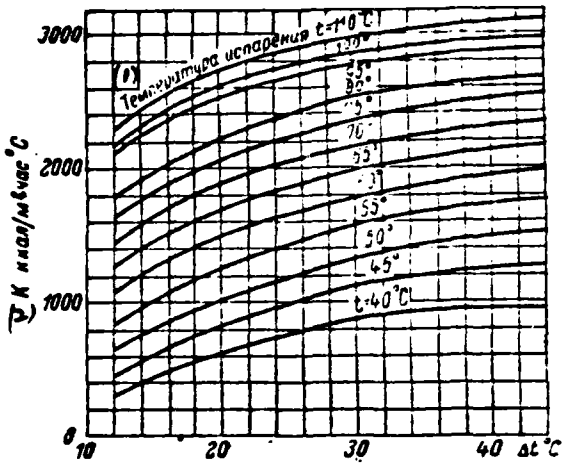

Fig. 40. Coefficient of heat transfer for the vaporizers/evaporators in depending on a difference in the temperatures (between the temperature of the saturation of primary and secondary steam) and the temperature of the evaporation of water.

Key: (1). Vaporization temperature. (2). To kcal/m²h °C.

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The coefficient of heat transfer from the vapor to petroleum residue M 20 and M 40 can be with sufficient precision/accuracy determined by the dependence:

$$k_{\text{н}} = \varepsilon_1 k \text{ kcal/m}^2\text{h } ^\circ\text{C}, \qquad (129)$$

where ε_1 - the correction factor, which considers a change in the brand of petroleum residue and taken: $\varepsilon_1 = 0{,}93$ - for petroleum residue M 20, $\varepsilon_1 = 0{,}87$ - for petroleum residue M 40;

k - coefficient of heat transfer from the vapor to petroleum residue M 12, determined in the graph/curve Fig. 41.

The coefficient of heat transfer from the vapor to the petroleum residue, which takes place in the tubes with established/installed in them retarders, can be determined the dependence

$$k_p = \varepsilon_2 k_м \text{ kcal/m}^2\text{h } ^\circ\text{C}, \qquad (130)$$

where ε_2 - correction coefficient, which considers the effect of retarders in depending on rate and mean temperature of petroleum residue, determined in the graph/curve Fig. 42;

$k_м$ - coefficient of heat transfer from the vapor to the petroleum residue of this brand, determined on formula (129) and graph/curve of Fig. 41.

As retarders were applied the flat/plane steel strips with a thickness of 1 mm and the spirals, convoluted from the same bands with different space of twisting.

Tests showed that with viscous motion of petroleum residue in the tube, which usually occurs in the fuel heaters, the decrease of the space (from 300 to 50 mm) or spiral retarders or the replacement by their flat/plane ones does not exert a substantial influence on an increase in the coefficient of heat transfer.

The coefficient of heat transfer from the vapor to oil in depending on rate and mean temperature of oil is determined on the graph/curve Fig. 43.

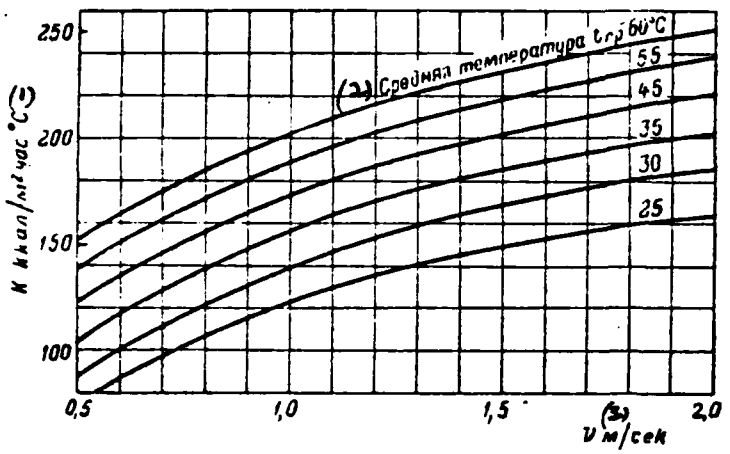

Fig. 41. Coefficient of heat transfer from the vapor to the petroleum residue in depending on its rate and mean temperature.

Key: (1). To the kcal/m²h °C. (2). Mean temperature. (3). m/s.

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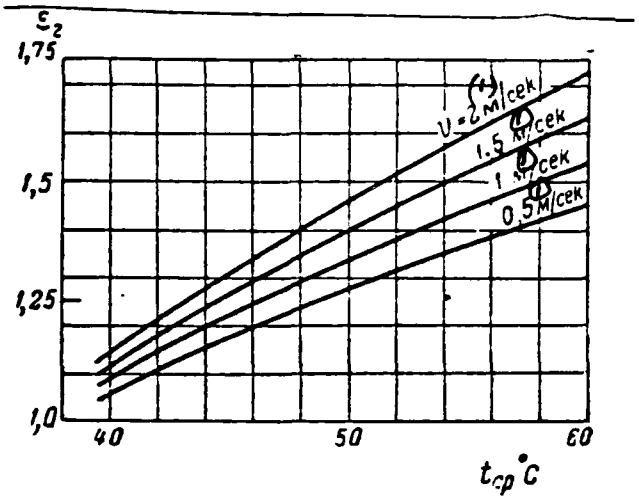

Fig. 42. Correction factor, which considers effect of retarders established/installed in tubes.

Key: (1). m/s.

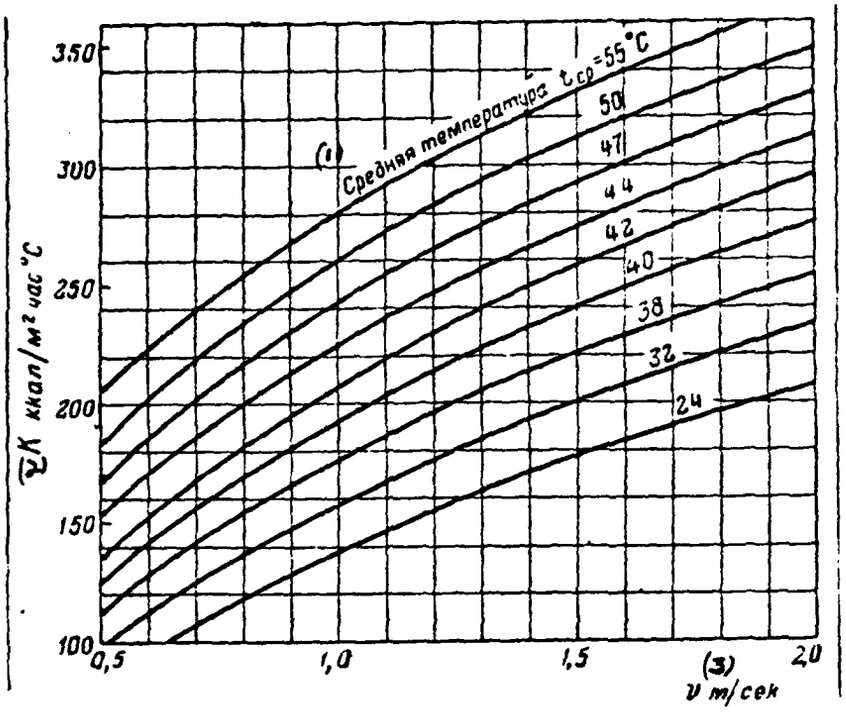

Fig. 43. Coefficient of heat transfer from vapor to oil in depending on its rate of mean temperature.

Key: (1). Mean temperature. (2). kcal/m²h °C. (3). m/s.

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The curves of graph/curve are constructed according to the data of tests for the course of oils of brands T and UT in the copper tubes with a diameter of 10/8 mm.

Tentative limits of the values of the coefficients of heat transfer k (kcal/m²h °C) in the shipboard heat exchangers:

from one gas to the next ... 25-40

from the gas to the water ... 50-100

from one water to the next ... 1000-2000

from the condensable vapor to the water ... 2500-3500

from the condensable vapor to the air ... 80-140

from the condensable vapor to oil ... 100-350

from the condensable vapor to the petroleum residue ... 100-400.

General/common/total heat-transfer coefficients.

Heat-transfer coefficient during the free convection (free motion) of liquid, gas (vapor) in the large volume is determined from the formula of M. A. Mikheev

$$\alpha = c\frac{\lambda}{d}(GrPr)^n \quad \text{kcal/m}^2\text{h °C}, \qquad (131)$$

where λ - coefficient of the thermal conductivity of medium, kcal/m-hour °C;

d - determining size/dimension (diameter), m;

Gr - Grashof's criterion;

Pr - Prandtl number;

c, n - coefficients.

The values of coefficients of c and n are given in Table 5.

Formula (131) is applied for any drop ones and gaseous liquids, for the vertical and horizontal ducts (wires), the horizontal plates/slabs and the spheres of any size/dimension. In this case, if the exothermal surface of plate/slab is turned upwards, then the obtained from formula (131) value of coefficient increases by 30o/c, but if the exothermal surface is turned downward, then value decreases by 30o/o.

As the determining size/dimension is accepted the diameter, and for the plates/slabs - smaller side of plate/slab.

Table 5. Values of coefficients of c and n.

Режим движения (1)	(GrPr)	c	n
Ламинарный (2)	$1\cdot10^{-3} \div 5\cdot10^{2}$	1,180	1/8
Переходный (3)	$5\cdot10^{2} \div 2\cdot10^{7}$	0,546	1/4
Турбулентный (4)	$2\cdot10^{7} \div 1\cdot10^{13}$	0,135	1/3

Key: (1). State of motion. (2). Laminar. (3). Transient. (4). Turbulent.

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As the determining temperature is accepted mean temperature of boundary layer, determined according to formula (16).

The coefficient of heat transfer with forced viscous motion of liquid, gas (vapor) in the duct is determined from the formula of I. T. Alad'yev

$$\alpha = 0{,}74\frac{\lambda}{d}Re^{0{,}2}(GrPr)^{0{,}1}Pr^{0{,}2}\ \text{kcal/m}^2\text{h}\ ^\circ\text{C}, \qquad (132)$$

where λ - coefficient of the thermal conductivity of medium, kcal/m-hour °C;

d - diameter of duct, m;

Re - Reynolds number;

Pr - Prandtl number;

Gr - Grashof's criterion.

Formula (132) is applied for the horizontal and stand pipes, and also for ducts and channels of any section: in this case instead of the diameter of ducts is substituted the equivalent diameter of section.

In the vertical position of ducts and with the coincidence of the directions of the free and constrained motion the coefficient of the heat emission in 15o/o than lower calculated according to formula (132), while in opposite direction - in 15o/o is above.

As the determining size/dimension is accepted the diameter of duct or the equivalent diameter of section, while for the determining temperature - temperature of boundary layer.

If the length of duct $l<50$ d, then the obtained value according to the formula must be multiplied by correction factor ε_l (Table 6).

Heat-transfer coefficient with the forced turbulent motion of liquid, gas (vapor) in the duct, and also with the longitudinal washing of the bank of tubes is determined from the formula

$$\alpha = 0{,}023 \frac{\lambda}{d} Re^{0.8} Pr^{0.4} \quad \text{kcal/m}^2\text{h}\ ^\circ\text{C}, \qquad (133)$$

where the designations the same as in formula (132).

Formula (133) is applied to the drop and elastic liquids for ducts and channels of any section, and also for the longitudinal external washing of the banks of tubes with $Re > 1 \cdot 10^4$ and $Pr = 0.7-2500$, also, at temperature of the wall lower than boiling point of liquid, and also for the superheated steam by pressure to 100 atm(abs.) with $Re \leq 2 \cdot 10^6$.

Table 6. Values of coefficients

l/d	1	2	5	10	15	20	30	40	50
ε_1	1,9	1,7	1,44	1,28	1,18	1,13	1,05	1,02	1,0

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As the determining size/dimension is accepted the equivalent diameter of duct and for the determining temperature - mean arithmetic temperature of liquid.

With $\frac{l}{d} < 50$ the obtained value for α must be multiplied by correction factor ε_1 (Table 7).

Formula (133) is valid also for ring cross-section $d_1/d_2=0.1-1.0$ in the case of heat exchange with the external (larger) surface.

For the ring cross-section and the heat exchange with the internal surface the formula takes the form

$$\alpha = 0{,}023 \frac{\lambda}{d_1} \left(\frac{d_2}{d_1}\right)^{0.45} Re^{0.8} Pr^{0.4} \text{ kcal/m}^2\text{h } ^\circ\text{C}, \qquad (134)$$

where d_1 - an outside diameter of core tube;

d_2 - inner diameter of body tube.

Heat-transfer coefficient during the transient mode/conditions. Motion is unstable. Reynolds number is within the limits of Re from 2200 to 10000.

In this case of formula (132) and (133) the heat emissions for the laminar and turbulent mode/conditions are not applied, but their extrapolation is not admitted.

Table 7. Values of coefficients ε_l

Re \ l/d	1	2	5	10	15	20	30	40	50
$1\cdot10^4$	1,65	1,50	1,34	1,28	1,17	1,13	1,07	1,03	1,0
$2\cdot10^4$	1,51	1,40	1,27	1,18	1,13	1,10	1,05	1,02	1,0
$5\cdot10^4$	1,34	1,27	1,18	1,13	1,10	1,08	1,04	1,02	1,0
$1\cdot10^5$	1,28	1,22	1,15	1,10	1,08	1,06	1,03	1,02	1,0
$1\cdot10^6$	1,14	1,11	1,08	1,05	1,04	1,03	1,02	1,01	1,0

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For determining the heat-transfer coefficient during the transient mode/conditions it should be used the following dependence:

$$\alpha = Nu\frac{\lambda}{d} \text{ kcal/m}^2\text{h } ^\circ\text{C}, \qquad (135)$$

where Nu - Nusselt's criterion, determined in depending on criteria Re, Pr and products $Gr\,Pr^3$ on the graph/curve Fig. 44 or according to formula (136);

λ - coefficient of the thermal conductivity of medium at mean temperature, kcal/m-hour °C;

d - diameter of duct, m.

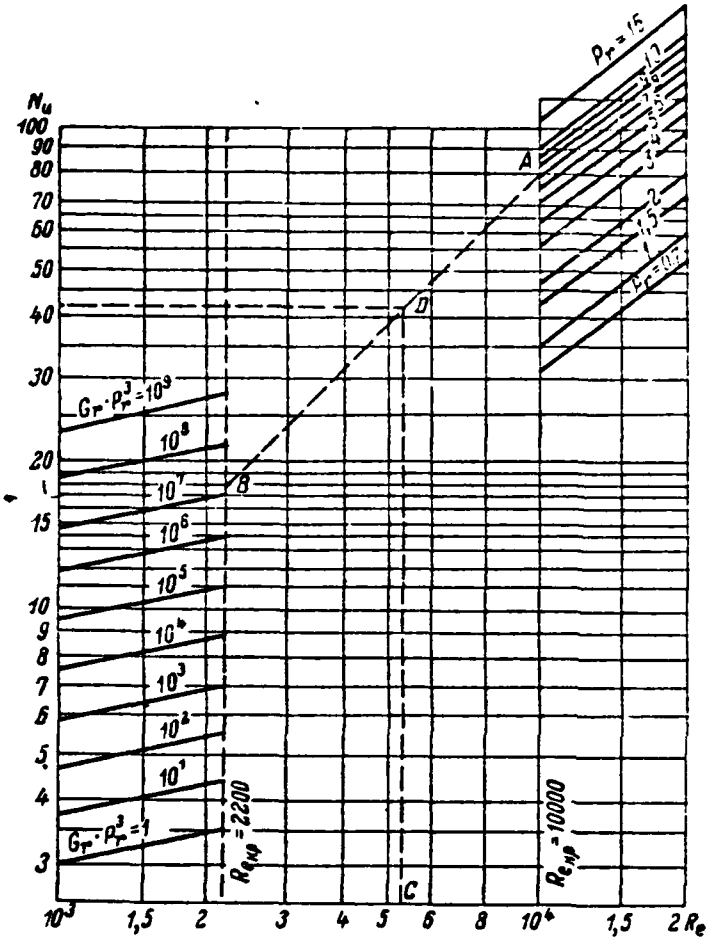

Fig. 44. Graph/curve of heat emission during the transient mode/conditions.

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Approximate value of Nusselt's criterion Nu for the transient mode/conditions through the graph/curve Fig. 44 is located in a

following manner:

1) on the ordinate at value $Re_{кр} = 10^4$ is plotted/deposited the value of Prandtl number Pr, calculated at mean temperature of medium (point A);

2) on the ordinate at value $Re_{кр} = 2200$ is plotted/deposited the value of the product of criteria Gr Pr^3, calculated at mean temperature of boundary layer (point B);

3) points A and B are connected by the straight line $\overline{AB}$;

4) on the axis/axle of abscissas is plotted/deposited the value of criterion Re for the transient mode/conditions (point C), and from point C is set up ordinate before the intersection with the straight line $\overline{AB}$ (point D);

5) by the value of ordinate CD is determined the unknown value of Nusselt's criterion Nu during transition mode/conditions.

Approximate value of Nusselt's criterion Nu during the transient mode/conditions can be also determined according to the formula

$$Nu = (Nu_T - Nu_A)\frac{Re - 2200}{7800} + Nu_A, \qquad (136)$$

where Nu_T - Nusselt's criterion, calculated for $Re_{кр} = 10^4$ according to

formula (133);

Nu_n - Nusselt's criterion, calculated for $Re_{кр} = 2200$ according to formula (132).

The coefficient of heat transfer during the transverse flow around duct by liquid and gas (vapor) is determined from the formulas of V. I. Gomelauri:

For the liquids

$$\alpha = c\frac{\lambda}{d}Re^{n}Pr^{0,4}\ \text{kcal/m}^2\text{h}\ ^\circ\text{C}. \qquad (137)$$

For the gases

$$\alpha = c\frac{\lambda}{d}Re^{n}\ \text{kcal/m}^2\text{h}\ ^\circ\text{C}, \qquad (138)$$

where c and n - the coefficients, which depend on the value of criterion Re (Table 8).

Table 8. Value of coefficients cr c and n.

(1) Критерий Рейнольдса Re	(2) Коэффициент c для жидкости	(3) Коэффициент c для газа (пара)	n
5÷80	0,930	0,810	0,40
80÷5000	0,715	0,625	0,46
5000÷100 000	0,226	0,197	0,60

Key: (1). Reynolds number. (2). Coefficient c for liquid. (3). Coefficient c for gas (vapor).

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Remaining designations the same as in the preceding/previous formulas.

Formulas (137) and (138) are applied for the drop ones and the the elastic liquids with the washing of single ducts.

As the determining size/dimension is accepted the diameter of streamline tube, while for the determining temperature - mean temperature of liquid.

The rate of flow is determined in the narrowest section of channel.

Heat-transfer coefficient during the transverse flow around the bank of tubes of gas (air) is determined on S. V. Litvinov's formula:

$$\alpha = c\varepsilon \frac{\lambda}{d} Re^{n}, \text{ kcal/m}^2\text{h } ^\circ\text{C}, \qquad (139)$$

where the values of coefficients of c, ε and n depend on the schematic of run of pipes in the beam, a number of series/rows and distance S_1 between the axes/axles of ducts in the series/row.

The values of coefficients of c, ε and n are given in Table 9; remaining designations the same as in the preceding/previous formulas.

The schematics of run of pipes in the beams are given in Fig. 45.

Formula (139) is applied for the air and the flue gases.

The rate of flow relates to the narrowest section in the beam (series/row).

Table 9. Value of coefficients cf c, ε and n.

(1) Ряды	(2) Расположение труб				c	(5) Примечание
	(3) коридорное		(4) шахматное			
	n	ε	n	ε		
1	0,60	0,150	0,60	0,150	$1+0{,}1\frac{S_1}{d}$	(6) При $\frac{S_1}{d}=1{,}2\div3$
2	0,65	0,138	0,60	0,200		
3	0,65	0,138	0,60	0,255	1,3	(6) При $\frac{S_1}{d}=3\div5$
4 и (7) т. д.	0,65	0,138	0,60	0,255		

Key: (1). Series/rows. (2). Run cf pipes. (3). Corridor. (4). Checkered. (5). Note. (6). with.

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As the determining size/dimension is accepted the diameter of duct, while for the determining temperature - mean temperature of flow.

The heat-transfer coefficient with the cross flow of air, calculated according to formula (139), is valid only for the cases when angle ϕ, comprised by direction of flow and by axis/axle of duct, called angle of attack, is equal to 90°. At angle ϕ, different from 90°, the value of heat-transfer coefficient, found from formula (139), should be multiplied by coefficient ε, obtained from the graph/curve Fig. 46.

Heat-transfer coefficient in bent tube is determined from the formula, derived on the basis of experimental data:

$$\alpha_{кон} = \left(1 + 1{,}77\,\frac{d}{R}\right)\alpha \text{ ккал}/\text{м}^2\text{-час}\,^\circ\text{C}, \qquad (140)$$

(1)

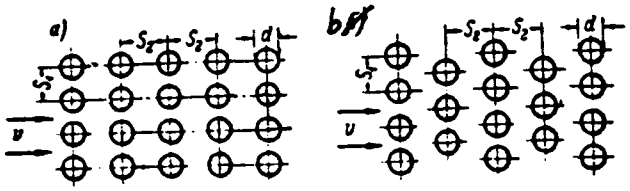
Key: (1). kcal/m²h.

where α - heat-transfer coefficient for straight/direct ducts, kcal/m²h °C;

d - diameter of duct, mm;

R - radius of curvature of duct, mm.

Heat-transfer coefficient in bent tube other conditions being equal will be more than in the straight line. This increase occurs due to the disturbance/breakdown of the laminarity of the flow in the rotation, which creates the conditions of more intense heat exchange. With an increase in the radius of curvature of duct the coefficient of heat transfer decreases.



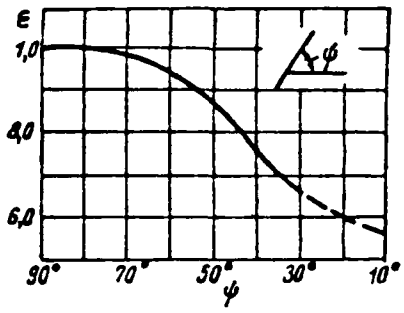


Fig. 45. Schematics of run of pipes in the beams: a) corridor; b) checkered.

Fig. 46. Dependence of heat emission of duct on angle of attack ψ.

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Particular heat-transfer coefficients.

Heat-transfer coefficient α for the water: 1) for the water, which takes place in tube or channel of any section with laminar flow, α is determined from formula (132);

2) for the water, which takes place in the tube with turbulent flow,

$$\alpha = Av^{0.8}d^{-0.2}\ \text{ккал}^{(1)}/\text{м}^2\text{-час}\ ^\circ\text{C}, \qquad (141)$$

Key: (1). kcal/m²h.

where $A = (1190 + 21{,}5\ t_{cp} - 0{,}015\ t^2_{cp})$;

v - speed of water, m/s;

d - diameter of tube, m;

t_{cp} - mean temperature of water, °C.

Values A, $v^{0.8}$, $d^{-0.2}$ are given in Tables 10, 11 and 12.

Table 10. Values A.

t_{cp}, °C	0	10	20	30	40	50	60
A	1190	1400,5	1602,0	1795,5	1978,0	2152,5	2318,0
t_{cp}, °C	70	80	90	100	120	140	—
A	2474,5	2622,0	2765,5	2890,0	3122,0	3318,0	

Table 11. Values $v^{0,8}$.

v	$v^{0,8}$	v	$v^{0,8}$	v	$v^{0,8}$	v	$v^{0,8}$	v	$v^{0,8}$	v	$v^{0,8}$
0,1	0,158	0,5	0,574	0,9	0,916	1,3	1,23	1,7	1,53	2,5	2,08
0,2	0,275	0,6	0,665	1,0	1,000	1,4	1,31	1,8	1,60	3,0	2,41
0,3	0,382	0,7	0,752	1,1	1,080	1,5	1,38	1,9	1,67	3,5	2,72
0,4	0,480	0,8	0,837	1,2	1,160	1,6	1,46	2,0	1,74	4,0	3,03

Table 12. Values $d^{-0,2}$.

d	$d^{-0,2}$	d	$d^{-0,2}$	d	$d^{-0,2}$	d	$d^{-0,2}$
0,010	2,51	0,020	2,19	0,030	2,02	0,055	1,79
0,012	2,42	0,022	2,15	0,035	1,96	0,060	1,76
0,014	2,35	0,024	2,11	0,040	1,90	0,070	1,70
0,016	2,29	0,026	2,07	0,045	1,86	0,080	1,66
0,018	2,23	0,028	2,04	0,050	1,82	0,100	1,52

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Fig. 47 gives the nomogram for determining the heat-transfer coefficient for the water, calculated according to formula (141).

Nomogram makes it possible to determine heat-transfer coefficient for different mean temperatures of water and different diameters of tubes in the dependence on the speed of water in the tubes. The determination of heat-transfer coefficient in the nomogram is shown by the arrows/pointers;

3) for the water, which flows around about the tubes during the free convection (free motion), α are determined from formula (131);

4) for the water, which flows around about the tubes at low speeds,

$$\alpha = 0{,}5\,\frac{\lambda}{d}\,\mathrm{Re}^{0{,}6}\mathrm{Pr}^{0{,}3}\ \text{ккал}^{(1)}/\text{м}^2\text{-час}\ ^\circ\mathrm{C}; \qquad (142)$$

Key: (1). kcal/m²h.

where λ, d, Re and Pr - the same as in the designation of similarity criteria.

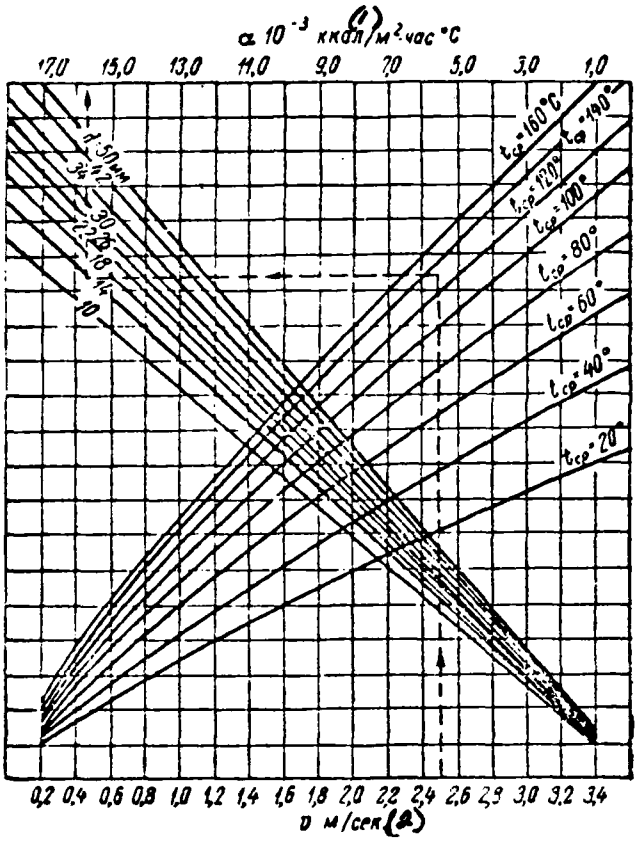

Fig. 47. Nomogram for determining the heat-transfer coefficient from the wall to the water and from the water to the wall.

Key: (1). kcal/m²h. (2). m/s.

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5) for the water during the transverse flow around tube α it is

determined from formula (137);

6) for the water, which flows around about the tubes lengthwise with the turbulent motion, α is determined from formula (133);

7) for the boiling water

$$\alpha = 22p^{0.58}\,\Delta t^{2.33}\ \text{ккал}^{(1)}/\text{м}^2\text{-час}\ ^\circ\text{C}, \qquad (143)$$

Key: (1). kcal/m²h.

where p - pressure in container, atm(abs.);

Δt - difference in the temperatures between the surface of wall and the boiling water, °C.

Fig. 48 gives the curve of heat-transfer coefficient α for the boiling water in the dependence on a difference in temperatures $t_{ст} - t_{в}$ (between the wall and the water) at the atmospheric pressure of the boiling liquid. Curve consists of two sections, which are shared with the point of the critical temperature head (by difference in the temperatures), equal to about 25°C).

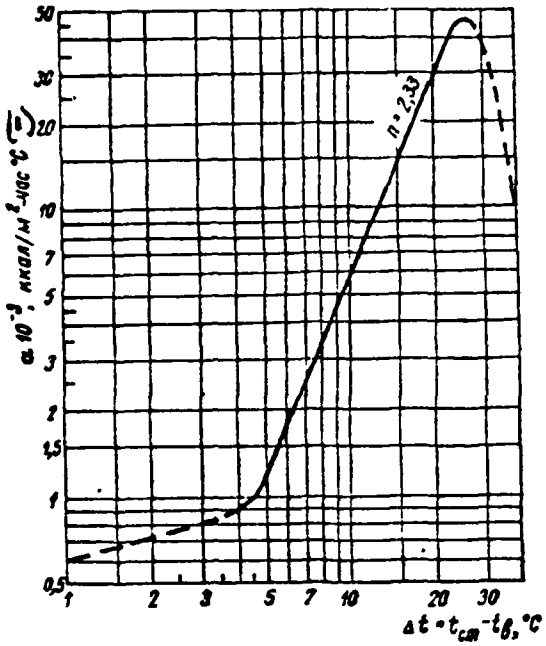

Fig. 48. Heat-transfer coefficient for the boiling water in depending on a difference in the temperatures between the wall and the boiling water.

Key: (1). kcal/m²h.

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The solid line of curve is located in limits of 5-25°C of the temperature head; it is calculated according to formula (143) for the atmospheric pressure.

Laws governing the heat-transfer coefficient, located in other limits of the temperature head, are different. An increase in the temperature head higher than critical leads to a sharp reduction in the heat-transfer coefficient for the boiling water.

Heat-transfer coefficient α for the oil-products: 1) for the oil-products, petroleum residue and oil, which take place in the tubes with viscous motion,

$$\alpha = 13{,}2\,\frac{\lambda}{d}\,\mathrm{Pe}^{0{,}23}\left(\frac{l}{d}\right)^{-0{,}5}\ \text{ккал}^{(1)}/\text{м}^2\text{-час}\ ^\circ\mathrm{C}, \qquad (144)$$

Key: (1). kcal/m²h.

where λ - coefficient of the thermal conductivity of oil-product, kcal/m·h °C;

d - diameter of tube, m;

l - length of tube, m;

Pe - Peclet's criterion.

The motion of oil-products usually occurs with laminar flow;

2) for oil, which flows around about the tubes across,

$$\alpha = 550\sqrt{\frac{v}{t-d_н}}\,(1+0{,}006t_{ср})\ \text{ккал}^{(1)}/\text{м}^2\text{-час}\ ^\circ\mathrm{C}, \qquad (145)$$

Key: (1). kcal/m²h.

where v - speed of oil, m/s;

t - space of tubes, mm;

$d_н$ - outside diameter of tubes, mm;

$t_{ср}$ - mean temperature of oil, °C.

Fig. 49 gives curves of heat-transfer coefficients for the oil coolers, calculated according to formula (145) in the dependence on the speed and mean temperature oils also of the space of tubes. With the space of tubes 21 mm the heat-transfer coefficient increases by 9c/o, while with the space 20 mm - to 22c/o;

3) for the oil-products, preheated in the cistern by coils (heat emission with the free action),

$$\alpha = 1{,}57 \sqrt[4]{\frac{t_{ст} - t}{v d_н}} \text{ ккал}^{(1)}/\text{м}^2\text{-час °C}; \qquad (146)$$

Key: (1). kcal/m²h.

4) for the oil-products, which take place along stand pipe,

$$\alpha = 2{,}61 \sqrt[3]{\frac{t_{ст} - t}{v}} \text{ ккал}^{(1)}/\text{м}^2\text{-час °C}; \qquad (147)$$

Key: (1). kcal/m²h.

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5) for the oil-products, which take place along horizontal duct,

$$\alpha = 1{,}91\sqrt[4]{\frac{t_{ст}-t}{\nu d_н}}\ \text{ккал}^{(1)}/м^2\text{-час}\ ^\circ\text{C}, \qquad (148)$$

Key: (1). the kcal/m²h.

where $t_{ст}$ - temperature of wall, determined according to formula (19), °C;

t - temperature of oil-products, °C;

ν - kinematic viscosity coefficient, m²/s;

$d_н$ - outside diameter of coil, m.

Heat-transfer coefficient for the condensing water vapor: 1) for the vertical wall or the stand pipe

$$\alpha_п = A\sqrt[4]{\frac{r}{H(t_s-t_{ст})}}\ \text{ккал}^{(1)}/м^2\text{-час}\ ^\circ\text{C}, \qquad (149)$$

Key: (1). kcal/m²h.

where $A = 0{,}943\sqrt[4]{\frac{\gamma^2\lambda^2}{\mu}}$ depends on temperature $t_{гр}$, of determined according to formula (16) or (21);

r - heat of vaporization, kcal/kg;

H - height of wall or duct, m;

t_s - temperature of the condensable vapor, °C.

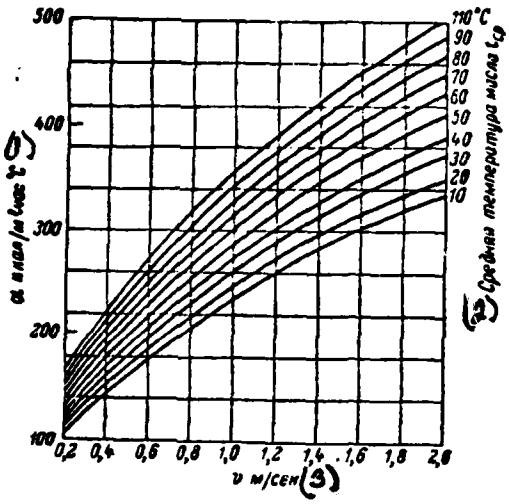

Fig. 49. Heat-transfer coefficient for the oil coolers in depending on speed and mean temperature of oil, which takes place between the tubes with a diameter of 16 mm and with space 22 mm.

Key: (1). kcal/m²h. (2). Mean temperature of oil. (3). m/s.

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$t_{ст}$ - temperature of wall, determined according to formulas (17)-(19), °C;

γ - the specific gravity/weight of condensate, kg/m³;

λ - coefficient of thermal conductivity, kcal/m-h °C;

μ - viscosity of condensate, kg•s/m².

Values A are given in Table 13;

2) for the inclined wall

$$\alpha_\beta = \alpha_в \sqrt[4]{\sin\beta} \ ккал^{(1)}/м^2\text{-}час\ °C, \qquad (150)$$

Key: (1). kcal/m²h.

where $\alpha_в$ - heat-transfer coefficient from the condensable vapor to the vertical wall or ttube, the kcal/m²- h °C;

β - angle of the slope of wall to the horizontal plane;

3) for the horizontal duct

$$\alpha_г = 0{,}77 A \sqrt[4]{\frac{r}{d_н (t_s - t_{ст})}} \ ккал^{(1)}/м^2\text{-}час\ °C, \qquad (151)$$

Key: (1). kcal/m²h.

where $d_н$ - outside diameter of duct, m;

A, r, t_s and $t_{ст}$ - the same as in formula (149);

4) for the beam of the horizontal ducts (arranged/located by one

under another so that the condensate of upper duct it flows on lower)

$$\alpha_n = \alpha_r \sqrt[4]{\frac{1}{n}} \text{ ккал}^{(1)}/\text{м}^2\text{-час °C}, \qquad (152)$$

Key: (1). kcal/m²•h.

where α_r - heat-transfer coefficient for the upper duct;

n - number of ducts, arranged/located on the vertical line under each other.

Fig. 50 gives the nomogram for determining the heat-transfer coefficient from the condensable vapor to the wall for the vertical and horizontal location of walls, calculated according to formulas (149) and (151).

Table 13. Values A.

$t_{гр}$	A	$t_{гр}$	A	$t_{гр}$	A	$t_{гр}$	A	$t_{гр}$	A	$t_{гр}$	A	$t_{гр}$	A
0	1147	30	1495	60	1795	90	2075	120	2330	150	2570	180	2775
10	1270	40	1600	70	1890	100	2160	130	2415	160	2640	190	2835
20	1387	50	1700	80	1985	110	2245	140	2495	170	2710	200	2890

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On the nomogram the value α is determined in depending on the product of the height/altitude of wall or beam of tubes to a difference in the temperatures of the condensable vapor and wall and on the temperature of boundary layer $t_{гр}$, of determined according to formula (16) or (21);

5) for the condensable vapor within the horizontal ducts and the coils

$$\alpha = (3400 + 100v_0)\sqrt[3]{\frac{1,21}{l}}\ \text{ккал}/\text{м}^2\text{-час}\ ^\circ\text{C},$$ (1)

Key: (1). kcal/m²h.

where v_0 - speed of steam with entrance into the duct, m/s;

l - length of duct or coil, m;

6) for the condensable vapor within the stand pipes α are determined from formula (149).

Heat-transfer coefficient for the condensable moving/driving vapor, which contains air, is determined from empirical formula VTI

$$\alpha = \frac{A(v_\gamma)^{n\Delta t^{0.167}}}{\Delta t^{0.167}} \text{ ккал/м}^2\text{-час °C}, \quad (153)$$

(1)

Key: (1). kcal/m²•h.

where v_γ - the mass flow rate of air-steam mixture in the wide section of channel, kg/m²s.

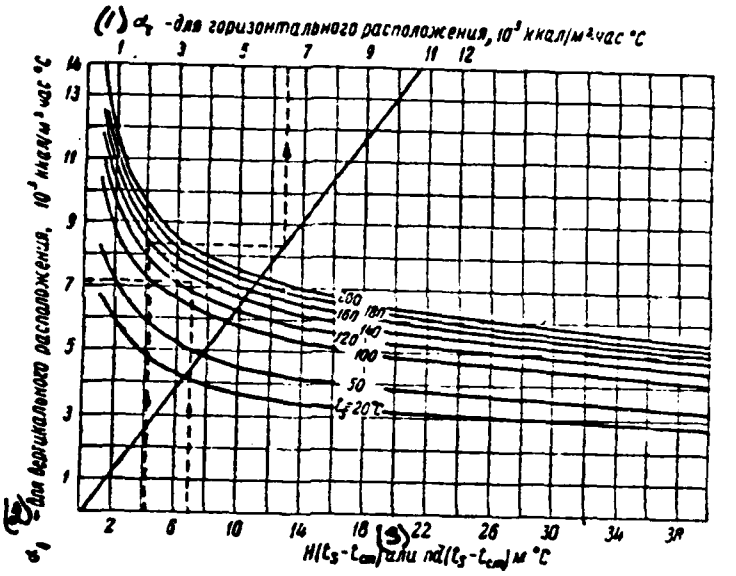

Fig. 50. Nomogram for determining the heat-transfer coefficient from the condensable vapor to the wall.

Key: (1). for the horizontal location, 10^3 kcal/m²•h°C. (2). for vertical run, 10^3 kcal/m²•h°C. (3). or.

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A, n - values, which depend on the content of air in vapor $\varepsilon = \frac{G_в}{G_п}$ and the temperature of mixture $t_{см}$, to equal temperature of steam $t_п$, determined on the curves of the graph/curve Fig. 51 and 52;

Δt - the temperature head (diference in the temperatures of

mixture and the walls of duct), °C.

Formula (153) is obtained according to experimental data for the horizontal beam of the brass ducts with a outside diameter of 19 mm and by space between them of 28 mm at $t_n = 30 \div 80°C$; $\Delta t = 3 \div 15°C$; $w_r = 0,1 \div 3,0$ kg/m$_2$s and $\varepsilon = 0 \div 0,3$ kg/kg.

Heat-transfer coefficient for the overheated (not condensing) vapor is determined from formula (133).

It is necessary to keep in mind that, if the temperature of the wall lower than temperature of saturation, then the condensation of the superheated steam flows/occurs/lasts then good as saturated.

Therefore heat-transfer coefficient for the superheated steam is defined:

1) according to formula (149) as for the condensable vapor, if the temperature of the wall lower than temperature of saturation of steam;

2) according to formula (133) as for the overheated (not condensing) steam (or gases), if the temperature of the wall higher than temperature of saturation.

During the determination of heat-transfer coefficient for the condensing superheated steam should be allowed its temperature of saturation at the appropriate pressure, but not the temperature of overheating.

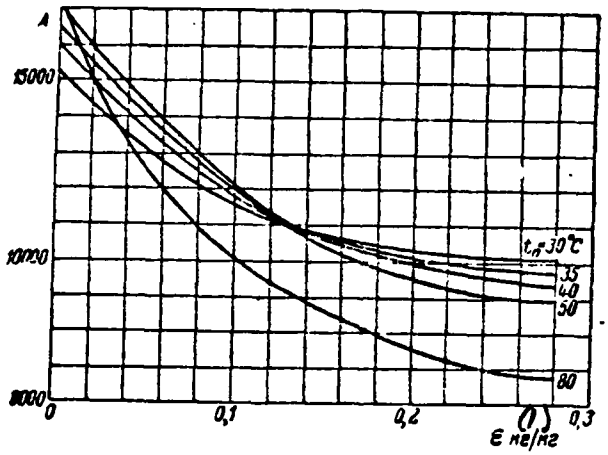

Fig. 51. Value of value A in depending on the content of air in steam and the temperature of air-steam mixture.

Key: (1). kg/kg.

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Heat-transfer coefficient for any gas and air: 1) for the gas and the air, which takes place in duct or channel of any section with viscous motion, heat-transfer coefficient is determined from formula (132);

2) for the gas and the air, which takes place in the duct or which flows around about the it lengthwise during turbulent motion, heat-transfer coefficient is determined from formula (133);

3) for the gas and the air with the transverse of the flow around the bank of tubes heat-transfer coefficient is determined from formula (139);

4) for the air (free convection or at the speed of motion is not more than 0.5 m/s) with the vertical run of the flat/plane or cylindrical walls

$$\alpha = 2{,}2\sqrt[4]{t_{ст} - t_{в}} \ \overset{(1)}{ккал/м^2\text{-}час}\ ^\circ C; \qquad (154)$$

Key: (1). kcal/m²•h°C.

5) for the air during the horizontal location of the flat/plane wall, turned by the heat-transmitting surface upward [condition for air circulation as for the formula (154)]

$$\alpha = 2{,}8\sqrt[4]{t_{ст} - t_{в}} \ \overset{(1)}{ккал/м^2\text{-}час}\ ^\circ C; \qquad (155)$$

Key: (1). cal/m²•h°C.

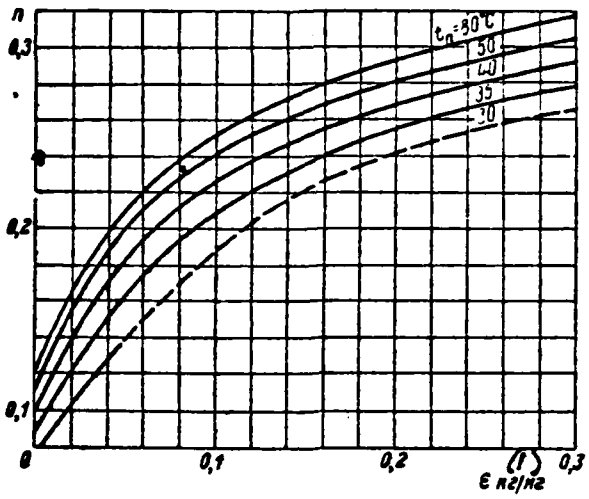

Fig. 52. Value of value n in depending on the content of air steam and the temperature of air-steam mixture.

Key: (1). kg/kg.

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6) for the air during the horizontal location of the flat/plane wall, turned by the heat-transmitting surface down [condition for air circulation as for the formula (154)]

$$\alpha = 1{,}13\sqrt[4]{t_{ст} - t_0} \ \overset{(1)}{ккал/м^2 \cdot час\ °C}; \qquad (156)$$

Key: (1). kcal/m²•h°C.

7) for the air during the horizontal location of the cylindrical

walls [condition for air circulation as for the formula (154)]

$$\alpha = 1{,}02\sqrt[4]{\frac{t_{ст} - t_в}{d_н}}\ ккал/м^2\text{-}час\ ^\circ C, \quad (157)$$

(1)

Key: (1). kcal/m²•h°C.

where $t_{ст}$ - temperature of wall, °C;

$t_в$ - temperature of surrounding air, °C;

$d_н$ - outside diameter of duct, m;

8) for the environment (air) from the surface of the walls of apparatuses and pipes in the closed location at temperature of heat-transfer agent from 0 to 150°C

$$\alpha \approx 8{,}4 + 0{,}06\,(t_{ст} - t_в)\ ккал/м^2\text{-}час\ ^\circ C. \quad (158)$$

(1)

Key: (1). kcal/m²•h°C.

In this formula is considered the convection and emission with 4.6 kcal/m²•h (°K)⁴.

Heat-transfer coefficient for the humid air

$$\alpha_{вл} = \xi\alpha_{сух}\ ккал/м^2\text{-}час\ ^\circ C, \quad (159)$$

(1)

Key: (1). kcal/m²•h°C.

where $\alpha_{сух}$ - heat-transfer coefficient for the dry air, kcal/m²•h°C;

ξ - coefficient of moisture removal, determined in the formula

$$\xi = 1 + \frac{d10^{-3}}{t_{cp} - t_{cr}} \frac{r - i_{вл}}{c_в};$$

where d - a moisture content of air, g/kg;

t_{cp} - mean temperature of air, °C;

t_{cr} - temperature of the surface of wall, °C;

r - heat of vaporization with t_{cp}, kcal/kg;

$i_{вл} \approx t_{cr}$ - enthalpy of moisture on the surface of wall, kcal/kg;

$c_в$ - average/mean heat capacity of the air, kcal/kg°C.

Tentative limits of the values of heat-transfer coefficients α in kcal/m²•h°C:

During heating and cooling air ... 10-150.

During heating and cooling of superheated steam ... 20-100.

During heating and cooling petroleum products ... 150-600.

During heating and cooling water ... 200-10000.

During boiling of water ... 500-45000.

During the condensation of water vapors ... 4000-15000.

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Radiation coefficient.

Heat transfer can be accomplished/realized also by a method of emission. With the heat transfer from the wall to the surrounding space simultaneously with the convection always has the place and the emission whose intensity depends on the degree of the warmth of the surface of wall.

The radiation/emission of heat by the surface of wall depends on a difference in the temperatures of the wall and the environment and on surface condition of wall, considered by radiation factor. A quantity of heat, emitted by the unit of surface for the time unit with a difference in the temperatures between the emitted surface and the environment in 1°C, is called radiation coefficient.

Radiation coefficient from the wall into the environment is determined from to the formula

$$\alpha_{луч} = C\frac{\left(\frac{T_{ст}}{100}\right)^4 - \left(\frac{T_{окр}}{100}\right)^4}{t_{ст} - t_{окр}} \text{ ккал}/\text{м}^2\text{-час}\ ^\circ\text{C}, \qquad (160)$$

(1)

Key: (1). kcal/m²•h°C.

where $T_{ст} = 273{,}2 + t_{ст}$ - absolute temperature of the wall, heat-radiating, °K;

$T_{окр} = 273{,}2 + t_{окр}$ - ambient temperature, °K;

$t_{ст}$ - temperature of wall, °C;

$t_{окр}$ - ambient temperature, °C;

C - radiation factor, the kcal/m²h(°K)⁴, depending on surface condition.

The values of value C are given in Table 14.

Table 14. Values of the coefficient radiation C.

(1) Наименование	C, ккал/м²·час (°K)⁴ (2)	(1) Наименование	C, ккал/м²·час (°K)⁴ (2)
(3) Абсолютно черное тело	4,96	(4) Никель полированный	0,3
(5) Алюминий листовой шероховатый	0,35	(6) Слюда	3,7
(7) Алюминий листовой полированный	0,26	(8) Стекло	4,45
(9) Железо	4,6	(10) Резина шероховатая серая	4,26
(11) Железо окисленное	3,64	(12) Резина гладкая черная	4,69
(13) Железо оцинкованное	1,37	(14) Картон асбестовый	4,76
(15) Медь шероховатая	3,6	(16) Краски алюминиевые	1,34—3,32
(17) Медь вальцованная	3,1	(18) Краски масляные разные	4,56—4,76
(19) Медь полированная	0,6	(20) Эмалевый лак	4,45
(21) Латунь вальцованная	0,34	(22) Бумага	4,6
(23) Латунь полированная	0,25	(24) Вода	4,75
		(25) Кирпич красный шероховатый	4,61

Key: (1). Designation. (2). kcal/m²h(°K)⁴. (3). Blackbody. (4). Nickel, polished. (5). Aluminum sheet rough. (6). Mica. (7). Aluminum sheet polished. (8). Glass. (9). Rubber rough gray. (10). Iron. (11). Rubber smooth black. (12). Iron, oxidized. (13). Cardboard (asbestos. (14). Iron, zinc-coated. (15). Paints/colors (aluminum. (16). Copper rough. (17). Paints/colors oil different. (18). Copper rolld. (19). Enamel varnish. (20). Copper polished. (21). Paper. (22). Brass rolled. (23). Water. (24). Brass polished. (25). Brick red rough.

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§ 10. Thermal loads, stresses/voltages and efficiencies.

Under the thermal loads and the stresses/voltages is implied the quantity of heat, per unit of surface (heating or cooling) or unit volume of apparatus.

Thermal loads and stresses/voltages can be expressed in the units the measurement: thermal (kcal/m²•h; kcal/m³•h), weight kg/m²-hour; kg/m³-hour) and volumetric (m³/m²- hour; m³/m³-hour).

Steam load of the condenser:

$$U = \frac{G}{F} \text{ кг/м}^2\text{-час}^{(1)}, \qquad (161)$$

Key: (1). kg/m²-hour.

where G - a quantity of condensed vapor in capacitor/condenser, kg/h;

F - cooling surface of capacitor/condenser, m².

The permissible values of the steam load of capacitors/condensers in depending on vacuum are represented in Table 15.

The multiplicity of cooling - these are the ratio of a quantity of cooling water to a quantity of condensed vapor or, otherwise, the expenditure of cooling water per 1 kg of the condensed vapor.

The multiplicity of cooling can be expressed by the formula

$$m = \frac{W}{G} \text{ кг воды}^{(1)}/\text{кг пара}, \qquad (162)$$

Key: (1). water/kg steam.

where W - a quantity of cooling water, kg/h;

G - quantity of condensed vapor, kg/h; or

$$m = \frac{i_2 - i_к}{c(t_2 - t_1)} \text{ кг воды}^{(1)}/\text{кг пара}, \qquad (163)$$

Key: (1). water/kg steam,

where i_2 - enthalpy of steam upon the entrance, kcal/kg;

$i_к$ - enthalpy of condensate, kcal/kg;

c - heat capacity of cooling water, kcal/kg°C;

t_1 - temperature of cooling water upon the entrance, °C;

t_2 - temperature of cooling water on leaving °C.

Table 15. Permissible values of steam load.

(1) Вакуум в конденсаторе, %	90	90—93	94—95	96—97
(2) Паровая нагрузка, кг/м²-час	150—200	110—150	60—90	50—70

Key: (1). Vacuum in the capacitor/condenser, c/c. (2). Steam load, kg/m²•h.

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The graph/curve of a change in the expenditure of cooling water for 1 kg of the condensed vapor in the dependence on the vacuum in the capacitor/condenser and temperatures of cooling water upon the entrance is shown in Fig. 53.

The permissible values of the multiplicity of cooling m in the capacitors/condensers can oscillate in the limits from 30-40 to 60-70, but sometimes in the single-pass capacitors/condensers they can reach 120, which draws an undesirable increase in productivity and power of circulating pump.

Stress/voltage of vaporization surface:

$$R_{\text{п}} = \frac{Dv}{F_{\text{п}}} \text{ м}^3/\text{м}^2\text{-час}^{(1)}, \quad (164)$$

Key: (1). m³/m²-hour.

where D - productivity of vaporizer/evaporator, kg/h;

v - the specific volume of secondary steam, m^3/kg;

$F_п$ - surface of the vaporization surface, m^2.

The value of the stress/voltage of vaporization surface in the vaporizers/evaporators usually is within the limits of 1500-2500 m^3/m^2-hour and with lowering in the pressure of the secondary steam (to 0.15 atm(abs.)) can reach 6000 $m^3/m^2 \cdot h$.

Stress/voltage of the heating surface:

$$R_п = \frac{D}{F_п} \text{ кг}/\text{м}^2\text{-час}, \quad (165)$$

Key: (1). kg/m^2-hour.

where D - productivity of vaporizer/evaporator, kg/h;

$F_п$ - surface of heating, m^2.

The value of the stress/voltage of the heating surface in the vaporizers/evaporators usually lies/rests within limits of 80-110 kg/m^2-hour and sometimes can reach 150 kg/m^2-hour, and with the reliable separators - to 200 kg/m^2-hour.

Stress/voltage of the steam volume:

$$R_v = \frac{Dv}{V} \text{ м}^3/\text{м}^3\text{-час}, \quad (166)$$

Key: (1). a m^3/m^3-hour.

where D - productivity of vaporizer/evaporator, kg/h;

v - the specific volume of secondary steam, m^3/kg;

V - volume of steam space, m^3.

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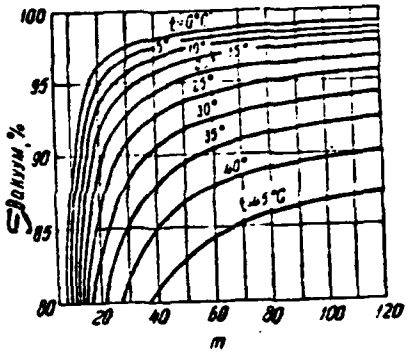

Fig. 53. Multiplicity cf cooling in depending on vacuum and temperature of circulation water.

Key: (1). Vacuum.

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The value of the stress/voltage of steam volume for the secondary steam of vaporizers/evaporators can reach:

1) for the vaporizers/evaporators of atmospheric pressure $R'_v = 3000$ m³/m³-hour;

2) for the vaporizers/evaporators, which work with the pressures, different from atmospheric

$$R_v = fR'_v \text{ м}^3/\text{м}^3\text{-час}, \quad (1)$$

Key: (1). m³/m³-hour.

where f - a coefficient of the pressure whose values are given in Table 16;

3) for the vaporizers/evaporators, which have the sufficiently effective built-in separators or the supplementary separating devices/equipment:

$$R_v = (1{,}2 \div 1{,}4) f R_v' \ м^3/м^3\text{-}час^{(1)}.$$

Key: (1). m^3/m^3•-hour.

The efficiency of heat exchangers η is equal to the ratio of a quantity of heat Q_2, obtained in the apparatus, to a quantity of heat Q_1, which is spent in the process of the work of apparatus, and it is expressed in general form by the formula

$$\eta = \frac{Q_2}{Q_1}. \qquad (167)$$

Efficiency of the apparatuses, which work without a change in the state of aggregation (coolants of water, oil, air, water-to-water preheaters, etc.):

$$\eta = \frac{G_2 c_2 (t_2' - t_2)}{G_1 c_1 (t_1' - t_1)}. \qquad (168)$$

Efficiency of the apparatuses, which work with a change in state of aggregation of one of the heat-transfer agents (steam preheaters of water, oil, air, fuel/propellant, capacitors/condensers, etc.):

$$\eta = \frac{G_2 c_2 (t_2' - t_2)}{D_1 (i_1 - c_1 t_1)}. \qquad (169)$$

Efficiency of the apparatuses, which work with total variation in the state of aggregation of one heat-transfer agent and partial change in the state of aggregation of another heat-transfer agent (vaporizers/evaporators, distillers, distillers, etc.):

$$\eta = \frac{D_2(i_2 - c_2 t_2) - \varepsilon D_2 c_2 (t_2' - t_2)}{D_1 (i_1 - c_1 t_1)}. \qquad (170)$$

Efficiency of the apparatuses, which work with a change in state of aggregation of both heat-transfer agents (evaporators, etc.):

$$\eta = \frac{D_2 (i_2 - c_2 t_2)}{D_1 (i_1 - c_1 t_1)}. \qquad (171)$$

Table 16. Values of the coefficients of pressure f.

p, ama (1)	16	4,0	2,0	1,0	0,8	0,7	0,6	0,5
f	0,8	0,87	0,915	1,00	1,15	1,25	1,4	1,6

Key: (1). atm (abs.).

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Here G_1 - quantity of cooling (or heating) medium, kg/h;

G_2 - quantity of heated (or cooled) medium, kg/h;

D_1 - quantity of heating condensing steam, kg/h;

D_2 - quantity of the secondary steam, kg/h;

ε - coefficient of the purging of the heated medium;

c_1 - heat capacity of the cooling (or heating) medium, kcal/kg °C;

c_2 - heat capacity of the cooled (or heated) medium, kcal/kg °C;

i_1 - enthalpy of heating condensing steam, kcal/kg;

i_2 - enthalpy of the secondary steam, kcal/kg;

t_1 - initial temperature of the cooling (or the final temperature of that heating) medium, °C;

t'_1 - the final temperature of the cooling (or the initial temperature of that heating) medium, °C;

t_2 - initial temperature of the heated (or the final temperature of that cooled) medium, °C;

t'_2 - the final temperature of the heated (or the initial temperature of that cooled) medium, °C.

Usually the efficiency of apparatuses for simplification in the calculations take as the equal to the following values which insignificantly differ from those calculated:

For the heat exchangers, which have thermal insulation ... η 0.97-0.98.

For the apparatuses, which do not have thermal insulation ...

η
0.93-0.95.

The efficiency of apparatuses for convenience in the calculations very frequently replace by the coefficient, which considers the heat loss by the apparatus into the environment, which also is designated through η. This coefficient is the value, reciprocal efficiency and takes as the equal to:

For the apparatuses, which have thermal insulation ...
η
1.03-1.02.

For the apparatuses, which do not have thermal insulation ...
η
1.07-1.05.

§ 11. Determination of some structural elements/cells of apparatuses.

With the execution of thermal designs usually it is necessary to define or to select some structural elements/cells of apparatuses, as, for instance : the space of the laying out of tubes, a number of tubes and their length, diameter of the tube plate and surface, formed by tubes and, etc. which have an effect both on the thermal design and on the construction/design of apparatus.

Are given below the most necessary formulas and initial data by choice and determination of some structural elements/cells.

The diameter of the branch pipe:

$$d=\sqrt{\frac{4F}{\pi}}=\sqrt{\frac{Dv}{2825u}}\ м, \qquad (172)$$

where d - an inner diameter of branch pipe, m;

F - sectional area of branch pipe, m^2;

D - expenditure of the medium through branch pipe, kg/h;

v - the specific volume of medium, m^3/kg;

u - speed of medium, m/s.

Equivalent (hydraulic) diameter in general form is expressed by the formula

$$d_э=\frac{4F}{\omega}\ м, \qquad (173)$$

where F - a cross-sectional area of channel, m^2;

ω - wetted perimeter of channel, m.

Equivalent diameter for some forms of channel is given in Table 17.

Table 17. Equivalent diameters $d_э$

(1) Форма канала	(2) Эквивалентный диаметр $d_э$
(3) Круглая труба диаметром d	d
(4) Квадрат со стороной a	a
(5) Прямоугольник со сторонами a и b:	
(6) теплообмен через все стороны	$\frac{2ab}{a+b}$
(7) теплообмен через две противоположные стороны a	$2b$
(8) теплообмен через одну сторону a	$4b$
(9) Кольцевое сечение (труба d в трубе D):	
(10) теплообмен через внутреннюю и внешнюю поверхности	$D-d$
(11) теплообмен только через внешнюю поверхность	$\frac{D^2-d^2}{D}$
(12) теплообмен только через внутреннюю поверхность	$\frac{D^2-d^2}{d}$
(13) Межтрубное пространство (диаметр корпуса D, диаметр трубок d и число трубок n):	
(14) теплообмен через трубный пучок	$\frac{D^2-nd^2}{nd}$

Key: (1). Form of channel. (2). Equivalent diameter. (3). Circular duct with a diameter of d. (4). Square with side a. (5). Rectangle with sides a and b. (6). heat exchange through all sides. (7). heat exchange through two opposite sides a. (8). heat exchange through one side a. (9). Ring cross-section (duct d in duct D). (10). heat exchange through internal and external surfaces. (11). heat exchange only through external surface. (12). heat exchange only through internal surface. (13). Intertube space (diameter of housing D, diameter of tubes d and number of fellings n). (14). heat exchange

through tube bank.

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Space t of the laying out of the tubes:

1) minimum space with the laying out on the triangle of the tubes with a outside diameter of $d_н$ (Fig. 54):

$$t = 1{,}33 d_н;$$

2) for the capacitors/condensers with the laying out on the triangle of the tubes with a diameter of $d_н = 16$ мм:

$$t = d_н + 9 \div 10 \text{ мм};$$

3) for the capacitors/condensers with the laying out of the tubes with a diameter of $d_н = 16$ мм on a radius or the rays/beams:

$$t = d_н + 16 \text{ мм};$$

4) for the small capacitors/condensers with low steam resistance, with rolled tubes $d_н = 16$ мм during the laying out of their space on the triangle

$$t = d_н + 5 \div 6 \text{ мм};$$

5) for the preheaters of water, oil coolers and other apparatuses, which have the tubes with a diameter of $d_н = 16$ мм during the laying out of their space on the triangle

$$t = d_н + 5 \div 6 \text{ мм};$$

6) for the petroleum heaters and other apparatuses, which have

the tubes with a diameter of $d_н = 17$ мм during the laying cut of their space on the triangle

$$t = d_н + 5 \div 6 \text{ мм}.$$

The area of the tube plate, necessary for the location of one tube on the triangle,

$$f = 0{,}866 t^2 \text{ мм}^2, \qquad (174)$$

where t - a space of the laying cut of tubes, mm.

The solidity/loading factor of the tube plate:

$$\eta_{тр} = 1{,}1 \frac{t^2 n}{D^2}, \qquad (175)$$

where t - a space of the laying cut of tubes, mm;

n - number of tubes, placed on the tube plate;

D - diameter of the socket/seat of tubes, mm.

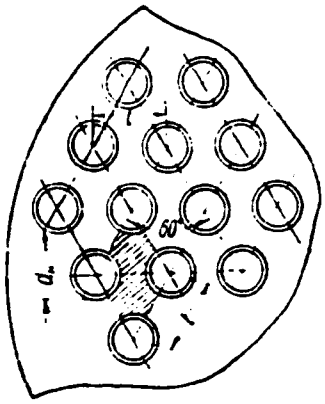

Fig. 54. Laying out of tubes on the triangle.

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The coefficient of filling of tube plate $\eta_{тр}$ is equal to:

For the single-pass capacitors/condensers ... 0.75-0.82.

For the two-pass ones and more than ... 0.72-0.78.

For the capacitors/condensers of the type O-V ... 0.58-0.65.

A number of cooling tubes in the capacitor/condenser:

$$n = \frac{Wz}{2825 d^2 v}, \qquad (176)$$

where W - a quantity of cooling water, m^3/h;

z - number of courses of the water;

d - inner diameter of tubes, m;

v - speed of water in tubes, m/s.

The length of tubes (distance between the tube panels):

$$L = \frac{F}{\pi dnz} \text{ м}, \qquad (177)$$

where F - a surface of heating or of cooling, m²;

d - outside diameter of tube, m;

n - number of tubes in the course;

z - number of courses.

The surface of heating or cooling:

$$F = \frac{Q}{k\Delta t} \text{ м}^2, \qquad (178)$$

where Q - a quantity of introduced or abstracted/removed heat, kcal/h;

k - coefficient of heat transfer, kcal/m²·h°C;

Δt - average/mean logarithmic difference in the temperatures (or a difference in the temperatures), °C.

Furthermore, surface F can be determined according to sizes/dimensions and number of tubes of heating or cooling:

$$F = \pi d l n \ \mu^2, \qquad (179)$$

where d - an outside diameter of tubes, m;

l - effective length of tubes, m;

n - total number of tubes in the apparatus.

The area of the smallest section of the nozzle:

$$F_{min} = \frac{G}{m\sqrt{\frac{p_0}{v_0}}}, \qquad (180)$$

where G - an expenditure of steam through the nozzle, kg/s;

m=199 - for the saturated steam and m=209 - for the superheated steam;

p_0 - pressure of steam in front of the nozzle, kg/cm²;

v_0 - specific volume of steam before nozzle, m^3/kg.

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The diameter of the smallest section of the nozzle:

$$d_{min} = m' \sqrt{\frac{G}{\sqrt{\frac{p_0}{v_0}}}} \text{ мм}, \qquad (181)$$

where m'=1.32 - for the saturated steam and m'=1.3 - for the superheated steam;

G, p_0, v_0 - the same as in formula (180).

The nozzle exit diameter:

$$d_n = 2{,}015 \sqrt{\frac{Gv_1}{\sqrt{h_0}}} \text{ мм}, \qquad (182)$$

where G - an expenditure of steam through nozzle, kg/h;

v_1 - specific volume of steam on leaving from nozzle, m^3/kg;

h_0 - adiabatic drop/jump is steam in nozzle, kcal/kg.

The initial diameter of the diffuser/exit cone:

$$D = 1{,}92 \sqrt{G_c v_n} \sqrt[4]{\frac{0{,}25 + u}{0{,}25 h_0}} \text{ мм}, \qquad (183)$$

where G_c - expenditure of compressed steam, kg/h;

v_n - the specific volume of sucked in vapor, m^3/h;

$u = \frac{G_n}{G}$ - coefficient of the injection;

$G_n = G_c - G$ - expenditure or sucked in vapor, kg/h;

h_0, G - the same as in formula (182).

Surface of zinc protectors/treads. For the protection equipment from the contact corrosion, which appears as a result of the use/application in the apparatuses of the heterogeneous materials, which work under the corrosive conditions, in the chambers/cameras of apparatuses are established zinc protectors/treads.

The working surface of protector/tread is determined in depending on the sum of all surfaces, which are contacted with corrosive environment, and the radius of action of protector/tread.

The radius of action of protector/tread in the chamber/camera of apparatus is spread not more than on 1-1.5 m, but in the beam of tubes - to the length, equal to ten diameters; therefore during the calculation of the shielded surface, besides the surfaces of

covers/caps and tube plates, should be considered also the surface of tubes, formed by their ends/leads, at the length, equal to their ten diameters.

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The working surface of the protector/tread

$$S = \pi R^2 \eta \ cm^2, \qquad (184)$$

where R - the radius of action of protector/tread, m; R=1.0-1.5 - for the chambers/cameras of the apparatuses; R=8-10 to the diameters of conduit/manifold, but not more than 2 m with the diameter of conduit/manifold D=200 mm and not more than 2.5-3 m with D>200 mm;

η - ratio of the area of protector/tread and area of the shielded construction/design, which undergoes contact corrosion under conditions of marine water, equal to:

For the chambers/cameras of apparatuses, formed by the surfaces of covers/caps, of tube plates and by the ends/leads of the tubes ... with 1/400-1/500.

For the ducts with bronze and brass fittings ... 1/200-1/500.

For the steel branch pipes and the housings of apparatuses with

bronze and brass accessories ... 1/200-1/300.

Calculation of the safety valves of containers. Capacity is the valve:

a) for the vapor or the gas

$$G = 225\mu dh\sqrt{p\gamma}\ \text{кг/час}^{(1)}; \qquad (185)$$

Key: (1). kg/h.

b) for the liquids

$$G = 500\mu dh\sqrt{p\gamma}\ \text{кг/час}^{(1)}, \qquad (186)$$

Key: (1). kg/h.

where μ=0.85 - a discharge coefficient;

d - diameter of valve (without the account to the area, occupied by the edges/fins of guides), cm;

$h \leq d/4$ - valve lift, cm;

p - the design pressure of the medium before the valve, kg/cm²;

γ - the specific gravity/weight of medium, kg/m³.

The calculation of electrical heating elements can be produced according to to the formula

$$Q = 0{,}86IVn = 0{,}86I^2Rn = \alpha F\Delta tn = \alpha\pi dl\Delta tn \text{ ккал}^{(1)}/\text{час}, \quad (187)$$

Key: (1). kcal/h.

where Q - the calorific requirement, kcal/h;

I - current strength, a;

V - voltage, v;

n - number of in parallel working conductors;

R - resistance of conductor, ohm;

α - heat-transfer coefficient from the surface of conductor to the heated medium, the kcal/m²-h°C;

F - surface of conductor, m²;

Δt - difference in the temperatures between the surface of conductor and the heated medium, °C;

d - diameter of conductor, m;

l - length of conductor, m.

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Chapter II.

EXAMPLES OF THERMAL DESIGNS.

§ 12. Calculation of auxiliary capacitor/condenser.

Initial data for the calculation.

A quantity is steam that enters capacitor/condenser, G_1=2700 kg/h.

Quantity of condensate G_2=1640 kg/h.

Enthalpy of steam i_1=650 kcal/kg.

Enthalpy of condensate q_2=133.4 kcal/kg.

Vacuum in capacitor/condenser V_{ac}=85%.

Quantity of cooling water D=150 m/h.

Temperature of cocling water upon entrance $t_1 = 18°C$.

We accept.

Tubes brass with a diameter of $d_w/d_в = 16/14$ *мм*.

Number of courses of cocling water in tubes z=2.

Course of computation.

1. Absolute conderser backpressure

$$p_к = 1 - \frac{V_{вп}}{100} = 1 - \frac{85}{100} = 0{,}15 \text{ ата}^{(1)}.$$

Key: (1). atm(abs.).

2. Condensation temperature of steam when $p_к$ (on tables 1-3 of applications/appendices)

$$t_s = 53{,}6°C.$$

3. Temperature of condensate, abstracted/removed from capacitor/condenser,

$$t_к = t_s - 4 = 53{,}6 - 4 = 49{,}6°C.$$

4. Quantity of heat, transferred by vapor and by condensate to cooling water,

$$Q = G_1(i_1 - t_к) + G_2(q_2 - t_к) = 2700(650 - 49{,}6) + \\ + 1640(133{,}4 - 49{,}6) = 175{,}7 \cdot 10^4 \text{ ккал}^{(1)}/\text{час}.$$

Key: (1). kcal/h.

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5. Temperature of cooling water, on leaving from condenser

$$t_2 = t_1 + \frac{Q}{Dc_p} = 18 + \frac{175,7 \cdot 10^6}{150 \cdot 10^3 \cdot 0,94} = 30,4^\circ \text{C},$$

where $c_p = 0,94$ kcal/kg of °C - heat capacity of cooling (marine) water.

6. Average/mean logarithmic difference in temperatures of vapor and water

$$\Delta t = \frac{t_2 - t_1}{2,3 \lg \frac{t_s - t_1}{t_s - t_2}} = \frac{30,4 - 18}{2,3 \lg \frac{53,6 - 18}{53,6 - 30,4}} = 29^\circ \text{C}.$$

7. Mean temperature of cooling water

$$t_{cp} = 0,5(t_1 + t_2) = 0,5(18 + 30,4) = 24,2^\circ \text{C}.$$

8. Speed of cooling water in tubes we accept v=1.6 m/s.

9. Coefficient of heat transfer for capacitors/condensers in depending on speed and mean temperature of water (on graph/curve Fig. 39) k_0=3040 kcal/m²-hour °C.

10. Calculated coefficient of heat transfer

$$k = \varphi_1 \varphi_2 k_0 = 1,02 \cdot 0,85 \cdot 3040 = 2640 \text{ kcal/m}^2\text{h} \quad ^\circ\text{C},$$

where ϕ_1=1.02 - coefficient for tubes with a diameter of $d_н = 16$ мм; ϕ_2=0.85 - coefficient, which considers pollution/contamination of tubes.

11. Coefficient of heat transfer for capacitor/condenser in formula VTI

$$k = 3500\left(\frac{1{,}1v}{\sqrt[4]{d_н}}\right)^x\left[1 - \frac{0{,}42\sqrt{\varphi_2}}{1000}(35 - t_1)^2\right]\Phi_z\Phi_s =$$

$$3500\left(\frac{1{,}1\cdot 1{,}6}{\sqrt[4]{16}}\right)^{0{,}378}\left[1 - \frac{0{,}42\sqrt{0{,}85}}{1000}(35 - 18)^2\right]1\cdot 1 =$$

$$2940 \text{ (1) ккал/м}^2\text{-час °C},$$

Key: (1). kcal/m²h.

where x - an exponent, equal to

$$x = 0{,}12\varphi_3(1 + 0{,}15t_1) = 0{,}12\cdot 0{,}85(1 + 0{,}15\cdot 18) = 0{,}378;$$

Φ_z - the factor, which considers the effect of a number of courses of water in the capacitor/condenser,

$$\Phi_z = 1 + \frac{z-2}{10}\left(1 + \frac{t_1}{35}\right) = 1 + \frac{2-2}{10}\left(1 + \frac{18}{35}\right) = 1;$$

Φ_s - the factor, which considers the effect of steam load on capacitor/condenser $\Phi_s = 1$ for the nominal steam load.

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12. Necessary cooling surface of condenser

$$F = \frac{Q}{\Delta t k} = \frac{175{,}7 \cdot 10^4}{29 \cdot 2640} = 22{,}9\ м^2.$$

We accept F=23.1 м².

13. Quantity cooling of tubes in capacitor/condenser

$$n = \frac{D\gamma}{2825 d_в^2 v_1} = \frac{150 \cdot 2}{2825 \cdot 0{,}014^2 \cdot 1{,}6 \cdot 1{,}0} = 340,$$

where γ=1.0 t/m³ - specific gravity/weight of cooling water.

14. Effective length of tubes (distance between tube plates)

$$l = \frac{F}{\pi d_н n} = \frac{23{,}1}{3{,}14 \cdot 0{,}016 \cdot 340} = 1{,}35\ м.$$

15. Space of laying out of tubes on triangle

$$t = d_н + 10 = 16 + 10 = 26\ мм.$$

16. Solidity/loading factor of pipe panel (from conditions of positioning/arranging of tubes and partitions/baffles in cover/cap for two ducts of water)

$$\eta_{тр} = 0{,}73.$$

17. Diameter of socket/seat of tubes (inner diameter of housing)

$$D_к = t\sqrt{\frac{1{,}1 \cdot n}{\eta_{тр}}} = 0{,}026\sqrt{\frac{1{,}1 \cdot 340}{0{,}73}} = 0{,}592\ м.$$

18. Quantity of air, driven out from capacitor/condenser

$$G_в = 1{,}5\left(\frac{G_1 + G_2}{2000} + 1{,}36\right) = 1{,}5\left(\frac{2700 + 1640}{2000} + 1{,}36\right) = 5{,}25\ kg/h.$$

§ 13. Calculation of deaerator.

Initial data for the calculation.

Productivity on the deaerated water D=70 m/h.

Pressure in deaerator $p_2 = 1{,}2$ atm

Pressure of that heating of steam $p_1 = 1.8$ atm

Temperature of that heating of steam $t_1 = 180°C$.

Temperature of the mixture of water, which enters the deaerator, which consists of 80c/c of condensate and 20c/o of additional water, $t_2 = 40°C$.

Oxygen content in deaerated water $a_p < 0{,}03$ mg/l.

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We accept.

Coefficient of the use of a body in deaerator $\eta = 0{,}97$.

Content of dissolved oxygen in the condensate, taking into account possible rhodes of air $a_к = 1{,}0$ mg/l.

We determine (on tables 1-3 of applications/appendices).

Enthalpy of water in deaerator $q_1 = 104,4$ kcal/kg.

Enthalpy of that heating or steam i_1=676.1 kcal/kg.

Temperature of water in deaerator $t_1 = 104,3°$ C.

Enthalpy of the mixture of water, which enters the deaerator, q_2=40 kcal/kg.

The specific volume of water in deaerator v=1.047 m³/t.

Course of computation.

1. Quantity of heating steam, required for heating of water in deaerator

$$G = \frac{D(q_1 - q_2)}{i_1 - q_2} = \frac{70(104,4 - 40)}{676,1 - 40} = 7,0 \text{ т/h}.$$

2. Quantity of mixture of water, which enters deaerator

$$W'_{см} = D - G = 70 - 7 = 63 \text{ т/ч}.$$

3. Quantity of additional water, which enters deaerator,

$$W_д = 0{,}2\, W_{см} = 0{,}2 \cdot 63 = 12{,}6 \text{ т/ч}.$$

4. Quantity of condensate, which enters deaerator

$$W_к = W_{см} - W_д = 63 - 12{,}6 = 50{,}4 \text{ т/ч}.$$

5. Content of dissolved oxygen in additional water at 40°C and pressure 760 mm Hg (on curve for oxygen, Fig. 33)

$$a_д = 6{,}5 \text{ mg/l}.$$

6. Content of dissolved oxygen in displace water, which enters deaerator,

$$a_{ксм} = \frac{a_к W_к + a_д W_д}{W_{см}} = \frac{1{,}0 \cdot 50{,}4 + 6{,}5 \cdot 12{,}6}{63} = 2{,}1 \text{ mg/l}.$$

7. Content of dissolved gases of air in additional water at 40°C and pressure 760 mm Hg (on curve for air, Fig. 33)

$$a'_г = 17{,}2 \text{ mg/l}.$$

8. Content of dissolved gases of air in condensate

$$a_г^{\cdot} = \frac{a_г^{\prime} a_к}{a_п} = \frac{17{,}2 \cdot 1{,}0}{6{,}5} = 2{,}65 \text{ mg/l}.$$

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9. Content of dissolved gases of air in the mixture of water, which enters the deaerator,

$$a_{см} = \frac{a_г^{\cdot} W_к + a_г^{\prime} W_п}{W_{см}} = \frac{2{,}65 \cdot 50{,}4 + 17{,}2 \cdot 12{,}6}{63} = 5{,}57 \text{ mg/l}.$$

10. Quantity of dissolved gases of air, introduced by water into deaerator,

$$G_г = (a_г^{\prime} W_п + a_г^{\cdot} W_к) 10^{-3} = (17{,}2 \cdot 12{,}6 + 2{,}65 \cdot 50{,}4) 10^{-3} = 0{,}35 \text{ kg/h}.$$

11. Ratio of equilibrium oxygen pressure in vapor to partial according to indications to formula (105), k=3.

12. Constant of weight solubility of oxygen in water at its pressure above water p_0=760 mm Hg and boiling point of water, equal to about 100°C (on curve of Fig. 34)

$a_0 = 24{,}5$ mg/l.

13. Partial oxygen pressure above surface of water in deaerator (retaining by its equal at pressure by p_0=760 mm Hg from condition of guaranteeing intensity of deaeration)

$$p_к = \frac{p_0 a_p}{k a_0} = \frac{1{,}033 \cdot 0{,}03}{3 \cdot 24{,}5} = 0{,}000422 \text{ atm}$$

14. Partial pressure of gass of air above surface of water in deaerator

$$p_г = \frac{p_к a_{гсм}}{a_{ксм}} = \frac{0{,}000422 \cdot 5{,}57}{2{,}1} = 0{,}00112 \text{ atm}$$

15. Partial pressure of steam in deaerator

$$p_п = p_а - p_г = 1{,}2 - 0{,}00112 \approx 1{,}199 \text{ atm}$$

16. Quantity of vapor (steam-gas mixture), driven out from deaerator,

$$G_{см} = G_г \left(1 + 0{,}622 \frac{p_п}{p_г}\right) = 0{,}35 \left(1 + 0{,}622 \frac{1{,}199}{0{,}00112}\right) = 234 \text{ kg/h}.$$

17. Total expenditure of steam for deaerator

$$G_п = (G + G_{см}) \frac{1}{\eta} = (7{,}0 + 0{,}234) \frac{1}{0{,}97} \approx 7{,}5 \text{ m/h}.$$

18. Necessary volume of deaerated water in deaerating tank

$$V = \frac{Dv}{15 \div 20} = \frac{70 \cdot 1{,}047}{18{,}3} = 4 \text{ м}^3.$$

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§ 14. Calculation of the preheater of water.

Initial data for the calculation.

Productivity of heater D=55 or m/h.

Temperature of water upon the entrance into preheater t_1=40°C.

Temperature of water on leaving from preheater t_2=110°C.

Pressure of feed water $p_в$=36 kg/cm².

Vapor pressure of heating $p_п$=1,8 atm

Temperature of that heating or steam t_3=220°C.

We accept.

Coefficient of utilization of heat η=0,98.

Tubes brass V-shaped with a diameter of $d_н/d_в$=16/13 мм.

Number of courses in the tubes of preheater z=6.

We determine (on tables 1-3 of applications/appendices).

Enthalpy of that heating of steam i=695.2 kcal/kg.

Temperature of the saturation of heating of steam $t_s = 116{,}3°$ C.

Enthalpy of liquid when t_s, equal to q=116.6 kcal/kg.

Heat capacity of feed water when t'_{cp}, equal to c~~1 kcal/kg °C.

Course of computation.

1. Quantity of heat, necessary for preheating water,

$$Q = Dc(t_2 - t_1) = 55\,000 \cdot 1\,(110 - 40) = 385 \cdot 10^4 \text{ kcal/h}.$$

2. Expenditure of steam for preheating of water

$$G = \frac{Q}{(i - q)\eta} = \frac{385 \cdot 10^4}{(695{,}2 - 116{,}6)\,0{,}98} = 6800 \text{ kg/h}.$$

3. Mean temperature of water in preheater

$$t'_{cp} = 0{,}5\,(t_1 + t_2) = 0{,}5\,(40 + 110) = 75°\text{C}.$$

4. On tables 6 of applications/appendices when t'_{cp} we determine:

1) specific gravity/weight of water $\gamma_в = 0{,}974$ $m/м^3$;

2) the dynamic viscosity of water $\mu_в = 38{,}66 \cdot 10^{-6}$ kg•s/m²;

3) the speed of water in the tubes we preliminarily accept $v_в = 1{,}7$ m/s.

5) Number of tubes in one course

$$n = \frac{D}{2825 d_в^2 v_в \gamma_в} = \frac{55}{2825 \cdot 0{,}013^2 \cdot 1{,}7 \cdot 0{,}974} \approx 70.$$

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6. Reynolds number for water

$$\mathrm{Re} = \frac{v_в d_в \gamma_в}{\mu_в g} = \frac{1{,}7 \cdot 0{,}013 \cdot 974}{38{,}66 \cdot 10^{-6} \cdot 9{,}81} = 56\,800.$$

7. Heat-transfer coefficient from wall to water, which takes place in tubes with turbulent motion,

$$\alpha_в = A v_в^{0{,}8} d_в^{-0{,}2} = 2548 \cdot 1{,}53 \cdot 2{,}385 = 9350 \text{ kcal/m}^2\text{-h °C},$$

where A=2048 (Table 10) depending on t'_{cp}; $v_в^{0{,}8} = 1{,}7^{0{,}8} = 1{,}53$ (Table 11); $d_в^{-0{,}2} = 0{,}013^{-2} = 2{,}385$ (Table 12).

8. Mean temperature of condensable steam and water

$$t''_{cp} = 0{,}5\,(t_s + t'_{cp}) = 0{,}5\,(116{,}3 + 75) = 95{,}7^\circ\,C.$$

9. Temperature riding-corps from the side of steam

$$t_{cr} = 0{,}5\,(t_s + t''_{cp}) = 0{,}5\,(116{,}3 + 95{,}7) = 106^\circ\,C.$$

10. Coefficient of heat transfer from steam to stand pipe

$$\alpha_n = A_1 \sqrt[4]{\frac{i-q}{H(t_s - t_{cr})}} = 2210 \sqrt[4]{\frac{695{,}2 - 116{,}6}{1{,}8\,(116{,}3 - 106)}} =$$

$$= 5260 \text{ ккал/м}^2\text{-час}^\circ\text{C}, \quad (1)$$

Key: (1). kcal/m²-h.

where A_1=2210 (Table 13) depending on t_{cr}; H=1,8 м - medium altitude of the V-shape of tube (assumed tentatively);

11. Average/mean logarithmic difference in the temperatures of vapor and water in the preheater

$$\Delta t = \frac{t_2 - t_1}{2{,}3 \lg \frac{t_s - t_1}{t_s - t_2}} = \frac{110 - 40}{2{,}3 \lg \frac{116{,}3 - 40}{116{,}3 - 110}} = 28{,}1^\circ\,C.$$

12. Coefficient of heat transfer from vapor to water

$$k = \frac{1}{\frac{1}{\alpha_n} \cdot \frac{2d_n}{d_n + d_n} + \frac{d_n - d_n}{2\lambda} + \frac{1}{\alpha_n}} =$$

$$\frac{1}{\frac{1}{9350} \cdot \frac{2 \cdot 0{,}016}{0{,}013 + 0{,}016} + \frac{0{,}016 - 0{,}013}{2 \cdot 90} + \frac{1}{5260}} = 3080 \text{ ккал/м}^2\text{-час}^\circ\text{C}, \quad (1)$$

Key: (1). the kcal/m²h.

where λ=90 kcal/m- hour °C - coefficient of the thermal conductivity of brass wall of tube.

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13. Coefficient of heat transfer from vapor to water in depending on speed and mean temperature of water can be also determined according to curve of Fig. 39. For brass tubes $d_н = 16$ мм we have

$$k = 1{,}02 \cdot k_0 = 1{,}02 \cdot 3640 = 3700 \text{ kcal/m}^2 - \text{h} \quad {}^\circ\text{C}.$$

14. Necessary surface of heating preheater

$$F = \frac{Q}{\Delta t k} = \frac{385 \cdot 10^4}{28{,}1 \cdot 3700} = 37{,}1 \text{ м}^2.$$

15. Real surface is accepted

$$F_п = 38 \text{ м}^2.$$

16. Average/mean length of semi-V-shaped tube

$$l = \frac{F_п}{\pi \cdot d_н n z} = \frac{38}{3{,}14 \cdot 0{,}016 \cdot 70 \cdot 6} = 1{,}8 \text{ м}.$$

If $l \neq H$=1.8 m, then in the presence of the small disagreement one should change $F_п$, but if disagreement is considerable, then should be the obtained value for l to substitute for approximate of that accepted for H and produced repeated calculation, after beginning it from determination $\alpha_п$.

17. Space of the location of the tubes

$$t = d_н + 6 = 16 + 6 = 22 \text{ мм.}$$

18. Inner diameter of housing (from conditions for location of bundles of V-shaped tubes, divided in cover/cap by partitions/baffles, that ensure six courses of water) is accepted

$$D_в = 550 \text{ мм.}$$

§ 15. Calculation of steam cooler.

Initial data for the calculation.

The productivity of steam cooler D=4000 kg/h

temperature of steam upon the entrance into steam cooler t_1=320°C.

Temperature is of steam on leaving their steam cooler t_2=220°C.

Pressure of steam p_1=8 atm

Quantity of cooling feed water G=50000 kg/h.

Temperature of water upon the entrance into steam cooler t_2=125°C.

Pressure of cooling water p_2=56 atm

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We accept.

Heat availability factor $\eta = 0{,}97$.

Tubes steel V-shaped with a diameter of $d_н/d_в = 17/13$ мм.

Number of courses of steam in tubes z_1=2.

Number of courses of water in the housing of steam cooler z_2=2.

We determine (on Tables 1-3 of applications/appendices).

Enthalpy of steam upon the entrance i_1=740 kcal/kg.

Enthalpy of steam on leaving i_2=688.7 kcal/kg.

Course of computation.

1. Quantity of heat, transferred by water vapor,

$$Q = D(i_1 - i_2) = 4000(740 - 688{,}7) = 205\,000 \text{ kcal/h}.$$

2. Mean temperature of overheated steam

$$t_n = 0{,}5(t_1 + t_2) = 0{,}5(320 + 220) = 270^\circ \text{C}.$$

3. On Tables 3 and Fig. 1-3 of applications/appendices when t_n we determine:

1) specific heat of steam $c_p = 0.51$ kcal/kg °C;

2) specific gravity/weight of steam $\gamma_n = 3{,}22$ kg/m³;

3). the coefficient of thermal conductivity $\lambda_n = 0{,}037$ kcal/m-hour °C;

4) dynamic viscosity is steam $\mu_n = 1{,}93 \cdot 10^{-6}$ kg•s/m².

4. Number of tubes in course (after accepting tentatively speed of steam in them about 50 m/s) we accept n=53.

5. Average speed of steam in tubes of steam cooler

$$v_n = \frac{D}{2825 d_в^2 n \gamma_n} = \frac{4000}{2825 \cdot 0{,}013^2 \cdot 53 \cdot 3{,}22} = 49 \text{ m/s}.$$

6. Criterion of Reynolds for steam.

$$Re = \frac{v_n d_в \gamma_n}{\mu_n g} = \frac{49 \cdot 0,013 \cdot 3,22}{1,93 \cdot 10^{-6} \cdot 9,81} = 108\,500.$$

7. Prandtl number for steam

$$Pr = \frac{3600 \cdot \mu_n g c_p}{\lambda_n} = \frac{3600 \cdot 1,93 \cdot 10^{-6} \cdot 9,81 \cdot 0,51}{0,037} = 0,942.$$

8. Heat-transfer coefficient from superheated steam to wall with $Re > 1 \cdot 10^4$ and $Pr = 0.7 - 2500$:

$$\alpha_n = 0,023 \frac{\lambda_n}{d_в} Re^{0,8} Pr^{0,4} = 0,023 \frac{0,037}{0,013} 108\,500^{0,8} \cdot 0,942^{0,4} =$$

$$= 685 \text{ cal/m}^2\text{h} \quad {}^\circ\text{C}.$$

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9. Temperature of cooling water on leaving

$$t_4 = t_3 + \frac{Q}{Gc_в} = 125 + \frac{205000}{50000 \cdot 1,017} \approx 129^\circ \text{C},$$

where $c_в = 1,017$ kcal/kg °C - heat capacity of water with t=127°C (Table 6 of applications/appendices).

10. Mean temperature of cooling water

$$t_в = 0,5(t_3 + t_4) = 0,5(125 + 129) = 127^\circ \text{C}.$$

11. On Table 6 of applications/appendices when $t_в$ we determine:

1) coefficient of thermal conductivity of water $\lambda_в = 0,59$

kcal/m-hour °C;

2) specific gravity/weight of water $\gamma_в = 937,3$ kg/m³;

3) dynamic viscosity of water $\mu_в = 22,2 \cdot 10^{-6}$ kg•s/m².

12. Inner diameter of housing of steam cooler (from conditions for location of beam of V-shaped tubes of that divided in cover/cap with partition/baffle, which ensures two courses of steam in tubes) we accept

$$D_к = 0,28 \text{ м}.$$

13. Area for passage of water in intertube space of steam cooler

$$f = \frac{0,785(D_к^2 - d_н^2 n z_1)}{z_2} = \frac{0,785(0,28^2 - 0,017^2 \cdot 53 \cdot 2)}{2} = 0,01875 \text{ м}^2.$$

14. They are equivalent heat-transmitting diameter of intertube space

$$d_э = \frac{4f}{\pi d_н n} = \frac{4 \cdot 0,01875}{3,14 \cdot 0,017 \cdot 53} = 0,0265 \text{ м}.$$

15. Average speed lauds in steam cooler

$$v_в = \frac{G}{3600 \cdot f \cdot \gamma_в} = \frac{50000}{3600 \cdot 0,01875 \cdot 937,3} = 0,79 \text{ m/s}.$$

16. Reynolds number for water

$$\mathrm{Re}_в = \frac{v_в d_э \gamma_в}{\mu_в g} = \frac{0,79 \cdot 0,0265 \cdot 937,3}{22,2 \cdot 10^{-6} \cdot 9,81} = 90\,000.$$

17. Prandtl number for water

$$Pr_в = \frac{3600\mu_в g c_в}{\lambda_в} = \frac{3600 \cdot 22,2 \cdot 10^{-6} \cdot 9,81 \cdot 1,017}{0,59} = 1,35.$$

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18. Heat-transfer coefficient from wall to water with longitudinal washing of ducts for Re>1•10⁴ and Pr=0.7-2500:

$$\alpha_в = 0,023 \frac{\lambda_в}{d_э} Re^{0,8} Pr^{0,4} = 0,023 \frac{0,59}{0,0265} 90\,000^{0,8} \cdot 1,35^{0,4} =$$

5350 kcal/m²h °C.

19. Heat-transfer coefficient from steam to water

$$k = \frac{1}{\frac{1}{\alpha_п} \cdot \frac{2d_н}{d_н + d_в} + \frac{d_н - d_в}{2\lambda} + \frac{1}{\alpha_в}} = \frac{1}{\frac{1}{685} \cdot \frac{2 \cdot 0,017}{0,017 + 0,013} + \frac{0,017 - 0,013}{2 \cdot 50} + \frac{1}{5350}} =$$

530 kcal/m²h of °C,

where λ=50 kcal/m- hour °C - thermal conductivity of wall of steel tube.

20. Average/mean logarithmic difference in temperatures for countercurrent

$$\Delta t = \frac{(t_1 - t_4) - (t_2 - t_3)}{2,3 \lg \frac{t_1 - t_4}{t_2 - t_3}} = \frac{(320 - 129) - (220 - 125)}{2,3 \lg \frac{320 - 129}{220 - 125}} = 137,7 \text{ C}.$$

21. Necessary surface of heating steam cooler

$$F = \frac{Q}{\Delta t k} = \frac{205\,000}{137,7 \cdot 530} = 2,8 \text{ м}^2.$$

22. Real surface taking into account pollution/contamination

$$F_1 = 1{,}07F = 1{,}07 \cdot 2{,}8 = 3{,}0\ м^2.$$

23. Average/mean length of semi-V-shaped tubes

$$l = \frac{F_1}{\pi d_w n z_2} = \frac{3{,}0}{3{,}14 \cdot 0{,}017 \cdot 53 \cdot 2} = 0{,}53\ м.$$

§ 16. Calculation of the coolant of water.

Initial data for the calculation.

Quantity of the water-cooled W_1=24 m/h.

Pressure of the water-cooled P_1=2 kg/cm².

Temperature of the water-cooled upon the entrance into coolant t_1=85°C.

Temperature of cooled water or leaving from from cooler t_2=75°C.

Quantity of the cooling (marine) water W_2=18 m/h.

Pressure of the cooling (marine) water p_2=3 kg/cm².

Temperature of the cooling (marine) water upon the entrance into coolant t_3=22°C.

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We accept.

Tubes German silver with a diameter of $d_w/d_e = 10/8$ мм.

Number of courses of cooling water in tubes z=1.

Course of computation.

1. Mean temperature of water-cooled in coolant

$$t'_{cp} = 0{,}5(t_1 + t_2) = 0{,}5(85 + 75) = 80°\,C.$$

2. On Table 6 of applications/appendices when t'_{cp} we determine:

1) heat capacity of water $c'_p = 1{,}007$ kcal/kg °C;

2) specific gravity/weight of water $\gamma_1 = 971.8$ kg/m³;

3) kinematic viscosity of water $\nu_1 = 0.366 \cdot 10^{-6}$ m²/s;

4) coefficient of thermal diffusivity of water $\alpha_1 = 5.9 \cdot 10^{-4}$ m²/h °C;

5) coefficient of thermal conductivity of water λ_1=0.58 kcal/m-hour °C.

3. Quantity of heat, given up to cooling water,

$$Q = W_1 c_p' (t_1 - t_2) = 24000 \cdot 1{,}007\,(85 - 75) = 242000 \text{ kcal/h}.$$

4. Temperature of cooling water on leaving

$$t_4 = t_3 + \frac{Q}{W_2 c_p''} = 22 + \frac{242000}{18000 \cdot 0{,}94} = 36{,}4^\circ \text{C},$$

where c_p''=0,94 kcal/kg °C - heat capacity of cooling (marine) water.

5. Mean temperature of cooling water

$$t_{cp}'' = 0{,}5\,(t_3 + t_4) = 0{,}5\,(22 + 36{,}4) = 29{,}2^\circ \text{C}.$$

6. Average/mean logarithmic difference in temperatures for countercurrent

$$\Delta t = \frac{(t_1 - t_4) - (t_2 - t_3)}{2{,}3 \lg \frac{t_1 - t_4}{t_2 - t_3}} = \frac{(85 - 36{,}4) - (75 - 22)}{2{,}3 \lg \frac{85 - 36{,}4}{75 - 22}} = 51{,}8^\circ \text{C}.$$

7. Speed of cooling water in tubes we accept v_2=0,8 m/s.

8. Number of cooling tubes

$$n = \frac{W_2}{2825 d_в^2 v_2 \gamma_2} = \frac{18}{2825 \cdot 0{,}008^2 \cdot 0{,}8 \cdot 1{,}025} = 121,$$

where γ_2=1.025 t/m³ - specific gravity/weight of cooling water.

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9. Reynolds number for cooling water

$$Re = \frac{v \cdot d_e}{\nu_2} = \frac{0,8 \cdot 0,008}{0,8 \cdot 10^{-6}} = 8000,$$

where $\nu_2 = 0,8 \cdot 10^{-6}$ m²/s - kinematic viscosity of cooling water when $t^{\circ}_{cp} = 29,2°C$ (it is determined according to Table 6 of applications/appendices).

With 2200<Re=8000<10000 the motion is unstable.

10. Prandtl number for cooling water will comprise [1]

$$Pr = \frac{3600 \nu_2}{a_2} = \frac{3600 \cdot 0,8 \cdot 10^{-6}}{5,3 \cdot 10^{-4}} = 5,4,$$

where $\alpha_2 = 5.3 \cdot 10^{-4}$ m²/h - coefficient of thermal diffusivity of water when t°_{cp} (it is determined according to Table 6 of applications/appendices).

FOOTNOTE [1]. For a more precise calculation the value of criteria Gr and Pr, entering product $GrPr^3$, it is necessary to determine them at temperature of boundary layer. ENDFOOTNOTE.

11. Grashof's criterion for cooling water will comprise [2]

$$Gr = \frac{g d_e^3 \beta \Delta t}{\nu_2^2} = \frac{9,81 \cdot 0,008^3 \cdot 3 \cdot 10^{-4} \cdot 14,4}{(0,8 \cdot 10^{-6})^2} = 3,4 \cdot 10^4,$$

where $g=9.81$ m/s² - acceleration of gravity; $\beta=3\cdot10^{-4}$ 1/°C - coefficient of expansion of water when t°_{cp} (it is determined according to Table 6 of appendices); $\delta t=t_4-t_3=36.4-22=14.4$°C - difference in temperatures of cooling water.

FOOTNOTE 2. Then. ENDFOOTNOTE.

Product of the criteria

$$GrPr^3=3,4\cdot10^6\cdot5,4^3=5,32\cdot10^6.$$

12. On graph/curve Fig. 44 in depending on $GrPr^3$ and Pr with Re=8000 for transient mode/conditions we determine Nu=56.

13. Heat-transfer coefficient from wall to cooling water

$$\alpha_2=\frac{Nu\,\lambda_2}{d_в}=\frac{56\cdot0,53}{0,008}=3710\,\text{kcal/m}^2\text{h}\quad{}^\circ\text{C},$$

where $\lambda_2=0.53$ - coefficient of thermal conductivity of cooling water when $t^{\circ}_{cp}=29,2^\circ$C.

14. Space of location of cooling tubes

$$t=1,35d_н=1,35\cdot10=13,5\ мм.$$

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15. Inner diameter of housing of coolant from conditions for

location of beam of tubes is taken $D_к = 0{,}17$ м.

16. Speed of water-cooled in intertube space with longitudinal washing of beam of tubes

$$v_1 = \frac{W_1}{2825\left(D_к^2 - d_н^2 n\right)\gamma_1} = \frac{24}{2825\,(0{,}17^2 - 0{,}01^2 \cdot 121)\,0{,}9718} = 0{,}52 \text{ m/s}.$$

17. Equivalent heat-transmitting diameter of intertube space

$$d_э = \frac{D_к^2 - d_н^2 n}{d_н n} = \frac{0{,}17^2 - 0{,}01^2 \cdot 121}{0{,}01 \cdot 121} = 0{,}014 \text{ м}.$$

18. Reynolds number for water-cooled

$$\mathrm{Re}_1 = \frac{v_1 d_э}{\nu_1} = \frac{0{,}52 \cdot 0{,}014}{0{,}366 \cdot 10^{-6}} = 19\,900.$$

19. Prandtl number for water-cooled

$$\mathrm{Pr}_1 = \frac{3600\nu_1}{a_1} = \frac{3600 \cdot 0{,}366 \cdot 10^{-6}}{5{,}9 \cdot 10^{-4}} = 2{,}23.$$

20. Heat-transfer coefficient from water-cooled to wall with turbulent flow for longitudinal washing of beam of ducts

$$\alpha_1 = 0{,}023\,\frac{\lambda_1}{d_э}\,\mathrm{Re}^{0{,}8}\mathrm{Pr}^{0{,}4} = 0{,}023\,\frac{0{,}58}{0{,}014}\,19\,900^{0{,}8} \cdot 2{,}23^{0{,}4} =$$

$$3600 \text{ kcal/m}^2\text{h} \quad {}^\circ\text{C}.$$

21. Coefficient of heat transfer from water-cooled to that cooling

$$k_0 = \frac{1}{\frac{1}{\alpha_1} + \frac{d_н - d_в}{2\lambda} + \frac{1}{\alpha_2} \cdot \frac{2d_н}{d_н + d_в}} =$$

$$= \frac{1}{\frac{1}{3600} + \frac{0,01 - 0,008}{2 \cdot 25} + \frac{1}{3710} \cdot \frac{2 \cdot 0,001}{0,01 + 0,008}} = 1620 \text{ ккал/м}^2\text{-час °C}, \quad (1)$$

Key: (1). kcal/m²-h, °C

where λ=25 kcal/m- hour °C - coefficient of the thermal conductivity of German silver tube.

22. Coefficient, which considers pollution/contamination of tubes, is accepted ϕ=0.8.

23. Calculated coefficient of heat transfer from one water to the next

$$k = \varphi k_0 = 0,8 \cdot 1620 = 1300 \text{ kcal/m}^2\text{-h °C}.$$

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24. Necessary cooling surface of coolant

$$F = \frac{Q}{\Delta t k} = \frac{242\,000}{51,8 \cdot 1300} = 3,6 \text{ м}^2.$$

25. Effective length of tubes (or distance between tube plates)

$$l = \frac{F}{\pi \cdot d_н n} = \frac{3,6}{3,14 \cdot 0,01 \cdot 121} \approx 0,95 \text{ м}.$$

We accept l=1.0 m.

§ 17. Calculation of fuel heater.

Initial data for the calculation.

Productivity of preheater D=5 m/h.

Temperature of petroleum residue upon the entrance in preheater t_1=15°C.

Temperature of petroleum residue on leaving from preheater t_2=95°C.

Brand of the petroleum residue; the sailor M20.

Pressure of that heating of steam P=29 atm

We accept.

Heat availability factor $\eta = 0{,}98$.

Tubes of steel V-shaped with a diameter of $d_w/d_в = 17/13$ мм.

Thickness of flat/plane retarders , established/installed in the straight/direct part of the tubes, $\delta=1.0$ mm.

Number of courses of petroleum residue in the tubes of preheater z=6.

We determine (on Tables 1-3 of applications/appendices).

Temperature of heating steam $t_n = 230.9°C$.

Enthalpy of heating steam $i_n = 669,5$ kcal/kg.

Enthalpy of the condensate of that heating of steam q=237.5 kcal/kg.

Course of computation.

1. Mean temperature of petroleum residue in preheater

$$t_{cp} = 0,5(t_1 + t_2) = 0,5(15 + 95) = 55°C.$$

2. efficient weight of petroleum residue M20 with t_1 on graph/curve Fig. 13

$$\gamma_{15} = 0,947\ m/м^3.$$

3. Average/mean heat capacity of petroleum residue with t_{cp}

$$c_p = (0{,}403 + 0{,}00081 t_{cp}) \frac{1}{\sqrt{\gamma_{15}}} = (0{,}403 + 0{,}00081 \cdot 55) \frac{1}{\sqrt{0{,}947}} =$$

0,461 kcal/kg °C.

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4. Quantity of heat, necessary for preheating petroleum residue,

$$Q = Dc_p (t_2 - t_1) = 5000 \cdot 0{,}461 \, (95 - 15) = 1{,}85 \cdot 10^5 \text{ kcal/ kg.}$$

5. Expenditure of heating of steam for preheater

$$G = \frac{Q}{(i_n - q)\eta} = \frac{1{,}85 \cdot 10^5}{(669{,}5 - 237{,}5)\, 0{,}98} = 437 \text{ kg/h.}$$

6. Average/mean logarithmic difference in temperatures

$$\Delta t_{cp} = \frac{t_2 - t_1}{2{,}3 \lg \frac{t_n - t_1}{t_n - t_2}} = \frac{95 - 15}{2{,}3 \lg \frac{230{,}9 - 15}{230{,}9 - 95}} = 174^\circ \text{C.}$$

7. Number of tubes in one course (on preliminarily taken speed of petroleum residue 0.8 m/s) n=15.

8. Area for passage of petroleum residue in tubes with presence of retarders

$$f = (0{,}785 d_в^2 - \delta d_в)\, n =$$
$$= (0{,}785 \cdot 0{,}013^2 - 0{,}001 \cdot 0{,}013)\, 15 = 0{,}0018 \text{ м}^2.$$

9. Specific weight of petroleum residue when t_{cp} we determine on graph/curve Fig. 13 or according to formula

$$\gamma_{cp} = \gamma_{20} - 0{,}000567\,(t_{cp} - 20) =$$
$$= 0{,}941 - 0{,}000567\,(55 - 20) = 0{,}922\ m/м^3,$$

where $\gamma_{20} = 0{,}941\ m/м^3$ - specific gravity/weight of petroleum residue with t=20°C.

10. Speed of petroleum residue, which takes place in tubes,

$$v = \frac{D}{3600/\gamma_{cp}} = \frac{5}{3600 \cdot 0{,}0018 \cdot 0{,}922} = 0{,}83\ м/s.$$

11. Coefficient of heat transfer from vapor to admiralty fuel oil M12 in depending on his speed and mean temperature, in reference to external surface of tubes, we determine on graph/curve Fig. 41

$$k_0 = 175\ \text{kcal}/м^2 - ч\ \ ^\circ C.$$

12. Correction factor, which calculates brand of petroleum residue M20 on the basis of data to formula (129), $\varepsilon_1 = 0{,}93$.

13. Correction factor, which calculates use/application of retarders on the basis of graph/curve Fig. 42 $\varepsilon_2 = 1{,}42$.

14. Calculated coefficient of heat transfer from vapor to

petroleum residue M20

$$k = \varepsilon_1 \varepsilon_2 k_0 = 0{,}93 \cdot 1{,}42 \cdot 1{,}75 = 232 \text{ kcal/м}^2 - h \quad ^\circ C.$$

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15. Necessary surface of heating preheater, referred to outside diameter of tubes

$$F = \frac{Q}{\Delta t k} = \frac{1{,}85 \cdot 10^6}{174 \cdot 232} = 4{,}57 \text{ м}^2.$$

16. Actual heating surface taking into account possible pollution/contamination

$$F_ф = 1{,}1 \cdot F = 1{,}1 \cdot 4{,}57 \approx 5{,}0 \text{ м}^2.$$

17. Average/mean length of semi-V-shaped tube

$$l \approx \frac{F_ф}{\pi \cdot d_н n z} = \frac{5}{3{,}14 \cdot 0{,}017 \cdot 15 \cdot 6} = 1{,}03 \text{ м}.$$

18. Space of location of pipes.

$$t = d_н + 6 = 17 + 6 = 23 \text{ мм}.$$

19. Inner diameter of housing (from conditions for location of beams of V-shaped tubes, divided in cover/cap by partitions/baffles, ensuring 6 courses of petroleum residue) is accepted $D_в = 283$ мм.

§ 18. Calculation of the preheater of oil.

Initial data for the calculation.

Productivity of preheater D=2000 kg/h.

Temperature of oil upon the entrance into preheater t_1=15°C.

Temperature of oil on leaving from preheater t_2=70°C.

Brand of oil: turbine UT.

Vapor pressure of heating $p_н$=29 atm

We accept.

Heat availability factor η=0,98.

tube copper V-shaped with a diameter of $d_н/d_в$=10/8 мм.

Number of courses of oil in the tubes of preheater z=4.

Let us determine (on Tables 1-3 of applications/appendices).

Temperature of heating of steam $t_н$=230,9°C.

Enthalpy of that heating of steam i=669.5 kcal/kg.

Enthalpy of the condensate of heating of steam when p_n, equal to q=237.5 kcal/kg.

Course of computation.

1. Mean temperature of oil in heater.

$$t_{cp} = 0{,}5\,(t_1 + t_2) = 0{,}5\,(15 + 70) = 42{,}5^\circ\,C.$$

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2. Specific gravity/weight of oil UT with t_1 on graph/curve Fig. 13

$$\gamma_{15} = 0{,}902\ m/м^3.$$

3. Average/mean heat capacity of oil with

$$c_p = (0{,}403 + 0{,}00081 t_{cp}) \frac{1}{\sqrt{\gamma_{15}}} = (0{,}403 + 0{,}00081 \cdot 42{,}5) \frac{1}{\sqrt{0{,}902}} =$$

0,428 kcal/kg °C.

4. Quantity of heat, necessary for heating of oil,

$$Q = Dc_p(t_2 - t_1) = 2000 \cdot 0{,}428\,(70 - 15) = 47\,200 \text{ kg/h}.$$

5. Expenditure of heating of steam for preheater

$$G = \frac{Q}{(i - q)\,\eta} = \frac{47200}{(669{,}5 - 237{,}5)\,0{,}98} = 112 \text{ kg/h}.$$

6. Average/mean logarithmic difference in temperatures

$$\Delta t = \frac{t_2 - t_1}{2{,}3 \lg \frac{t_n - t_1}{t_n - t_2}} = \frac{70 - 15}{2{,}3 \lg \frac{230{,}9 - 15}{230{,}9 - 70}} = 187^\circ \text{C}.$$

7. Number of tubes in one course (on preliminarily taken speed of oil 1.5 m s) we accept n=8.

8. Area for passage of oil in tubes

$$f = 0{,}785 d_в^2 n = 0{,}785 \cdot 0{,}008^2 \cdot 8 = 0{,}000402 \ м^2.$$

9. Specific gravity/weight of oil when $t_{ср}$ is determined on graph/curve Fig. 13

$$\gamma_{ср} = 0{,}886 \ m/м^3.$$

10. Speed of oil, which takes place in tubes,

$$v = \frac{D}{3600 f \gamma_{ср}} = \frac{2}{3600 \cdot 0{,}000402 \cdot 0{,}886} = 1{,}5 \ м/s.$$

11. Coefficient of heat transfer from vapor to oil in depending on its speed and mean temperature, in reference to external surface of tubes, is determined on graph/curve Fig. 43

$$k = 263 \ \text{kcal}/м^2 - h \quad ^\circ C.$$

12. Necessary surface of heating preheater, in reference to

outside diameter of tubes,

$$F = \frac{Q}{\Delta t k} = \frac{47200}{187 \cdot 263} = 0{,}96 \ м^2.$$

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13. Actual surface of heating preheater taking into account possible pollution/contamination

$$F_ф = 1{,}04 \cdot F = 1{,}04 \cdot 0{,}96 = 1{,}0 \ м^2.$$

14. Average/mean length of semi-V-shaped tube

$$l = \frac{F_ф}{\pi \cdot d_н n z} = \frac{1{,}0}{3{,}14 \cdot 0{,}01 \cdot 8 \cdot 4} \approx 1{,}0 \ м.$$

15. Space of location of tubes

$$t = 1{,}3 d_н = 1{,}3 \cdot 10 = 13 \ мм.$$

16. Inner diameter of housing (from conditions for location of beams of V-shaped tubes, divided in cover/cap by partitions/baffles, ensuring four courses of oil) we accept $D_к = 100$ мм.

§ 19. Calculation of oil cooler.

Initial data for the calculation.

Productivity of oil cooler D=16 m/h.

Temperature of oil upon the entrance into oil cooler $t_1=55°C$.

Temperature of oil on leaving from oil cooler $t_2=37°C$.

Brand of oil: Turbine T.

Oil pressure in the oil cooler $p_1=3$ kg/cm².

Quantity of that cooling water (marine) G=50 m/h.

Temperature of cooling water upon entrance $t_3=15°C$.

Pressure of cooling water $p_2=2$ kg/cm².

We accept.

Tubes German silver of straight lines with a diameter of $d_н d_в = 10/8$ мм.

Number of courses of cooling water in tubes z=2.

Intertube space is divided by segmental partitions/baffles.

Heat capacity of cooling (marine) water $c_в = 0.94$ kcal/kg °C.

The specific gravity/weight of cooling (marine) water $\gamma_в = 1{,}025\ m/м^3$.

Course of computation.

1. Mean temperature of oil in oil cooler

$$t'_{cp} = 0{,}5(t_1 + t_2) = 0{,}5(55 + 37) = 46°\,C.$$

2. Specific gravity/weight of oil when t'_{cp} on graph/curve Fig. 13 $\gamma_м = 879$ kg/m³.

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3. Average/mean heat capacity of oil with t'_{cp}

$$c_p = (0{,}403 + 0{,}00081\,t'_{cp})\frac{1}{\sqrt{\gamma_{15}}} = (0{,}403 + 0{,}00081 \cdot 46)\frac{1}{\sqrt{0{,}9}} =$$

0,462 kcal/kg °C,

where γ_{15}=0.9 t/m³ - specific gravity/weight of oil with t=15°C on graph/curve Fig. 13.

4. Quantity of heat, given up by oil to water,

$$Q = Dc_p(t_1 - t_2) = 16000 \cdot 0{,}462(55-37) = 132000 \text{ kcal/h}.$$

5. Temperature of cooling water on leaving from oil cooler

$$t_4 = t_3 + \frac{Q}{Gc_в} = 15 + \frac{132000}{50000 \cdot 0{,}94} = 17{,}8^\circ \text{C}.$$

6. Mean temperature of cooling water

$$t'_{cp} = 0{,}5(t_3 + t_4) = 0{,}5(15 + 17{,}8) = 16{,}4^\circ \text{C}.$$

7. Average/mean logarithmic difference in temperatures between oil and water according to formula (36) for crosscurrent

$$\Delta t = \frac{(t_1 - t_4) - (t_2 - t'_{cp})}{2{,}3 \lg \frac{t_1 - t_4}{t_2 - t'_{cp}}} = \frac{(55-17{,}8) - (37-16{,}4)}{2{,}3 \lg \frac{55-17{,}8}{37-16{,}4}} = 28^\circ \text{C}.$$

8. Speed of cooling water in tubes we preliminarily accept $v'_в = 0{,}7$ m/s.

9. Number of cooling tubes in oil cooler in preliminary determination.

$$n' = \frac{Gz}{2825\, d_в^2 v'_в \gamma_в} = \frac{50 \cdot 2}{2825 \cdot 0{,}008^2 \cdot 0{,}7 \cdot 1{,}025} = 771.$$

10. Space of location of tubes on triangle

$$t = 1{,}35 d_н = 1{,}35 \cdot 10 = 13{,}5 \text{ мм}.$$

11. Inner diameter of housing (from conditions for location of beam of tubes, divided in cover/cap by partition/baffle, which ensures two courses of water in tubes) we accept $D_к = 435$ мм.

12. Number of cooling tubes, placed in oil cooler, n=778.

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13. Speed of cooling water in tubes

$$v_в = \frac{Gz}{2825 \cdot d_в^2 \pi \gamma_в} = \frac{50 \cdot 2}{2825 \cdot 0{,}008^2 \cdot 778 \cdot 1{,}025} = 0{,}693 \text{ m/s}.$$

14. Kinematic viscosity of water with $t_{ср}^{в}$ on Table 6 of appendices

$$\nu_в = 1{,}11 \cdot 10^{-6} \text{ m}^2/\text{s}.$$

15. Criterion of Reynolds for water

$$Re = \frac{v_в d_в}{\nu_в} = \frac{0{,}693 \cdot 0{,}008}{1{,}11 \cdot 10^{-6}} = 5000.$$

With 2200<Re=5000<10000 the motion is unstable.

16. Prandtl number for water will comprise [1]

$$Pr = \frac{3600 \cdot \nu_в}{a_в} = \frac{3600 \cdot 1{,}11 \cdot 10^{-6}}{5{,}03 \cdot 10^{-4}} = 7{,}93,$$

where $a_в = 5{,}03 \cdot 10^{-4}$ m²/h - coefficient of thermal diffusivity of water with $t_{ср}^{в} = 16{,}4°C$, determined in Table 6 of applications/appendices.

FOOTNOTE [1]. See footnote to § 16. ENDFOOTNOTE.

17.
Grashof's criterion for the water [2]

$$Gr = \frac{g d_в^3 \beta \delta t}{\nu_в^2} = \frac{9{,}81 \cdot 0{,}008^3 \cdot 1{,}14 \cdot 10^{-4} \cdot 2{,}8}{(1{,}11 \cdot 10^{-6})^2} = 1330,$$

where $\beta = 1.14 \cdot 10^{-4}$ 1/°C - coefficient of the expansion of water in Table 6 of applications/appendices when $t_{ср}^{в} = 16{,}4$°C; $g = 9.81$ m/s² - acceleration of gravity $\delta t = t_4 - t_3 = 17.8 - 15 = 2.8$°C - difference in the temperatures of water.

FOOTNOTE [2]. Then. ENDFOOTNOTE.

18. Product of criteria

$$GrPr^3 = 1330 \cdot 7{,}93^3 = 6{,}65 \cdot 10^5.$$

19. On graph/curve Fig. 44 in depending on $GrPr^3$ and Pr with Re=5000 for transient mode/conditions we determine Nu=38.5.

20. Heat-transfer coefficient from wall to water

$$\alpha_в = \frac{Nu \lambda_в}{d_в} = \frac{38{,}5 \cdot 0{,}507}{0{,}008} = 2440 \text{ kcal/m}^2 \cdot \text{h °C},$$

where $\lambda_в = 0{,}507$ kcal/m- hour °C - thermal conductivity of water when on tables 6 of applications/appendices.

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21. From conditions of laying out of tubes and location of partitions/baffles in housing of oil cooler we accept:

n_1=12 - number of gaps/intervals (sections) between partitions/baffles;

h=0.094 m - distance between partitions/baffles;

m=18 - number of series/rows of tubes, arranged/located between shear/sections of partitions/baffles;

m_3=492 - number of clearances between tubes in series/rows, streamlined with cross flow;

y_0=0.0153 m - average distance between housing and wing tubes;

ϕ=116° - central angle of segment, formed by groove in partition/baffle;

n_2=126 - number of tubes, arranged/located in segmental groove of partition/baffle.

22. Clearance between tubes

$$y = t - d_н = 13{,}5 - 10 = 3{,}5 \text{ мм} = 0{,}0035 \text{ м}.$$

23. Average/mean area of section for passage of oil between partitions/baffles

$$f_1 = \left(2y_0 + \frac{3m_2}{2m} y\right) h = \left(2 \cdot 0{,}0153 + \frac{3 \cdot 492}{2 \cdot 18} 0{,}0035\right) 0{,}094 =$$
$$= 0{,}0164 \text{ м}^2,$$

24. Sectional area for passage of oil above partitions/baffles

$$f_2 = \frac{D_в^2}{8}\left(\frac{\varphi\pi}{180} - \sin\varphi\right) - \frac{\pi d_н^2}{4} n_2 =$$
$$= \frac{0{,}435^2}{8}\left(\frac{116 \cdot 3{,}14}{180} - \sin 116\right) - \frac{3{,}14 \cdot 0{,}01^2}{4} 126 = 0{,}0164 \text{ м}^2.$$

25. Average speed of oil between partitions/baffles and above them, since $f_1 = f_2$,

$$v_м = \frac{Q}{3600 \cdot f_1 \gamma_м} = \frac{16}{3600 \cdot 0{,}0164 \cdot 0{,}879} = 0{,}307 \text{ м/сек}.$$ (1)

Key: (1). m/s.

26. Average speed of oil in oil cooler with transverse segmental partitions/baffles

$$v_{ср} = \frac{L v_м + (N-1) A v_м}{L + (N-1) A} = \frac{1{,}04 \cdot 0{,}307 + (11-1)\, 2{,}32 \cdot 0{,}307}{1{,}04 + (11-1)\, 2{,}32} = 0{,}308 \text{ м/сек}.$$ (1)

Key: (1). m/s.

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Here L=1.04 m - distance between the inlets and oil outlet;

N=11 - number of partitions/baffles;

f - area of the segment above the partition/baffle:

$$f = f_з + \frac{\pi d_н^2}{4} n_з = 0{,}0164 + \frac{3{,}14 \cdot 0{,}01^2}{4} 126 = 0{,}0265 \ м^2;$$

$$A = \frac{S}{6f} = \frac{0{,}369}{6 \cdot 0{,}0265} = 2{,}32 \ м,$$

where S - a chord length;

$$S = D_в \sin\frac{\varphi}{2} = 0{,}435 \cdot \sin\frac{116}{2} = 0{,}369 \ м.$$

27. Heat-transfer coefficient from oil to wall of tube

$$\alpha_м = 550 \sqrt{\frac{v_{ср}}{t - d_н}} (1 + 0{,}006 t'_{ср}) =$$

$$= 550 \sqrt{\frac{0{,}03}{13{,}5 - 10}} (1 + 0{,}006 \cdot 46) = 208 \ ккал/м^2 \cdot час\,°C.$$ (1)

Key: (1). the kcal/m²h °C.

28. Coefficient of thermal conductivity of German silver tubes (on tables 38) λ=25 kcal/m- hour °C.

29. Coefficient of heat transfer from oil to cooling water

$$k = \frac{1}{\frac{1}{\alpha_н} + \frac{d_н - d_в}{2\lambda} + \frac{1}{\alpha_в} \cdot \frac{2d_н}{d_н + d_в}} =$$

$$= \frac{1}{\frac{1}{200} + \frac{0{,}01 - 0{,}008}{2 \cdot 25} + \frac{1}{2400} \cdot \frac{2 \cdot 0{,}01}{0{,}01 + 0{,}008}} = 188 \text{ ккал}/м^2 \cdot час\,°C.$$ (1)

Key: (1). the kcal/m²h °C.

30. Necessary cooling surface of oil cooler

$$F = \frac{Q}{\Delta t k} = \frac{132000}{28 \cdot 188} = 25{,}1 \text{ м}^2.$$

31. Distance between tube plates or effective length of tubes

$$l = n_1 h + N\delta = 12 \cdot 0{,}094 + 11 \cdot 0{,}003 = 1{,}163 \text{ м},$$

where with δ=0.003 m - thickness of partitions/baffles.

32. Complete cooling surface of oil cooler

$$F_п = \pi d_н l n = 3{,}14 \cdot 0{,}01 \cdot 1{,}163 \cdot 778 = 28{,}6 \text{ м}^2.$$

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§20. Calculation of air preheater.

Initial data for the calculation.

Productivity of preheater at temperature t=15°C: $G_в$ =5000 m³/h.

Temperature of the air, which enters the preheater, t_1=-25°C.

Temperature of the air, which emerges from the preheater, t_2=+15°C.

Vapor pressure of heating p_n =5 atm(abs.).

We accept.

Heat availability factor η =0.98.

Tubes brass of diameters t_w/d_n =10/8 mm.

Number of courses in tubes z=1.

Space of tubes in the width of beam s_1=15 mm.

Space of tubes in the depth of beam s_2=12.5 mm.

We determine (on Table 1-3 of applications/appendices).

Temperature of heating steam t_s =151.1°C.

Heat of vaporization r=504.2 kcal/kg.

Course of computation.

1. Mean temperature of air

$$t_{cp} = 0{,}5(t_1 + t_2) = 0{,}5(-25 + 15) = -5°C.$$

2. On Table 5 of applications/appendices when t_{cp} we determine:

1) kinematic viscosity of air $\nu = 12.9 \cdot 10^{-6}$ m/s;

2) coefficient of thermal conductivity $\lambda = 2.02 \cdot 10^{-2}$ kcal/m h°C;

3) heat capacity of the air c_p =0.241 kcal/kg of °C;

4) specific gravity/weight of air γ =1.280 kg m³;

5) specific gravity/weight of air with t=15°C: γ_{15} =1.185 kg/m³.

3. Weight quantity of air, passing through heater.

$$G'_в = G_в \gamma_{15} = 5000 \cdot 1{,}185 = 5930 \text{ кг/час}^{(1)}.$$

Key: (1). kg/h.

4. Volume of air with

$$G''_в = \frac{G'_в}{\gamma} = \frac{5930}{1{,}280} = 4650 \text{ м}^3/\text{час}^{(1)}.$$

Key: (1). m³/h.

5. Quantity of heat, required for heating of air,

$$Q = G_в c_p (t_2 - t_1) = 5930 \cdot 0{,}241\,(15 + 25) = 57\,200 \text{ ккал/час.}^{(1)}$$

of Key: (1). kcal/h.

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6. Expenditure pair for preheating of air

$$G_п = \frac{Q}{r\eta} = \frac{57200}{504{,}2 \cdot 0{,}98} = 116 \text{ кг/час.}^{(1)}$$

Key: (1). kg/h.

7. Temperature head between vapor and air

$$\Delta t = t_s - t_{ср} = 151{,}1 + 5 = 156{,}1°\text{C}.$$

8. We preliminarily accept following structural/design sizes/dimensions of preheater, being guided by fulfilled draft:

number of series/rows of tubes in depth of beam:

with even quantity of tubes ... $m_1=3$

with odd quantity of tubes ... $m_2=2$

number of tubes in even series/row ... $n_1=30$

number of tubes in odd series/row ... $n_2=29$

Distance between tube plates ... l=0.68 m

distance from wall of housing to wing tube ... δ=0.003 m.

9. Dimensions of section of housing for passage of air in width of beam

$$b=(n_1-1)s_1+d_n+2\delta=(30-1)0{,}015+0{,}01+$$
$$+2\cdot 0{,}003=0{,}45\ м.$$

10. Clear area for passage of air

$$f=\left(b-\frac{m_1n_1+m_2n_2}{m_1+m_2}d_n\right)l=\left(0{,}45-\frac{3\cdot 30+2\cdot 29}{3+2}0{,}01\right)0{,}68=$$
$$=0{,}1049\ м^2.$$

11. Average/mean air speed in preheater

$$v=\frac{G_в^*}{3600f}=\frac{4650}{3600\cdot 0{,}1049}=12{,}3\ м/сек.\ (1)$$

Key: (1). m/s.

12. Reynolds number for air

$$\mathrm{Re}=\frac{vd_n}{\nu}=\frac{12{,}3\cdot 0{,}01}{12{,}9\cdot 10^{-6}}=9550.$$

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13. Heat-transfer coefficient from wall to air for transverse

flow around tubes of staggered arrangement will be determined according to to formula

$$\alpha = c\varepsilon \frac{\lambda}{d_н} \mathrm{Re}^n = 1{,}15 \cdot 0{,}223 \frac{2{,}02 \cdot 10^{-2}}{0{,}01} 9550^{0{,}6} = 127 \text{ ккал}/\text{м}^2\text{-час °C}.$$ (1)

by Key: (1). kcal/m²h °C.

where c - a coefficient (on Table 9) when $\frac{s_1}{d_н} = \frac{15}{10} = 1{,}5$:

$$c = 1 + 0{,}1 \frac{s_1}{d_н} = 1 + 0{,}1 \frac{15}{10} = 1{,}15;$$

ε - coefficient in Table 9 as average/mean for five series:

$$\varepsilon = \frac{n' + n'' + 3n'''}{5} = \frac{0{,}15 + 0{,}20 + 3 \cdot 0{,}255}{5} = 0{,}223;$$

n=0.6 - an exponent on Table 9.

14. Coefficient of heat transfer from vapor to air

$$k \approx \alpha = 127 \text{ ккал}/\text{м}^2\text{-час °C}.$$ (1)

Key: (1). kcal/m²h °C.

15. Necessary surface of heating preheater

$$F = \frac{Q}{\Delta t k} = \frac{59100}{156{,}1 \cdot 127} \approx 3{,}0 \text{ м}^2.$$

16. Accepted surface according to preliminary sizes/dimensions

$$F_ф = (m_1 n_1 + m_2 n_2) \pi d_н l = (30 \cdot 3 + 29 \cdot 2) 3{,}14 \cdot 0{,}01 \cdot 0{,}68 = 3{,}16 \text{ м}^2.$$

In the case of disagreement it is more than to -5-+10o/c between the necessary surface and surface, accepted according to preliminary sizes/dimensions, should be changed the sizes/dimensions accepted and again produced calculation.

During the setting up of air preheaters in the special compartments from which the fans supply air into the operating locations, the heat availability factor is accepted $\eta = 1.0$.

§21. Calculation of the coolant or air.

Initial data for the calculation.

Productivity of coolant at temperature t=15°C, G_0 =3000 m³/h.

Temperature of the air, which enters the coolant, t_1=27°C.

Temperature of the air, which emerges from coolant t_2=18°C.

Temperature of the brine, which enters in coolant, t_3=7.5°C.

Temperature of the brine, which emerges from the coolant, t_4=10.5°C.

We accept.

Tubes brass with a diameter of $d_н/d_в = 16/14$ мм.

Number of courses of brine in tubes z=2.

Space of tubes in the width of beam s_1=22 mm.

Space of tubes in the depth of beam s_2=20 mm.

Heat capacity of brine c_p' =0.93 kcal/kg °C.

The specific gravity/weight of brine γ_p =1.025 т/м³.

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Course of computation.

1. Mean temperature of air

$$t_{cp}' = 0{,}5\,(t_1 + t_2) = 0{,}5\,(27 + 18) = 22{,}5^\circ\,\mathrm{C}.$$

2. On Table 5 of layings when t_{cp}' we determine:

1) heat capacity of the air c_p =0.242 kcal/kg°C;

2) coefficient of thermal conductivity $\lambda = 2.18 \cdot 10^{-2}$ kcal/m•h°C;

3) kinematic viscosity ν =15.93•10^{-6} m^2/s.

4) specific gravity/weight γ =1.155 kg/m^3;

5) specific gravity/weight with t=15°C, equal to γ_{15} =1.185 kg/m^3.

3. Weight quantity of air, passing through coolant,

$$G'_в = G_в \gamma_{15} = 3000 \cdot 1{,}185 = 3560 \overset{(1)}{кг/час}.$$

Key: (1). kg/h.

4. Volume of air with $t'_{ср}$

$$G'_в = \frac{G'_в}{\gamma} = \frac{3560}{1{,}155} = 3080 \overset{(1)}{м^3/час}.$$

Key: (1). m^3/h.

5. Quantity of heat, abstracted/removed by brine,

$$Q = G'_в c_p (t_1 - t_2) = 3560 \cdot 0{,}242 (27 - 18) = 7800 \overset{(1)}{ккал/час}.$$

Key: (1). kcal/h.

6. Mean temperature of brine

$$t''_{ср} = 0{,}5 (t_3 + t_4) = 0{,}5 (7{,}5 + 10{,}5) = 9° C.$$

7. Quantity of brine, required for cooling of air,

$$W_р = \frac{Q}{c_р (t_4 - t_3)} = \frac{7800}{0{,}93 (10{,}5 - 7{,}5)} = 2800 \overset{(1)}{кг/час}.$$

Key: (1). kg/h.

8. We preliminarily accept following structural/design sizes/dimensions of coolant, being guided by fulfilled draft:

number of series/rows of tubes in depth of beam ... m=16.

Number of tubes in the width of beam ... n=18.

Distance between the tube plates ... l=0.485 m.

Distance from the wall of housing to farthest tube with δ=0.009 m.

9. Size/dimension of section of housing for passage of air in width of beam

$$b=(n-1)s_1+d_н+2\delta=(18-1)0.022+0.016+2\cdot0,009=$$
$$=0,408\ м.$$

10. Clear area for passage of air

$$f=(b-nd_н)l=(0,408-18\cdot0,016)0,485=0,0582\ м^2.$$

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11. Average/mean air speed in coolant

$$v_в=\frac{G_в^*}{3600f}=\frac{3080}{3600\cdot0,0582}=14,6\ \overset{(1)}{м/сек}.$$

Key: (1). m/s.

12. Reynolds number for air

$$\mathrm{Re} = \frac{v_в d_н}{\nu} = \frac{14,6 \cdot 0,016}{15,93 \cdot 10^{-6}} = 14700.$$

13. Heat-transfer coefficient from wall to air for transverse flow around tubes of staggered arrangement will be determined according to to formula

$$\alpha_в = c\varepsilon \frac{\lambda}{d_н} \mathrm{Re}^n = 1,1375 \cdot 0,245 \frac{2,18 \cdot 10^{-2}}{0,016} 14700^{0,6} =$$

$$= 123 \overset{(1)}{ккал/м^2 \cdot час\,°C},$$

by Key: (1). kcal/m²h °C.

where coefficient c in Table 9 when $\frac{s_1}{d_н} = \frac{22}{16} = 1,375$:

$$c = 1 + 0,1 \frac{s_1}{d_н} = 1 + 0,1 \frac{22}{16} = 1,1375;$$

ε - coefficient in Table 9 as average for 16 series/rows:

$$\varepsilon = \frac{0,15 + 0,20 + 14 \cdot 0,255}{16} = 0,245;$$

n=0.6 - index of degree on Table 9.

14. Mean temperature of wall of tube

$$t_{ст} = 0,5\,(t'_{ср} + t''_{ср}) = 0,5\,(22,5 + 9) = 15,75°\,C.$$

15. Temperature of boundary layer from the side of brine

$$t_{гр} = 0,5\,(t_{ст} + t''_{ср}) = 0,5\,(15,75 + 9) \approx 12,3°\,C.$$

16. Rate of brine in tubes

$$v_р = \frac{W_{рz}}{2825 d_в^2 \gamma_р n m} = \frac{2,8 \cdot 2}{2825 \cdot 0,014^2 \cdot 1,025 \cdot 18 \cdot 16} = 0,0342 \overset{(1)}{м/сек}.$$

Key: (1). m/s.

17. Reynolds number for brine

$$Re = \frac{v_p d_e}{\nu_p} = \frac{0,0142 \cdot 0,014}{1,23 \cdot 10^{-6}} = 390,$$

where $\nu_p = 1,23 \cdot 10^{-6}$ at t_{rp} =12.3°C (on table 6 of applications/appendices).

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18. Prandtl number for brine

$$Pr = \frac{3600 \cdot \nu_p}{a} = \frac{3600 \cdot 1,23 \cdot 10^{-6}}{5,15 \cdot 10^{-4}} = 8,6,$$

where $a = 5.15 \cdot 10^{-4}$ m²/h - coefficient of thermal diffusivity of brine when t_{rp} (on table 6 appendices).

19. Grashof's criterion for brine

$$Gr = \frac{g d_e^3 \beta \delta t}{\nu_p^2} = \frac{9,81 \cdot 0,014^3 \cdot 1,16 \cdot 10^{-4} \cdot 3}{(1,23 \cdot 10^{-6})^2} = 6250,$$

where $\beta = +1.16 \cdot 10^{-4}$ 1/°C - coefficient of expansion of water when t_{rp} (on table 6 of applications/appendices); $\delta t = t_4 - t_3 = 10,5 - 7,5 = 3°C$ - difference in temperatures of brine.

20. product $GrPr = 6250 \cdot 8.6 = 5.35 \cdot 10^4$.

21. Heat-transfer coefficient from wall to brine for laminar

flow of brine in tubes

$$\alpha_p = 0{,}74\frac{\lambda_p}{d_в}\mathrm{Re}^{0.2}(\mathrm{GrPr})^{0.1}\mathrm{Pr}^{0.2} = 0{,}74\frac{0.5}{0{,}014}390^{0.2}\cdot 53\,500^{0.1}\cdot 8{,}6^{0.2} =$$
$$= 397 \text{ ккал}/м^2\text{-час}^\circ\text{C}, \quad (1)$$

Key: (1). the kcal/m²-h°C.

where λ_p =0.5 a kcal/m-hour °C - thermal conductivity of brine when $t_{ср}$ according to the data of Table 6 applications/appendices.

22. Ratio of length of tubes to diameter

$$\frac{l}{d_в} = \frac{0{,}485}{0{,}014} = 34{,}6.$$

23. Correcting coefficient ε on Table 6: ε =1.036.

24. Heat-transfer coefficient from wall to brine with consideration correction factor

$$\alpha_p' = \varepsilon\alpha_p = 1{,}036\cdot 397 = 412 \text{ ккал}/м^2\text{-час}^\circ\text{C}. \quad (1)$$

Key: (1). kcal/m²-h°C.

25. Coefficient of thermal conductivity of brass tubes λ=90 kcal/m-h°C.

26. Coefficient of heat transfer from air to brine

$$k = \frac{1}{\frac{1}{\alpha_в} + \frac{d_н - d_в}{2\lambda} + \frac{1}{\alpha_p'}\cdot\frac{2d_н}{d_н + d_в}} =$$
$$= \frac{1}{\frac{1}{123} + \frac{0{,}016 - 0{,}014}{2\cdot 90} + \frac{1}{412}\cdot\frac{2\cdot 0{,}016}{0{,}016 + 0{,}014}} \approx 93 \text{ ккал}/м^2\text{-час}^\circ\text{C}. \quad (1)$$

Key: (1). kcal/m²-h°C.

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27. Average/mean logarithmic difference in temperatures for crosscurrent of air and brine

$$\Delta t = \frac{(t_1 - t_4) - (t_2 - t_{cp}')}{2{,}3 \lg \frac{t_1 - t_4}{t_2 - t_{cp}'}} = \frac{(27 - 10{,}5) - (18 - 9)}{2{,}3 \lg \frac{27 - 10{,}5}{18 - 9}} = 12{,}35^\circ \text{C}.$$

28. Necessary cooling surface

$$F = \frac{Q}{\Delta t k} = \frac{7800}{12{,}35 \cdot 93} = 6{,}85 \ м^2.$$

29. Actual cooling surface according to preliminarily taken sizes/dimensions

$$F_\phi = \pi d_н l m n = 3{,}14 \cdot 0{,}016 \cdot 0{,}485 \cdot 16 \cdot 18 \approx 7{,}0 \ м^2.$$

In the case of cooling external atmospheric air in the calculation of coolant should be considered the moisture content of air, and also the permissible (prescribed/assigned) moisture content of the cooled air.

In this case with the execution of calculation is applied I-d

the diagram of humid air [1].

FOOTNOTE [1]. A. V. Nesterenko, use/application I-d diagram in the calculations of ventilation, Stroyizdat, 1950. ENDFOOTNOTE.

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Chapter III.

Calculations of resistances.

§22. Losses of head in the apparatuses.

Losses of head in the apparatuses depend on the presence of resistances which must overcome the moving/driving mass of liquid on its path.

These resistances are of two kinds: a) the frictional resistance of liquid against the walls, which depends on the physical properties of liquid, its rate, from the quality of surface and sizes/dimensions of the duct; b) local resistances, which appear as a result of changing the direction of motion, and also as a result of a change in the geometric form of fluid flow.

With the course of liquids distinguish character their motions. In the rectilinear direction the motions and during the sufficiently coze of the liquid of its particle move rectilinearly and in parallel to each other. This motion is called flowing, or laminar.

At high rates, even in the case of rectilinear direction, flow, single particles the liquids move disorderly, over the curved lines and in different directions, moreover the particle path they constantly change. This motion is called vortex/eddy, or turbulent.

The diagram of laminar and turbulent fluid flows, which shows the distribution of rates according to the diameter of conduit/manifold, is represented in Fig. 55.

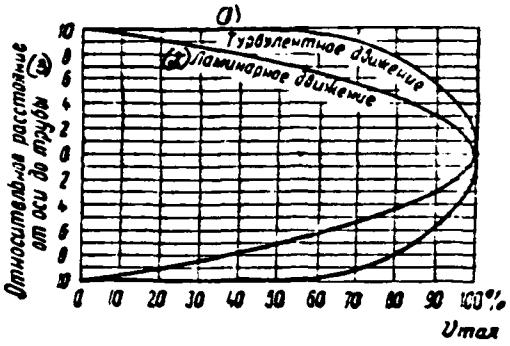

Fig. 55. Diagram of the laminar and turbulent motion of liquid in the duct.

Key: (1). Turbulent motion. (2). Viscous motion. (3). Relative distance from axis/axle to duct.

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The criterion by which it is possible to judge about the character of the state of motion of flow, is the value of Reynolds number. The value of Reynolds number, with whom occurs the transition of mode/conditions from laminar to turbulent, is called critical, and the rate of flow, which corresponds to a critical number, is called critical speed.

Reynolds number (or Reynolds's parameter) is expressed by the following formula:

$$\mathrm{Re} = \frac{vd}{\nu} = \frac{vd\gamma}{\mu g}, \qquad (188)$$

where v - a rate of medium, m/s; d - diameter of duct, m; ν - kinematic viscosity, m^2/s; γ - specific gravity/weight, kg/m^3; μ - dynamic viscosity, $kg \cdot s/m^2$; g=9.81 - acceleration of gravity m/s^2.

With:

Re<2200 - laminar flow; 2200<Re<10000 - wobble; Re>10000 - the turbulent flow;

Thus:

Number 2200 - lower critical Reynolds number.

Number 10000 - upper critical Reynolds number.

Loss to friction in the straight/direct section of the duct

$$\Delta p = \lambda \frac{l}{d} \frac{v^2 \gamma}{2g} \; кг/м^2, \qquad (189)$$

where λ - coefficient of friction drag; l - length of duct, m; d - diameter of duct, m; v - rate of medium, m/s; γ - the specific gravity/weight of medium, $кg/m^3$. g=9.81 - acceleration of gravity m/s^2.

The local losses:

$$\Delta p = \zeta \frac{v^2 \gamma}{2g} \text{ кг/м}^2, \qquad (190)$$

where ζ - coefficient of local resistance; v - rate of medium after local obstruction, m/s; γ - the specific gravity/weight of medium, kg/m³; g - acceleration of gravity m/s².

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Resistance in the tube system of the apparatus:

$$h = z\left(0{,}031\frac{l}{d}\frac{v^2}{2g}\beta + 1{,}4\frac{v^2}{2g}\right) + \frac{v_1^2}{2g} \text{ м вод. ст.}^{(1)} \qquad (191)$$

Key: (1). water column.

where z - a number of courses of water in the apparatus; l - length of tube, m; d - inner diameter of tube, m; v - the average speed of water in tubes, m/s; g - acceleration of gravity m/s²; β - coefficient, which considers the effect of mean temperature and rate of water (it is accepted on of the curves of Fig. 56); v_1 - velocity of water in branch pipes, m/s.

In formula (191) the first term in the brackets considers losses of head to friction in the tubes; the second term in the brackets considers local losses in the tubes. Losses in the branch pipes of apparatus are considered by the latter/last member of formula.

Fig. 56 gives curves for determining the value of coefficient β in the dependence on mean temperature and rate of water.

With the loads of lower than the calculated resistance in the apparatuses is determined from to the formula

$$h' = h\left(\frac{W'}{W}\right)^{1.8} м \overset{(1)}{\text{вод. ст.}}, \qquad (192)$$

by Key: (1). water column.

where W, W' - consumption of water respectively with calculated and smaller loads, m^3/h; h, h' - hydraulic resistance respectively with calculated and smaller loads, m water column.

Hydraulic resistance of capacitor according to the data of VTI:

$$h = z\,(bLv^{1.75} + 0.135v^{1.5})\, м \overset{(1)}{\text{вод. ст.}}, \qquad (193)$$

Key: (1). water column.

where z - a number of courses of water in the capacitor; b - coefficient, depending on the inner diameter of tubes and mean temperature of water $t_{ср}$. determined on Table 18; L - length of tubes, m; v - rate of water in tube, m/s.

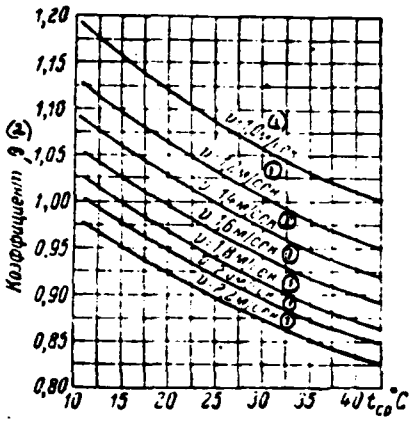

Fig. 56. Value of coefficient β in depending on mean temperature and rate of water.

Key: (1). m/s. (2). Coefficient.

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With a significant deviation of t_{cp} from 20°C the indicated in Table 18 value b should be multiplied by value $\phi = 1 + 0.007\,(t_{cp} - 20)$.

Resistance in the intertube space of apparatus with the transverse bulkheads:

1) in the passages between the partitions/baffles

$$\Delta p = \frac{4 f m v_1^2 \gamma n}{2g} \text{ (1) } \text{кг/м}^2, \qquad (194)$$

Key: (1). kg/m².

where f - a function of Reynolds number, equal to

$$f = 0{,}75\left(\frac{a v_1 \gamma}{\mu g}\right)^{-0{,}2};$$

m - number of series/rows of tubes, intersected by the flow of the medium; γ - the specific gravity/weight of medium, kg/m³; n - number of gaps/intervals between the partitions/baffles; a - distance (clearance) between the series/rows of tubes, m; v_1 - rate of liquid at the edge of partition/baffle, m/s; μ - absolute viscosity at mean temperature of medium, kg•s/m²; g - acceleration of gravity m/s².

2) during the flow through the partitions/baffles

$$\Delta p = \frac{0{,}0815 u^2 z}{\gamma} \text{ кг/м}^2, \quad (195)$$

Key: (1). kg/m².

where z - a number of partitions/baffles; u - the mass flow rate through partition/baffle, equal to

$$u = v_2 \gamma \text{ кг/м}^2\text{-сек};$$

Key: (1). the kg/m²s.

v_2 - rate of the medium above partition/baffle, m/s.

Fig. 57 schematically depicts heat exchanger with the transverse

bulkheads and flow chart fluid flow in its intertube space.

Resistance in the tubular heat exchangers with the course of medium in the intertube space is parallel to the axis/axle of tubes is defined normally, as for the case of the course of medium on the straight/direct tubes whereby into the formula is substituted equivalent hydraulic diameter.

Table 18. Values of coefficient of b.

$d_в$, мм	14	16	18	20	22	24	26
b	0,138	0,117	0,101	0,088	0,078	0,070	0,064

Page 119. The losses of head of petroleum residue on 1 lin. m in depending on rate and mean temperature of petroleum residue are determined on the graph/curve Fig. 58. The curves of graph/curve are constructed according to the data of tests for the course of petroleum residue M12, M20 and M40 in the steel tubes with a diameter of 17/13 mm.

Losses of head on 1 lin. m for the same brands of petroleum residue with their course in the same tubes with retarders depending on rate and mean temperature of petroleum residue are determined on the graph/curve of Fig. 59 whose curves are also constructed according to the data of the tests (about the construction/design of retarders see Page 56).

The losses of head of oil on 1 lin. m in depending on rate and mean temperature of oil are determined on the graph/curve Fig. 60. Curves of the graph/curve are plotted according to the data of tests for the course of oils of brands T and UT in the copper tubes with a diameter of 10/8 mm.

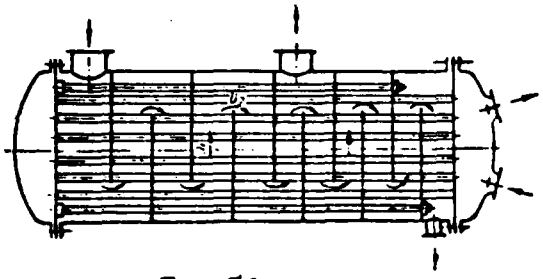

Fig. 57

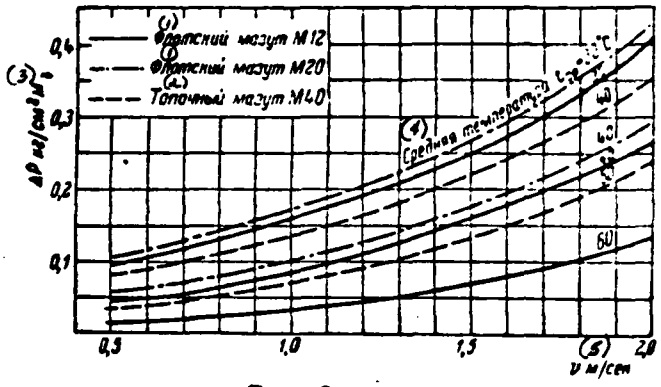

Fig. 58.

Fig. 57. Flow chart of fluid flow in the intertube space of heat exchanger.

Fig. 58. Curves of losses of head of petroleum residue with course in steel tubes with a diameter of 17/13 mm.

Key: (1). The admiralty fuel oil. (2). heating oil. (3). kg/cm²m. (4). Average/mean temperature. (5). m/s.

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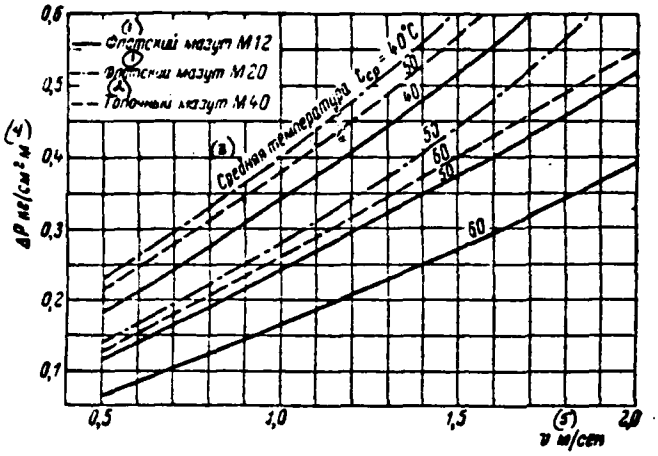

Fig. 59. Curves of losses of head of petroleum residue with course in steel tubes with a diameter of 17/13 mm with retarders.

Key: (1). The admiralty fuel oil. (2). Fuel mazut. (3). Mean temperature. (4). kg/cm²m. (5). m/s.

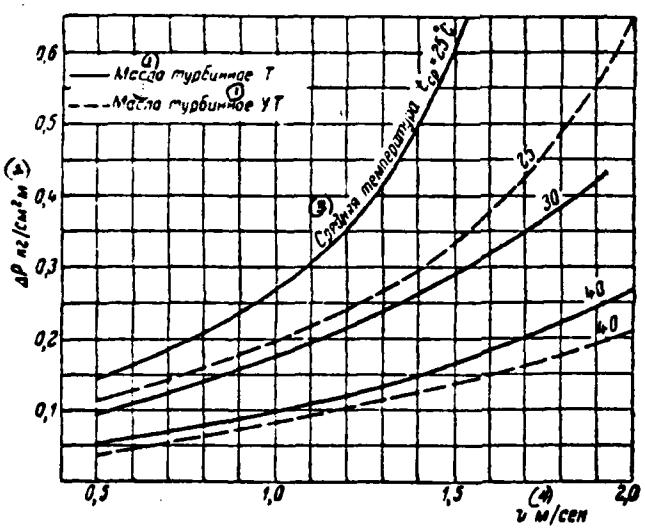

Fig. 60

Fig. 60. Curves of losses of head of oil with course in copper tubes with a diameter of 10/8 mm.

Key: (1). Oil is turbine. (2). kg/cm²m. (3). Mean temperature. (4). m/s.

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Resistance in the beam of the ducts, washed by the cross flow of air (gas):

1) in the checkered beams with $\varepsilon = \dfrac{1 - \dfrac{d}{t_2'}}{\dfrac{t_1}{d} - 1} \leqslant 0{,}53$

$$\Delta p = 2{,}8\,(z+1)\,\mathrm{Re}^{-0{,}25}\,\frac{\gamma v^2}{2g}\ \overset{(1)}{кг/м^2}\ \text{или мм вод. ст.;} \quad (196)$$

Key: (1). kg/m² or mm H_2C.

with $\varepsilon = \dfrac{1 - \dfrac{d}{t_2'}}{\dfrac{t_1}{d} - 1} > 0{,}53$

$$\Delta p = 3{,}86\,(z+1)\sqrt{\frac{1 - d/t_2'}{t_1/d - 1}}\,\mathrm{Re}^{-0{,}25}\,\frac{\gamma v^2}{2g}\ \overset{(1)}{кг/м^2}\ \text{или мм вод. ст.;} \quad (197)$$

Key: (1). kg/m² or mm H_2C.

2) in the corridor beams with $\varepsilon = \dfrac{\dfrac{t_2}{d} - 0{,}8}{\dfrac{t_1}{d} - 1} \leqslant 1$

$$\Delta p = 0{,}53\left(\frac{t_2/d - 0{,}8}{t_1/d - 1}\right)^{2{,}5} z\,\mathrm{Re}^{m}\,\frac{\gamma v^2}{2g}\ \overset{(1)}{кг/м^2}\ \text{или мм вод. ст.;} \quad (198)$$

Key: (1). kg/m² or mm H_2C.

with $\varepsilon = \dfrac{\dfrac{t_2}{d} - 0{,}8}{\dfrac{t_1}{d} - 1} > 1$

$$\Delta p = 0{,}53\left(\frac{t_2/d-0{,}8}{t_1/d-1}\right)^2 z\,\mathrm{Re}^m \frac{\gamma v^2}{2g}\ \text{кг/м}^2 \text{ или мм вод. ст.}, \quad (199)$$

Key: (1). kg/m² or mm H_2C.

where m - an exponent; when $\varepsilon = \frac{t_2}{d} \geqslant 1{,}24$

$$m = 0{,}88\left(\frac{t_1/d-1}{t_2/d-1} - 0{,}1\right)^{0{,}138} - 1;$$

when $\varepsilon = \frac{t_2}{d} < 1{,}24$

$$m = 0{,}88\left(\frac{t_2/d}{1{,}24}\right)^{0{,}7}\left(\frac{t_1/d-1}{t_2/d-1} - 0{,}1\right)^{0{,}138} - 1.$$

Resistance, which considers correction for a change in velocity head in connection with a change in the temperature,

$$\Delta p_t = \frac{2(t_в'' - t_в')}{273 + t_{ср}} \frac{\gamma v_{ср}^2}{2g}\ \text{кг/м}^2 \text{ или мм вод. ст.} \quad (200)$$

Key: (1). kg/m² or mm H_2C.

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Here d - outside diameter of tubes, cm; t_1 - space of tubes in the series/row (in the width of beam), cm; t_2 - space of the tubes between the series/rows (in the depth of beam), cm; t'_2 - diametric space of tubes, cm; z - number of series/rows of tubes in the beam; v - greatest rate in the beam, m/s; $v_{ср}$ - average/mean air speed, m/s; g=9.81 m/s² - acceleration of gravity γ - the specific gravity/weight

of air, kg/m³; $t'_в$ - temperature of air upon the entrance, °C; $t''_в$ - temperature of air on leaving °C; Re - Reynolds number.

Formulas (196)-(200) are applied with Re from 6000 to 60000 and on spacings between tubes:

1) for the checkered beams

$$0{,}25 < \frac{1-\frac{d}{t_2}}{\frac{t_1}{d}-1} < 2{,}5;$$

2) for the corridor beams

$$0{,}2 < \frac{\frac{t_2}{d}-0{,}8}{\frac{t_1}{d}-1} < 6{,}5.$$

Formulas (196)-(200) are valid for resistances at the angle of attack $\psi=90°$. With a decrease of the angle of attack of resistance decrease. The values of correction factor $\varepsilon=\frac{\Delta p_\psi}{\Delta p_{90}}$ are given in Table 19.

Steam resistance of the capacitors:

$$\Delta p = \mu \frac{u^2}{v} \text{ мм рт. ст.}^{(1)}, \qquad (201)$$

Key: (1). Hg.

where u - velocity of vapor in the capacitor, m/s [see formula (86)]; v - specific volume of vapor, m³/kg; μ - coefficient of steam resistance:

For the nonregenerative capacitors with the laying cut of the tube plate on the triangle ... 0.04.

For the nonregenerative capacitors from the combined by laying out tube plate ... 0.03.

For the regenerative capacitors with the laying out of the tube plate on the triangle ... 0.018.

For the regenerative capacitors from the combined by laying cut tube plate ... 0.012.

Table 19. Values of correction factor ε for the angle of attack.

ψ°	90	80	70	60	50	40	30	10
ε	1	1	0,95	0,83	0,69	0,53	0,38	0,15

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Maximum permissible resistance of capacitor. Normally the value of steam resistance of capacitor must not exceed the data, given in Table 20.

Precise calculation of resistances cannot be fulfilled virtually. In the critical cases resistance must be determined experimentally.

Table 20. Steam resistance of capacitor.

(1) Диаметр конденсатора D, м	1,8	2,4	3,0	(2) Свыше 3,0
(3) Допускаемое сопротивление Δp, мм рт. ст.	3,8	4,5	5,0	6,5

Key: (1). Diameter of capacitor D, m. (2). It is more than. (3). Permissible resistance Δp, mm Hg.

§23. Coefficients of friction drag.

Coefficients of friction drag can be determined according to the following formulas.

For the liquids:

1) laminar flow - Reynolds number $Re \leqslant 2200$

$$\lambda = \frac{64}{Re}; \qquad (202)$$

2) duct with the smooth walls - Reynolds number $Re \leqslant 100000$

$$\lambda = \frac{0.3164}{\sqrt[4]{Re}}, \qquad (203)$$

where Re - Reynolds number - see formula (188).

The values of coefficient λ, calculated according to formula (203), are given in Table 21.

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Table 21. Values of coefficient λ.

Re 10^{-3}	λ	Re 10^{-3}	λ	Re 10^{-3}	λ	Re 10^{-3}	λ	Re 10^{-3}	λ
2	0,0472	10	0,0316	50	0,0212	250	0,0142	700	0,0109
3	0,0427	15	0,0295	60	0,0202	300	0,0135	800	0,0106
4	0,0401	20	0,0266	70	0,0195	350	0,0130	1000	0,0100
5	0,0376	25	0,0252	80	0,0188	400	0,0126	1500	0,0094
6	0,0359	30	0,0240	100	0,0177	450	0,0121	2000	0,0084
7	0,0346	35	0,0231	150	0,0161	500	0,0119	2500	0,00795
8	0,0335	40	0,0224	200	0,0150	600	0,0114	3000	0,0076

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Fig. 61 gives nomogram for determining the losses of pressure in the dependence on the speed of water and diameter of smooth tubes.

For the oil-products:

$$\lambda = 0{,}02 + \frac{1{,}7}{\sqrt{Re}}. \qquad (204)$$

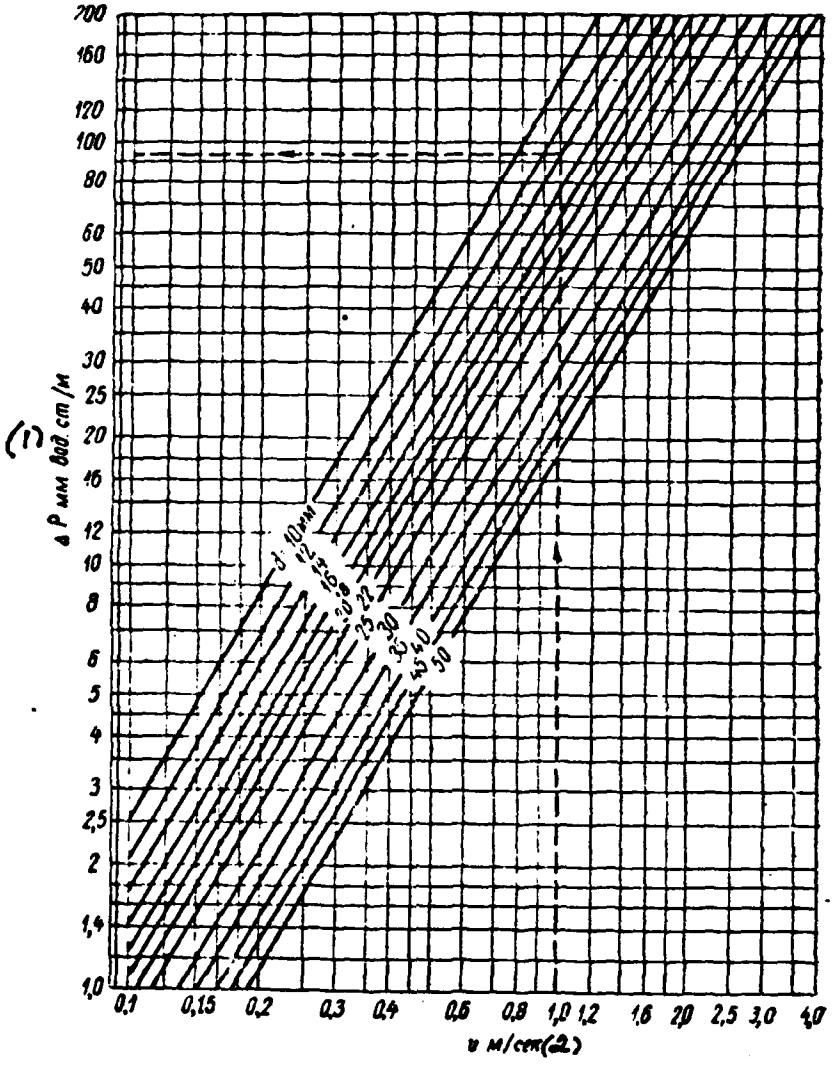

Fig. 61. Nomogram for determining the losses of head in the smooth tubes in depending on the speed of water and diameter of tubes.

Key: (1). water, cm/m. (2). m/s.

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For the air:

$$\lambda = 0{,}0125 + \frac{0.0011}{d}, \qquad (205)$$

where d - an inner diameter of tube, mm.

For the water vapor with Re from $0.5 \cdot 10^6$ to $7 \cdot 10^6$ and for liquid with Re>100000

$$\lambda = \frac{1}{\left(1.74 + 2\lg \frac{r}{k}\right)^2}, \qquad (206)$$

where r - an inside radius of tube, mm; k=0.064-0.10 - absolute roughness, mm.

For the gases and the water vapor with tubes with the rough walls and Reynolds number Re<500000

$$\lambda = \frac{0{,}08186}{d^{0.133}} \mathrm{Re}^{-0.148}, \qquad (207)$$

where d - an inner diameter of tube, mm.

For simplicity of calculation we convert formula (207):

$$\lambda = \frac{\lambda_1}{\lambda_2}; \quad \lambda_1 = \frac{0{,}08186}{d^{0.133}}; \quad \lambda_2 = \mathrm{Re}^{0.148}.$$

The values λ_1 and λ_2, calculated according to the obtained formulas, are given in tables 22 and 23.

Table 22. Values λ_1.

d	λ_1	d	λ_1	d	λ_1	d	λ_1	d	λ_1
0,005	0,1656	0,070	0,1167	0,135	0,1068	0,200	0,1015	0,28	0,0970
0,010	0,1511	0,075	0,1156	0,140	0,1063	0,205	0,1011	0,29	0,0965
0,015	0,1431	0,080	0,1147	0,145	0,1058	0,210	0,1008	0,30	0,0961
0,020	0,1378	0,085	0,1136	0,150	0,1054	0,215	0,1005	0,31	0,0957
0,025	0,1346	0,090	0,1128	0,155	0,1050	0,220	0,1002	0,32	0,0953
0,030	0,1305	0,095	0,1121	0,160	0,1046	0,225	0,0999	0,33	0,0949
0,035	0,1279	0,100	0,1113	0,165	0,1041	0,230	0,0996	0,34	0,0945
0,040	0,1256	0,105	0,1105	0,170	0,1037	0,235	0,0993	0,35	0,0941
0,045	0,1237	0,110	0,1098	0,175	0,1033	0,240	0,0990	0,36	0,0938
0,050	0,1219	0,115	0,1092	0,180	0,1028	0,245	0,0987	0,37	0,0934
0,055	0,1205	0,120	0,1086	0,185	0,1025	0,250	0,0985	0,38	0,0931
0,060	0,1191	0,125	0,1080	0,190	0,1022	0,255	0,0980	0,39	0,0928
0,065	0,1178	0,130	0,1074	0,195	0,1018	0,260	0,0975	0,40	0,0925

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For the flexible hoses:

$$\lambda = 2gk, \qquad (208)$$

where g - acceleration of gravity m/s²; k - coefficient, equal to:

For the very smooth rubber hoses ... 0.00086.

For the usual rubber hoses ... 0.000899.

For very smooth ones within the rubberized hoses/pipes ... 0.000884.

For very rough rubberized hoses/pipes 0.00163.

For the usual hemp hoses/pipes ... 0.00213.

For the best leather hose/pipe ... 0.00317.

Table 23. Values λ_2.

Re 10^{-3}	λ_2	Re 10^{-3}	λ_2	Re 10^{-3}	λ_2	Re 10^{-3}	λ_2	Re 10^{-3}	λ_2
4	3,413	21	4,364	38	4,762	55	5,032	90	5,412
5	3,527	22	4,391	39	4,782	56	5,042	100	5,496
6	3,623	23	4,424	40	4,799	57	5,085	110	5,572
7	3,707	24	4,447	41	4,815	58	5,070	120	5,647
8	3,783	25	4,474	42	4,832	59	5,083	130	5,709
9	3,847	26	4,502	43	4,851	60	5,096	140	5,781
10	3,909	27	4,528	44	4,867	61	5,107	150	5,833
11	3,964	28	4,550	45	4,883	62	5,120	160	5,894
12	4,014	29	4,573	46	4,899	63	5,131	170	5,944
13	4,063	30	4,596	47	4,918	64	5,143	180	5,998
14	4,110	31	4,621	48	4,932	65	5,156	190	6,044
15	4,150	32	4,642	49	4,945	66	5,168	200	6,091
16	4,189	33	4,663	50	4,963	67	5,179	250	6,295
17	4,227	34	4,684	51	4,975	68	5,192	300	6,464
18	4,266	35	4,704	52	4,989	69	5,202	400	6,747
19	4,297	36	4,722	53	5,008	70	5,214	500	6,974
20	4,331	37	4,742	54	5,015	80	5,319	600	7,163

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§ 24. Coefficients of local resistances.

1. Values of coefficients of local resistances in intertube space of apparatus without partitions/baffles with course of medium in perpendicular direction to location of tubes can be determined:

1) with turbulent and viscous motion of gas

$$\zeta = 3m\left(\frac{\mu}{dv\rho}\right)^{0,2} \qquad (209)$$

or

$$\zeta = 3m\left(\frac{1}{\mathrm{Re}}\right)^{0.2};$$

2) with turbulent motion of liquid

$$\zeta = 4f\frac{l}{d_h}; \qquad (210)$$

3) with viscous motion of liquid

$$\zeta = 106\frac{l}{d_h}\frac{\mu}{vd_h\rho}. \qquad (211)$$

Here m - number of series/rows of tubes, arranged/located perpendicularly to the flow of the medium;

μ - the absolute viscosity of medium, kg•s/m²;

a=t-d - distance (clearance) between the series/rows of tubes, m (here t - space of tubes, m; d - outside diameter of tubes, m);

v - the maximum speed of the medium through the minimum cross section, m/s;

ρ - density of medium, kg•s²/m⁴;

Re - Reynolds number [in the formula (188)]:

f - coefficient of external friction (according to the data of Table 24);

l - length of the beam of tubes in the direction of flow, m;

d_h - hydraulic diameter, m [according to the formula (173)].

2. Values of coefficients of local resistances for local obstructions of heat exchangers can be accepted on Table 25.

Table 24. Values of the coefficient of external friction f.

Re	f при охлаждении (1)	f при t=const (2)	f при нагревании (3)	Re	f при охлаждении (1)	f при t=const (2)	f при нагревании (3)
2	30,6	11,3	6,58	1 000	0,153	0,141	0,136
10	5,85	2,47	1,67	5 000	0,104	0,111	0,104
50	1,17	0,565	0,447	10 000	0,098	0,102	0,095
100	0,630	0,315	0,275	15 000	0,093	0,095	0,087
200	0,364	0,212	0,193	20 000	0,088	0,090	0,082
500	0,204	0,156	0,153				

Key: (1). during the cooling. (2). with. (3). during heating.

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The recommended in Table 25 coefficients of local resistances are referred to the speed of medium in the tubes or between the tubes.

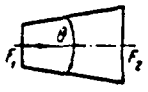
3. Values of coefficients of local resistances for different local obstructions of manifolds can be determined according to tables 26. These coefficients are given for the speed of medium after the local obstruction.

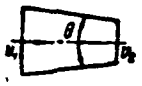
Table 25. Values of the coefficients of local resistances ζ.

(1) Наименование местного препятствия в аппарате	(2) Значение коэффициента
(3) Входные и выходные камеры	1,5
(4) Поворот на 180° внутри камеры при переходе из одного пучка трубок в другой	2,5
(5) Поворот на 180° при переходе из одной секции в другую через колено	2,0
(6) Вход в межтрубное пространство перпендикулярно трубкам	1,5
(7) Переход из одной секции в другую под углом в 90° в межтрубном пространстве	2,5
(8) Поворот на 180° около тонкой перегородки внутри межтрубного пространства	1,5
(9) Поворот на 180° в V-образной трубке	0,5
(10) Огибание перегородок, поддерживающих трубки	0,5
(11) Выход из межтрубного пространства под углом 90°	1,0

Key: (1). Designation of local obstruction in the apparatus. (2). Value of coefficient. (3). Input and downstream chambers. (4). Rotation on 180° within chamber/camera upon transfer of one beam of tubes in another. (5). Rotation on 180° upon transfer of one section to another through elbow. (6). Entrance into intertube space it is perpendicular to tubes. (7). Transition of one section to another at angle of 90° in intertube space. (8). Rotation on 180° about thin partition/baffle within intertube space. (9). Rotation on 180° in V-shaped tube. (10). Bending of partitions/baffles, which support tubes. (11). Output from intertube space at angle of 90°.

Page 129. Table 26. Coefficients of local line resistance.

(1) Наименование и эскиз	(2) Формулы и таблицы значений коэффициента ζ									
(3) Переходный расходящийся конус 	$\zeta = k\left(\frac{F_2}{F_1} - 1\right)^2$									
	θ	k	θ	k	θ	k	θ	k	θ	k
	5°	0,13	20°	0,41	45°	0,98	70°	1,13	100°	1,06
	10°	0,17	30°	0,71	50°	1,03	80°	1,10	120°	1,05
	15°	0,26	40°	0,90	60°	1,12	90°	1,07	140°	1,04

(4) Переходный сходящийся конус 	θ	7°	10°	15°	20°	25°	30°	35°	40°
	ζ	0,16	0,16	0,18	0,20	0,22	0,24	0,26	0,28
	θ	45°	50°	55°	60°	65°	70°	75°	80°
	ζ	0,30	0,31	0,31	0,32	0,33	0,34	0,34	0,35

(5) Внезапное расширение	$\zeta = \left(1 - \frac{F_1}{F_2}\right)^2$											
	$\frac{F_1}{F_2}$	1	0,9	0,8	0,7	0,6	0,5	0,4	0,3	0,2	0,1	0
	ζ	0	0,01	0,04	0,09	0,16	0,25	0,36	0,49	0,64	0,81	1

(6) Внезапное сужение	$\frac{F_2}{F_1}$	0,01	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
	ζ	0,5	0,47	0,42	0,38	0,34	0,30	0,25	0,20	0,15	0,09	0

continuation Table 26.

(7) Диафрагма в трубе	$\frac{F_0}{F_2}$	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
	ζ	226	47,8	17,5	7,8	3,75	1,80	0,80	0,29	0,06	0,00
(9) Диафрагма при входе в трубу	(8) а) случай „совершенного" сжатия ($F_1 > 20F_0$)										
	$\frac{F_0}{F_2}$	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
	ζ	232	51,0	19,8	9,61	5,26	3,08	1,88	1,17	0,73	0,48
	(10) б) случай „несовершенного" сжатия ($F_1 < 20F_0$) $\zeta = \left(\frac{F_2}{EF_0} - 1\right)^2$ (значение E определено ниже)										
	$\frac{F_0}{F_2}$	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
	E	0,62	0,63	0,64	0,66	0,68	0,71	0,76	0,81	0,89	1,0

Key: (1). Designation and draft. (2). Formulas and table of values of coefficient. (3). Transient divergent cone. (4). Transient convergent cone. (5). Sudden expansion. (6). Sudden contraction. (7). Diaphragm in duct. (8). case of "ideal" compression. (9). Diaphragm upon entrance into duct. (10). case of "inadequate" compression ($F_1<20F_0$) $\zeta=(F_2/EF_0-1)^2$ (value E is determined below).

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§ 25. Discharge coefficients.

During the discharge the liquids from the openings/apertures of various forms take the place of the losses, which decrease the real fluid flow rate, computed from formula (89), and the real discharge velocity, determined according to formula (78).

These losses depend on the compression of liquid jet, i.e. by the decrease of section, and by the appearance of friction in the opening/aperture with the discharge from it of real liquid.

Real expenditure and speed of liquid are calculated taking into account the losses which are estimated by means of the introduction to calculation formulas (78) and (89) discharge coefficients in the form of factors.

By the discharge coefficient they imply:

1. The contraction coefficient ε, equal to the ratio of the sectional area of jet to the area of the opening/aperture from which escape/ensues liquid.

2. Velocity coefficient φ, equal to ratio of real discharge velocity to theoretical taking into account friction in

opening/aperture.

3. Coefficient of expenditure μ, equal to product of contraction coefficients and speed.

4. Drag coefficient ζ, determined in § 24.

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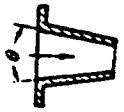
Table 27. Values of discharge coefficients.

(1) Наименование и эскиз	(2) Значения коэффициентов			
	μ	φ	ε	ζ
(3) Отверстие в тонкой стенке	0,62	0,97	0,64	0,06
(4) Длинный насадок Вентури	0,82	0,82	1,0	0,5
(5) Насадок	0,48	0,48	1,0	—
(6) Насадок Борда	0,71	0,71	1,0	1,0
(7) Насадок по форме сжатой струи	0,97	0,97	1,0	—

(8) Насадок Вентури под углом	θ	0°	10°	20°	30°	40°	50°	60°
	μ	0,815	0,80	0,782	0,764	0,731	0,731	0,719

(10) Конический насадок	(9) Наилучший угол конусности 13°							
	θ	μ	φ	ε	θ	μ	φ	ε
	0°	0,829	0,829	—	16°	0,938	0,969	—
	1°	0,852	0,852	—	20°	0,922	0,971	—
	3°	0,892	0,892	—	25°	0,908	0,974	—
	5°	0,92	0,92	1,0	30°	0,896	0,975	—
	10°	0,937	0,949	—	35°	0,883	0,977	—
	13°	0,945	0,961	0,99	45°	0,857	0,883	0,88

The designations: μ - coefficient of the expenditure; φ - velocity coefficient; ζ - drag coefficient; ε - contraction coefficient.

Key: (1). Designation and draft. (2). Values of coefficients. (3). Opening/aperture in thin wall. (4). Venturi's long nozzle. (5). Nozzle. (6). Borda mouthpiece. (7). Nozzle in form of compressed jet. (8). Venturi's nozzle at angle. (9). Best angle of taper. (10). Conical nozzle.

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The values of discharge coefficients for the various forms of openings/apertures and nozzle are given in table 27, dependence

in Table

between the coefficients ζ and ϕ 28, between the coefficients μ, ϕ and ε - in the formulas:

$$\mu = \varepsilon\varphi; \quad \varphi = \sqrt{\frac{1}{1+\zeta}}; \quad \varepsilon = \frac{F_1}{F_2}, \qquad (212)$$

where F_1 - an area of contracted section; F_2 - area of opening/aperture.

The values of coefficients for the small openings are close to the following: ζ=0.06; ϕ=0.97; ε=0.64; μ=0.62.

Table 28. Dependence between the coefficients ζ and ϕ.

ζ	φ	ζ	φ	ζ	φ	ζ	φ	ζ	φ	ζ	φ
0,02	0,99	0,15	0,93	0,50	0,82	1,50	0,63	4,50	0,43	9,00	0,32
0,04	0,98	0,18	0,92	0,60	0,80	2,00	0,58	5,00	0,41	10,0	0,30
0,06	0,97	0,20	0,91	0,70	0,77	2,50	0,54	5,50	0,39		
0,08	0,96	0,25	0,89	0,80	0,75	3,00	0,50	6,00	0,38		
0,10	0,95	0,30	0,88	0,90	0,73	3,50	0,47	7,00	0,35		
0,13	0,94	0,40	0,85	1,00	0,71	4,00	0,45	8,00	0,33		

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Chapter IV.

EXAMPLES OF THE CALCULATIONS OF RESISTANCES IN APPARATUSES.

§ 26. Calculation of resistances in the tube part of the apparatuses.

Hydraulic resistance of capacitor.

Initial data for the calculation (from the thermal design).

Expenditure of cooling water D=150 t/h.

Speed of cooling water in the tubes with v_1=1.6 m/s.

Mean temperature of cooling water t_{cp} =24.2°C.

The specific gravity/weight of cooling water γ=1.025 t/m³.

Number of courses of water in tubes z=2.

Length of the tubes between the tube plates l=1.35 m.

The thickness of the tube plate is s=0.02 m.

Inner diameter of tubes $d_в$ =0.014 m.

Course of computation.

1. Inner diameter of inlets and yield of water is taken d_1=0.15 m.

2. Speed of cooling water in branch pipes

$$v_2 = \frac{D}{2825 d_1^2 \gamma} = \frac{150}{2825 \cdot 0,15^2 \cdot 1,025} = 2,3 \text{ м/сек.}$$ (1)

Key: (1). m/s.

3. Overall length of tubes

$$L = l + 2s = 1,35 + 2 \cdot 0,02 = 1,39 \text{ м.}$$

4. Value of correction factor β for mean temperature and speed of cooling water (on graph/curve Fig. 56): β=0.965.

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5. Hydraulic resistance of capacitor

$$h = z\left(0{,}031\frac{L}{d_в}\frac{v_1^2}{2g}\beta + 1{,}4\frac{v_1^2}{2g}\right) + \frac{v_2^2}{2g} =$$
$$= 2\left(0{,}031\frac{1{,}39}{0{,}014}\cdot\frac{1{,}6^2}{2\cdot 9{,}81}0{,}965 + 1{,}4\frac{1{,}6^2}{2\cdot 9{,}81}\right) + \frac{2{,}3^2}{2\cdot 9{,}81} =$$
$$= 1{,}41 \text{ м вод. ст.}$$

(1)

Key: (1). water column.

Hydraulic resistance of capacitor according to the formula VTI:

$$h = z(bLv_1^{1,75} + 0{,}135v_1^{1,5}) =$$
$$= 2(0{,}138\cdot 1{,}39\cdot 1{,}6^{1,75} + 0{,}135\cdot 1{,}6^{1,5}) = 1{,}48 \text{ м water column},$$

where b=0.138 - the coefficient, depending on the diameter of tubes $d_в$ and mean temperature of cooling water $t_{ср}$, determined on table 18.

Hydraulic heater resistance of feed water.

Initial data for the calculation (from the thermal design).

Speed of water in the tubes with v_1=1.7 m/s.

The specific gravity/weight of water γ=0.974 t/m³.

Number of courses of water in tubes z=6.

Average/mean length of tubes in the course of l=1.8 m.

The thickness of the tube plate is s=0.5 m.

Inner diameter of tube $d_в$ =0.013 with m.

Reynolds number Re=56800.

Course of computation.

1. Overall length of tube in course

$$L = l + 2s = 1{,}8 + 2 \cdot 0{,}05 = 1{,}9.$$

2. Coefficient of friction drag for water

$$\lambda = \frac{0{,}3164}{\sqrt[4]{Re}} = \frac{0{,}3164}{\sqrt[4]{56\,800}} = 0{,}0205.$$

3. Losses to friction in straight/direct section of tubes

$$\Delta p_1 = \lambda \frac{zL}{d_в} \frac{v_{IT}^2}{2g} = 0{,}0205 \frac{6 \cdot 1{,}9}{0{,}013} \cdot \frac{1{,}7^2 \cdot 974}{2 \cdot 9{,}81} = 2600 \text{ кг/м}^2. \quad (1)$$

Key: (1). kg/m².

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4. Local losses during rotation on 180° in V-shaped tube

$$\Delta p_2 = \zeta_1 \frac{z v_{IT}^2}{2 \cdot 2g} = 0{,}5 \frac{6 \cdot 1{,}7^2 \cdot 974}{2 \cdot 2 \cdot 9{,}81} = 215 \text{ kg/m}^2,$$

where ζ_1=0.5 - drag coefficient during rotation in V-shaped tube (on Table 25).

5. Local losses to rotation in chambers/cameras upon transfer of

one beam of tubes in another

$$\Delta p_3 = \zeta_2 \frac{z}{3} \frac{v_1^2 \gamma}{2g} = 2{,}5 \frac{6}{3} \cdot \frac{1{,}7^2 \cdot 974}{2 \cdot 9{,}81} = 717 \ kg/m^2,$$

where ζ_2=2.5 - drag coefficient to rotation in chambers/cameras (on table 25).

6. Local losses in input and downstream chambers

$$\Delta p_4 = \zeta_2 2 \frac{v_1^2 \gamma}{2g} = 1{,}5 \cdot 2 \cdot \frac{1{,}7^2 \cdot 974}{2 \cdot 9{,}81} = 430 \ kg/m^2,$$

where ζ_2=1.5 - drag coefficient in input and downstream chambers (on table 25).

7. Hydraulic heater resistance of feed water

$$h = (\Delta p_1 + \Delta p_2 + \Delta p_3 + \Delta p_4) \cdot 10^{-3} =$$
$$= (2600 + 215 + 717 + 430) \cdot 10^{-3} = 3{,}962 \ м \ water \ column.$$

Hydraulic heater resistance of fuel/propellant.

Initial data for the calculation (from the thermal design).

Brand of the petroleum residue: sailor M20.

Speed of petroleum residue in the tubes with retarders v=0.83 m/s.

Mean temperature of petroleum residue t_{cp}° =55°C.

Inner diameter of V-shaped tube $d_в$ =0.013 with m.

Average/mean length of tubes in the course of l=1.03 m.

Number of courses of petroleum residue in tubes z=6.

The thickness of the tube plate is s=0.035 m.

Course of computation.

1. Overall length of tube in course

$$L = l + 2s = 1{,}03 + 2 \cdot 0{,}035 = 1{,}1 \text{ м}.$$

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2. Losses of head on 1 lin. m in tubes with retarders and chambers/cameras in depending on speed v and mean temperatures $t_{ср}$ of petroleum residue of М20 are determined on graph/curve Fig. 59:

$$\Delta p = 0{,}21 \text{ кг/см}^2 \cdot \text{м}. \quad (1)$$

Key: (1). kg/cm²•m.

3. Hydraulic heater resistance of fuel/propellant

$$h = \Delta p L z = 0{,}21 \cdot 1{,}1 \cdot 6 = 1{,}39 \text{ kg/cm}^2.$$

Steam resistance of steam cooler.

Initial data for the calculation (from the thermal design).

The speed is steam in tubes $v_n = 49$ m/s.

Specific gravity/weight is steam $\gamma_n = 3.22$ kg/m³.

Number of courses of steam in tubes z=2.

Average/mean length of tubes in the course of $l = 0.53$ m.

Inner diameter of V-shaped tube $d_в = 0.013$ m.

The thickness of the tube plate is s=0.025 m.

Number of Reynolds Re=108500.

Course of computation.

1. Overall length of tube in course

$$L = l + 2s = 0{,}53 + 2 \cdot 0{,}025 = 0{,}58 \text{ м}.$$

2. Coefficient of friction drag

$$\lambda = \frac{0{,}08186}{d_в^{0{,}133}} \mathrm{Re}^{-0{,}148} = \frac{0{,}08186}{0{,}013^{0{,}133}} 108\,500^{-0{,}148} = 0{,}0263.$$

3. Loss to friction in straight/direct section of tubes

$$\Delta p_1 = \lambda \frac{zL}{d_э} \frac{v_п^2 \gamma_п}{2g} = 0{,}0263 \frac{2 \cdot 0{,}58}{0{,}013} \cdot \frac{49^2 \cdot 3{,}22}{2 \cdot 9{,}81} = 923 \text{ kg/m}^2.$$

4. Drag coefficient to rotation of steam in tubes (on Table 25) $\zeta_1 = 0.5$.

5. Local losses during rotation of steam in tubes

$$\Delta p_2 = \zeta_1 \frac{v_п^2 \gamma_п}{2g} = 0{,}5 \frac{49^2 \cdot 3{,}22}{2 \cdot 9{,}81} = 197 \text{ kg/m}^2.$$

6. Drag coefficient in input and downstream chambers (on Table 25) $\zeta_1 = 1.5$.

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7. Local losses with entrance into chambers/cameras and output of them

$$\Delta p_3 = \zeta_2 \frac{2 v_п^2 \gamma_п}{2g} = 1{,}5 \frac{2 \cdot 49^2 \cdot 3{,}22}{2 \cdot 9{,}81} = 1180 \text{ kg/m}^2.$$

8. Steam resistance of steam cooler

$$\Delta p = (\Delta p_1 + \Delta p_2 + \Delta p_3)\, 10^{-4} =$$
$$= (923 + 197 + 1180)\, 10^{-4} = 0{,}23 \text{ kg/cm}^2.$$

§ 27. Calculation of resistances in the intertube space of apparatuses.

Steam resistance of capacitor.

Initial data for the calculation (from the thermal design).

Quantity of that condensing steam G_1=2700 kg/h.

Quantity of condensate, which enters the capacitor, G_2=1640 kg/h.

Enthalpy of condensate q_2=133.4 kcal/kg.

Condensation temperature of steam t_s =53.6°C.

Inner diameter of the housing of capacitor $D_к$=0.592 m.

Outside diameter of tubes $d_н$ =0.016 m.

Space of the location of the tubes with t=0.026 m.

Distance between the tube plates l=1.35 m.

Solidity/loading factor of tube plate $\eta_{тр}$=0.73.

We determine (on table 1-3 of applications/appendices).

Heat of vaporization when t_s, equal to r=566.9 kcal/kg.

Specific volume of steam when t_s, equal to v_s =10.2 m³/kg.

Course of computation.

1. Quantity of that is formed from condensate,

$$G_2 = \frac{G_2(q_2 - t_s)}{r} = \frac{1640(133,4 - 53,6)}{566,9} = 230 \text{ кг/час.}$$ (1)

Key: (1). kg/h.

2. Total quantity of steam in capacitor

$$G = G_1 + G_2 = 2700 + 230 = 2930 \text{ kg/h.}$$

3. Speed of condensable steam in capacitor

$$v = \frac{Gv_s}{3600 D_в l \left(1 - \frac{d_н}{t}\sqrt{\tau_{тр}}\right)} =$$

$$= \frac{2930 \cdot 10,2}{3600 \cdot 0,592 \cdot 1,35 \left(1 - \frac{0,016}{0,026}\sqrt{0,73}\right)} = 22 \text{ m/s}.$$

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4. Coefficient of steam resistance for nonregenerative capacitors with laying out of tubes in triangle according to given

formula (201) $\mu=0.04$.

5. Steam resistance of capacitor

$$\Delta p=\mu\frac{v^2}{v_s}=0{,}04\,\frac{22^2}{10{,}2}=1{,}9\ \text{мм рт. ст.}\ (1)$$

Key: (1). Hg.

Hydraulic resistance of steam cooler.

Initial data for the calculation (from the thermal design).

Speed of water in steam cooler $v_в=0.79$ m/s.

Inner diameter of housing $D_в=0.28$ m.

Area for the passage of water in the intertube space f=0.01875 m.

Number of tubes in course n=53.

Outside diameter of tubes $d_н=17$ mm.

Average/mean length or the beam of semi-V-shaped tubes with l=0.53 m.

Number of courses of water in housing z=2.

The specific gravity/weight of water $\gamma_в$ =937.3 kg/m³.

Dynamic viscosity of water μ=22.2•10^{-6} kg•s/m².

Course of computation.

1. Equivalent hydraulic diameter of one course (half intertube space)

$$d_э = \frac{4f}{\pi(0,5D_к + d_w n) + D_к} =$$
$$= \frac{4 \cdot 0.01875}{3,14\,(0,5 \cdot 0,28 + 0,017 \cdot 53) + 0,28} = 0,0209\ м.$$

2. Reynolds number for water

$$Re = \frac{v_в d_э \gamma_в}{\mu g} = \frac{0,79 \cdot 0,0209 \cdot 937,3}{22,2 \cdot 10^{-6} \cdot 9,81} = 71\,000.$$

3. Coefficient of friction drag for water

$$\lambda = \frac{0.3164}{\sqrt[4]{Re}} = \frac{0.3164}{\sqrt[4]{71\,000}} = 0,01935.$$

4. Losses to friction in straight/direct sections of intertube space

$$\Delta p_1 = \lambda \frac{zl}{d_э} \frac{v_в^2 \gamma_в}{2g} = 0,01935 \frac{2 \cdot 0,53}{0,0209} \cdot \frac{0,79^2 \cdot 937,3}{2 \cdot 9,81} = 29,3\ кг/м^2.$$

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5. Drag coefficient during rotation on 180° in intertube space

(on Table 25) $\zeta_1=1.5$.

6. Local losses during rotation of flow on 180°

$$\Delta p_2=\zeta_1\frac{v_s^2\gamma_0}{2g}=1{,}5\,\frac{0{,}79^2\cdot 937{,}3}{2\cdot 9{,}81}=44{,}7\ \text{kg/m}^2.$$

7. Drag coefficient upon entrance into intertube space (on Table 25) $\zeta_2=1.5$.

8. Drag coefficient on leaving from intertube space (on Table 25) $\zeta_3=1.0$.

9. Local entry loss into intertube space and output from it

$$\Delta p_3=(\zeta_2+\zeta_3)\frac{v_s^2\gamma_0}{2g}=(1{,}5+1{,}0)\,\frac{0{,}79^2\cdot 937{,}3}{2\cdot 9{,}81}=74{,}5\ \text{kg/m}^2.$$

10. Hydraulic resistance of steam cooler

$$h=(\Delta p_1+\Delta p_2+\Delta p_3)\,10^{-3}=$$
$$=(29{,}3+44{,}7+74{,}5)\,10^{-3}\approx 0{,}15\ \text{м water column}.$$

Hydraulic resistance of oil cooler.

Initial data for the calculation (from the thermal design).

Productivity of oil cooler D=16 t/h.

The length of the edge (chord) of partition/baffle is s=0.366 m.

Space of the location of the tubes with t=13.5 mm.

Outside diameter of tubes d_u=10 with mm.

Distance between the housing and wing tubes with y_0=15.3 mm.

Number of series/rows of tubes, intersected by flow, m=18.

Number of gaps/intervals between partitions/baffles n=12.

Distance between the partitions/baffles h=0.094m.

The average speed of oil between the partitions/baffles v_1=0.307 m/s.

The average speed of oil above the partitions/baffles v_2=0.307 m/s.

Kinematic viscosity of oil of brand T at mean temperature $v=57 \cdot 10^{-6}$ m^2/s.

The specific gravity/weight of oil at mean temperature γ=879 kg/m^3.

Area of section for the passage of oil above partitions/baffles $f_2=0.0164$ m².

Course of computation.

1. Size/dimension of clear opening for passage of oil at edge of partition/baffle

$$b = s - \frac{s - 2y_0 - d_н}{t} d_н =$$
$$= 0{,}366 - \frac{0{,}366 - 2\cdot 0{,}0153 - 0{,}01}{0{,}0135} 0{,}01 = 0{,}116 \text{ м}.$$

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2. Sectional area for passage of oil at edge of partition/baffle

$$f_1 = bh = 0{,}116\cdot 0{,}094 = 0{,}0109 \text{ м}^2.$$

3. Speed of oil at edge of partition/baffle

$$v = \frac{D}{3600 f_1 \gamma} = \frac{16}{3600\cdot 0{,}0109\cdot 0{,}879} = 0{,}462 \text{ m/s}.$$

4. Function of Reynolds number

$$f = 0{,}75\left[\frac{v(t - d_н)}{\nu}\right]^{-0{,}2} = 0{,}75\left[\frac{0{,}462(0{,}0135 - 0{,}01)}{57\cdot 10^{-6}}\right]^{-0{,}2} = 0{,}384.$$

5. Losses of head of oil in passages between partitions/baffles

$$\Delta p_1 = \frac{4 f m v^2 \gamma n}{2g} = \frac{4\cdot 0{,}384\cdot 18\cdot 0{,}462^2\cdot 879\cdot 12}{2\cdot 9{,}81} = 3200 \text{ kg/m}^2.$$

6. Losses of head of oil during flow through partitions/baffles

$$\Delta p_2 = 0{,}0815 v_{21}^2 \gamma (n - 1) = 0{,}0815\cdot 0{,}307^2\cdot 879 (12 - 1) = 74 \text{ kg/m}^2.$$

7. Losses of head of oil with entrance into intertube space and output from it

$$\Delta p_3 = (\zeta_1 + \zeta_2)\frac{v_1^2 \gamma}{2g} = (1{,}5 + 1{,}0)\frac{0{,}307^2\cdot 879}{2\cdot 9{,}81} = 10{,}6 \text{ kg/m}^2.$$

ζ_1=1.5 - drag coefficient upon entrance into intertube space (on table 25); ζ_2=1.0 - drag coefficient on leaving from intertube space (on table 25).

8. Resistance in intertube space (oil cavity) of oil cooler

$$\Delta p = (\Delta p_1 + \Delta p_2 + \Delta p_3)\,10^{-4} =$$
$$= (3200 + 74 + 10{,}6)\,10^{-4} = 0{,}33 \text{ kg/cm}^2.$$

Aerodynamic drag of air cooler.

Initial data for the calculation (from the thermal design).

Outside diameter of tubes $d_н$ =16 mm.

Space of tubes in the series/row (in the width of beam) t_1=22 mm.

Space of tubes in the depth of beam t_2=20 mm.

Number of series/rows of tubes in beam z=16.

Average/mean air speed in the coolant v=14.6 m/s.

Temperature of air upon entrance t_1=27°C.

Temperature of air on leaving t_2=18°C.

Mean temperature in coolant t_{cp} =22.5°C.

The specific gravity/weight of air γ=1.155 kg/m³.

Reynolds number Re=14700.

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Course of computation.

1. Diameter pitch of tubes of checkered bundle

$$t=\sqrt{\left(\frac{t_1}{2}\right)^2+t_2^2}=\sqrt{\left(\frac{22}{2}\right)^2+20^2}=22{,}9\ \text{мм}.$$

2. Value

$$\varepsilon=\frac{1-d_w/t}{t_1/d_w-1}=\frac{1-16/22{,}9}{22/16-1}=0{,}8>0{,}53.$$

3. Resistance in checkered bundle of ducts, washed by cross flow of air, when ε >0.53

$$\Delta p_1=3{,}86\,(z+1)\sqrt{\varepsilon}\,\mathrm{Re}^{-0{,}25}\frac{v^2\gamma}{2g}=$$

$$=3{,}86\,(16+1)\sqrt{0{,}8}\cdot 14700^{-0{,}25}\cdot\frac{14{,}6^2\cdot 1{,}155}{2\cdot 9{,}81}=66{,}5\ \text{мм water column}.$$

4. Resistance, which considers correction for change in velocity head in connection with change in temperature,

$$\Delta p_2 = \frac{2(t_2 - t_1)}{273 + t_{cp}} \frac{v^2 \gamma}{2g} = \frac{2(27 - 18)}{273 + 22,5} \frac{14,6^2 \cdot 1,155}{2 \cdot 9,81} = 0,76 \text{ мм water column.}$$

5. Aerodynamic drag of air cooler

$$\Delta p = \Delta p_1 + \Delta p_2 = 66,5 + 0,76 \approx 67,3 \text{ мм water column.}$$

CHAPTER V.

Materials and their design characteristics.

At present in the practice of the manufacture of different apparatuses and vessels the widest acceptance obtained welding as the most rational and cheap production method, which ensures good quality of production and safe operation.

Therefore all given below data will relate in essence to the materials, used for the welded apparatuses and the vessels. The types of welded joints in the ship-building are applied according to the appropriate standards.

§ 28. Steel.

The materials, used for the apparatuses and the vessels, which work under the pressure, must contain (according to controlling-chemical analysis for any steel) not more than 0.3o/c C - during the use/application of an electric welding and not more than

0.35o/o C - during the use/application of other means of welding, or to satisfy the requirements of the corresponding standards.

For manufacturing the shipboard heat exchangers steel is applied mainly in the form of rolled stock, castings and forgings.

The parts of apparatuses and vessels, working medium of which are vapors, condensate, oil, petroleum and air, are fulfilled made of carbon steel, if they do not undergo the straight/direct effect of sea water. For the welded steel housings, the bottoms, the covers/caps and other parts, which work under pressure, is applied sheet steel of brand St. 3, while for the parts of less critical/heavy-duty ones - steel St. 2. The steel cast covers/caps, flanges and other parts are cast made of steel on GOST 977-53. For the steel tube plates, the flanges and other parts in the majority of the cases is applied steel St. 4 and less frequently St. 5. Steel tubes are fulfilled by seamless ones or seamless-rolled of carbon steel on GOST 301-50.

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The parts of apparatuses, which require the increased strength or the necessary and sufficient corrosive resistance, and which also undergo the action of high temperatures, are made made of the nickel,

chrome-nickel and other alloy and low-alloy steel.

The fundamental characteristics of different steels, used for manufacturing the basic parts of heat exchangers and vessels, are given in Table 29-37 and on Figs. 62-67.

Table 29. Mechanical properties of shaped castings from carbon steel (according to GOST 977-53).

(1) Марка стали	(2) Предел прочности σ_b, кг/мм²	(3) Предел текучести σ_s, кг/мм²	(4) Относительное удлинение δ_5, %	(5) Поперечное сжатие ψ, %
	(6) не менее			
15Л	40	20	24	35
20Л	42	22	23	35
25Л	45	24	19	30
30Л	48	26	17	30
35Л	50	28	15	25
40Л	53	30	14	25
45Л	55	32	12	20
50Л	58	34	11	20
55Л	60	35	10	18

Key: (1). Trademark of steel. (2). Limit of strength kgf/mm². (3). Yield point kgf/mm². (4). Elongation per unit length. (5). Lateral contraction. (6) not less.

Table 30. Mechanical properties of steel casting at elevated temperatures.

(1) Температура, °C	20	100	200	300	400	500
(2) Предел прочности σ_b, кг/см²	4165	4567	5253	5052	4043	2365
(3) Предел текучести σ_s, кг/см²	2375	2156	2186	1911	1384	—
(4) Удлинение δ, %	28	16	18	25	36	64
(5) Поперечное сжатие ψ, %	57	46	41	48	63	81

Key: (1). Temperature, °C. (2). Limit of strength kg/cm². (3). Yield point kg/cm². (4). Elongation δ, o/c. (5). Lateral contraction.

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Table 30 gives the mechanical properties of steel casting (with content of C - 18c/o; Mn - 0.36c/c; Si - 0.28c/c; S+P+Cu - 0.29o/o with the duration of testing 40 min.) at elevated temperatures.

The physicomechanical properties of the metals, used in the apparatus construction, are given in tables 38.

Is most negatively strength and safety of the work of apparatuses affect high temperature and corrosion - phenomena, which are most frequently encountered during the operation.

Tables 31. Mechanical properties of forgings made of carbon steel (on GOST 2335-50).

(1) Класс поковки	(2) Диаметр поковки, мм	(3) Марка стали	(4) Предел прочности σ_b, кг/мм²	(5) Предел текучести σ_s, кг/мм²	(6) Твердость по Бринеллю H_B
			(7) не менее		(8) не более
I	100 100—300 300—500	15	35 34 33	20 17 15	143
II	100 100—300 300—500 500—750	20	40 38 37 36	22 20 19 18	156
III	100 100—300	25	43 40	24 22	170
IV	100 100—300 300—500 500—750	30	48 47 46 45	25 24 23 22	179
V	100 100—300 300—500 500—750	35	52 50 48 46	27 26 24 23	187

Key: (1). Class of forging. (2). Diameter of forging, mm. (3). Trademark of steel. (4). Limit of strength kgf/mm². (5). Yield point kgf/mm². (6). Hardness according to Brinell. (7) not less. (8) not more.

Tables 32. Mechanical properties of steel tubes (according to GOST 301-50).

(1) Марка стали	(2) Предел прочности σ_b, кг/мм²	Относительное удлинение, %	
		(3) δ_5	δ_{10}
	(4) не менее		
10	32	24	20
20	40	20	17
35	52	17	14
45	60	14	12
(5) Ст. 2	34	24	20
Ст. 4	42	20	17
Ст. 5	50	17	14
Ст. 6	60	14	12

Key: (1). Trademark of steel. (2). Limit of strength kgf/mm². (3). Elongation per unit length, o/o. (4) not less. (5). St.

Table 33. Mechanical properties of carbon hot-rolled steel of the usual quality of group A (on GOST 380-50).

(1) Марка стали	(2) Предел прочности σ_b, кг/мм²	(3) Предел текучести σ_s, кг/мм²	(4) Относительное удлинение, %	
			δ_5	δ_{10}
	(5) не менее			
(6) Ст. 0	32—47	19	22	18
Ст. 1	32—40	—	33	28
Ст. 2	34—42	22	27—31	23—26
Ст. 3	38—47	24	25—26	21—22
Ст. 4	42—52	26	21—24	17—20
Ст. 5	50—62	28	15—20	13—16
Ст. 6	60—72	31	13—14	11—12

Key: (1). Trademark of steel. (2). Limit of strength kgf/mm². (3). Yield point kgf/mm². (4). Elongation per unit length, o/o. (5) not less. (6). St.

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Table 34. Mechanical properties of carbon structural steel (cn GOST 1050-52).

(1) Марка стали	(2) Предел прочности σ_b, кг/мм²	(3) Предел текучести σ_s, кг/мм²	Относительное (4) удлинение δ_5, %
	(5) не менее		
10	34	21	31
15	37	22	27
20	41	25	25
25	44	28	23
30	48	29	21
35	52	31	20

Key: (1). Trademark of steel. (2). Limit of strength kgf/mm². (3). Yield point kgf/mm². (4). Elongation per unit length. (5) nct less.

Table 35. Mechanical properties of steels at different temperatures.

(1) Температура испытания, °C	(2) Ст. 3		(2) Ст. 4		(2) Ст. 5		(2) Ст. 6	
	(3) Предел прочности σ_b, кг/мм²	(4) Предел текучести σ_s, кг/мм²	(3) Предел прочности σ_b, кг/мм²	(4) Предел текучести σ_s, кг/мм²	(3) Предел прочности σ_b, кг/мм²	(4) Предел текучести σ_s, кг/мм²	(3) Предел прочности σ_b, кг/мм²	(4) Предел текучести σ_s, кг/мм²
20	35—45	19—25	45	26	55	30	65	36
200	35	18	43	21	55	23	—	—
300	32	15	42	17	52	19	65	25
350	28	13	38	15	48	17	55	21
400	21	11	36	13	42	15	46	17
450	20	9	32	11	36	13	39	15
500	16	7	20	9	28	11	33	12

Key: (1). Temperature cf testing, °C. (2). St. (3). Limit of strength

(4). Yield point kgf/mm².

Table 36. Mechanical properties of carbon structural steel at elevated temperatures.

(1) Марка стали	(2) Предел прочности σ_b при 20° С, кг/мм²	(3) Предел текучести σ_s, кг/мм², при температурах							
		20	200	250	300	350	400	450	500
10	32	18	16	14,5	13,5	11,5	10	8	6
15	35	20	17,5	16	14,5	12,5	11	9	7
20	40	22	19	17,5	15,5	13,5	12	10	8
25	43	24	20,5	18,5	16,5	14,5	13	11	9
30	48	26	22	20	17,5	15,5	13,5	11,5	9,5
35	52	28	24	21,5	19	17	14,5	12,5	10,5

Key: (1). Trademark of steel. (2). Limit of strength with 20°C, kgf/mm². (3). Yield point kgf/mm², at temperatures.

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Temperature effect on the strength is considered, beginning with 230°C, with a reduction/descent in the allowable stress for steel.

Allowable stresses for steel of brand St. 3 in the dependence on the temperature are given in Fig. 62.

For steel St. 2 stresses must be respectively lowered/reduced. For steel St. 4 stresses at temperature more than 300°C cannot be increased in comparison with the stresses/voltages for steel St. 3 Fig. 62.

Table 37. Mechanical properties of some alloy steels.

(1) Марка стали	(2) Предел прочности σ_b, кг/мм²	(3) Предел текучести σ_s, кг/мм²	(4) Относительное удлинение δ, %
1Х18Н9Т (ЭЯ1Т)	50—60	20	40
30ХМА	80—90	60	14
СХЛ-4	54	40	18
35Х	95	75	10

Key: (1). Trademark of steel. (2). Limit of strength kgf/mm². (3). Yield point kgf/mm². (4). Elongation per unit length.

Tables 38. Physicomechanical properties of metals.

(1) Материал	(2) Удельный вес γ, г/см³	(3) Коэффициент линейного расширения $10^6\alpha$ на 1°С между 0—100°С	(4) Коэффициент теплопроводности λ, ккал/м·час°С	(5) Модуль упругости 10^{-6} E, кг/см²	(6) Модуль сдвига 10^{-5} G, кг/см²	(7) Коэффициент Пуассона μ
(8)						
Сталь углеродистая (9)	7,85	1,25	45	2,0—2,2	8,0—8,5	0,3
Сталь никелевая	7,85	1,2	15—22	2,09	8,1—8,4	0,3
Чугун (10)	7,0—7,4	1,1	54	1,0—1,2	2,9—5,5	0,27—0,15
Медь (11)	8,9	1,73	320—334	1,1—1,3	4,1—4,9	0,32—0,35
Латунь (12)	8,6	1,9	74—90	0,65—1,0	3,1—4,1	0,33
Бронза (13)	8,8	1,8	51	0,9—1,2	3,8	0,34
Никель (14)	8,9	1,3	50	2,05	—	0,33
Алюминий (15)	2,7	2,4	175	0,68—0,72	2,5—3,5	0,363
Цинк (16)	7,15	1,65	95	0,9—1,2	3,7—4,1	0,205
Олово (17)	7,3	2,2	96	0,4	1,6	—
Мельхиор (18)	8,9	1,6	25	0,85	—	—

Key: (1). Material. (2). Specific gravity/weight γ, g/cm³. (3). Coefficient of linear expansion 10^6 α on 1°C between 0-100°C. (4).

Coefficient of thermal conductivity λ, kcal/m•h°C. (5). Modulus/module of elasticity 10^{-6} E, kg/cm². (6). Modulus of shear 10^{-5} G, kg/cm². (7). Poisson ratio. (8). Steel carbonic. (9). Steel nickel. (10). Cast iron. (11). Copper. (12). Brass. (13). Bronze. (14). Nickel. (15). Aluminum. (16). Zinc. (17). Tin. (18). German silver.

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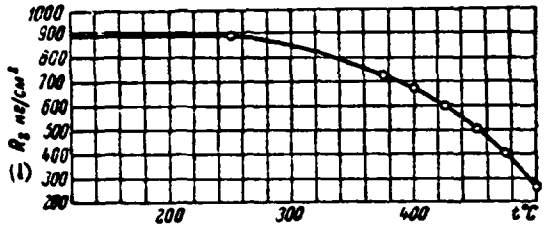

Fig. 62. Allowable stress of steel St. 3 in dependence on temperature.

Key: (1) кg/cm².

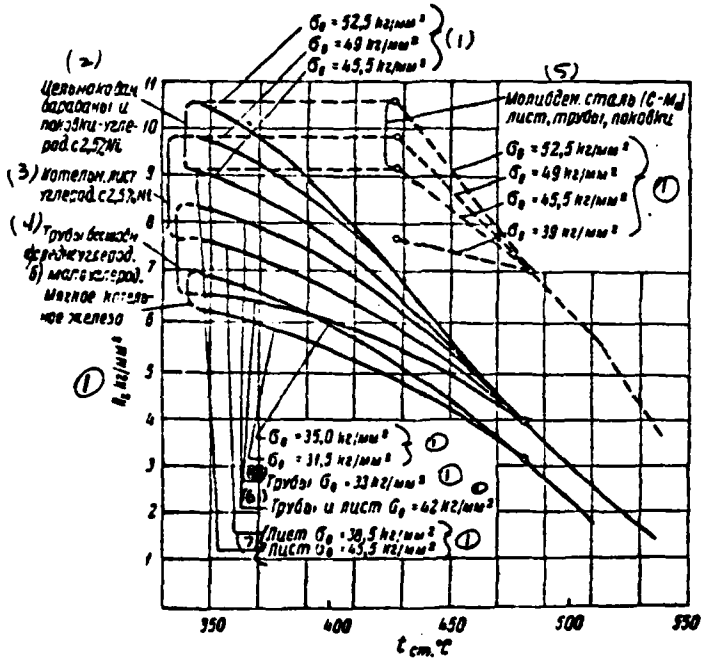

Fig. 63. Allowable stresses in different steels in depending on temperature.

Key: (1) kgf/mm². (2). Seamless forged drums and forging-carbon. with 2.5o/o Ni. (3). boiler plate carbon. with 2.5c/o Ni. (4). Tubes jointless. a) medium carbon. b) low carbon. Soft boiler plate. (5). Molybdenum. steel (C-M_o) sheet, tubes, forgings. (6). Tubes and sheet. (7). Sheet. (8). Tubes kgf/mm².

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It is necessary to keep in mind that the allowable stresses (Fig. 62) include the total stresses/voltages which can arise from all loads, which effect on the apparatus, namely: a) the internal pressure; b) impact loads, involving a sudden change in the pressure; c) the weight of apparatus and containing in it working media under operating condition; d) the load, caused by the tossing; e) the local stresses, called by the pick ups and the rings; f) a difference in the temperatures.

Usually in the calculations when selecting of the relationships/ratios of allowable stresses it is customary to assume that

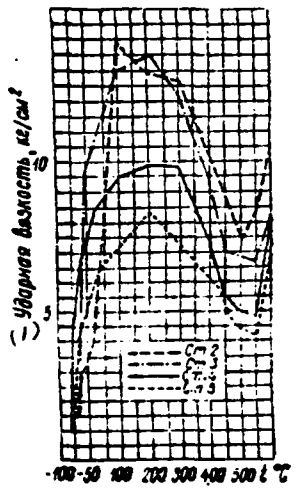
$$R_z = R_d = R_b;$$
$$R_{cm} = 1{,}8R_z;$$
$$R_{cp} = 0{,}8R_z,$$

where R_z — permissible tensile stress; R_d — permissible compression stress; R_b — allowable stress or the bend; R_{cp} — permissible shear

stress; R_{cm} — permissible crumpling stress.

The graph of the permissible operating stresses/voltages for different carbon and alloy steels at temperatures more than 350°C is given on Fig. 63.

The graphs of a change in the impact toughness and limit of the strength of different steels in the dependence on the temperature are given on Fig. 64 and 65.



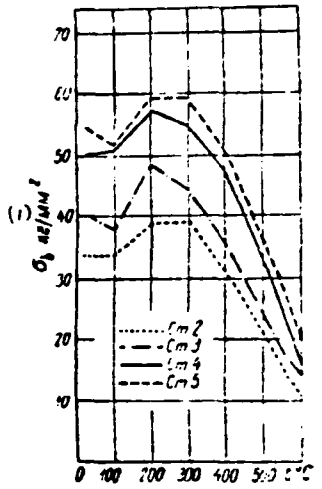


Fig. 64. Changes of the impact toughness of steels in the dependence on the temperature.

Key: (1). Impact toughness, kg/cm².

Fig. 65. Change of limit of strength of steels in dependence on temperature.

Key: (1) kgf/mm².

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With the work of apparatuses or their parts on compression either buckling is considered also the effect of elevated temperatures on the stability of the walls of apparatus or part

itself by the method of reducing/descending computed value of the yield point and modulus of elasticity of material.

The graph of a change of the yield point in the dependence on the temperature for the common carbon steel is shown in Fig. 66.

The graph of a change of the modulus of elasticity in the dependence on the temperature for the common carbon steel is given in Fig. 67.

Taking into account the effect of corrosion on the strength of apparatus, usually increase thickness walls by value C, taken within the limits from 1 to 3 mm.

§ 29. Nonferrous metals and alloys.

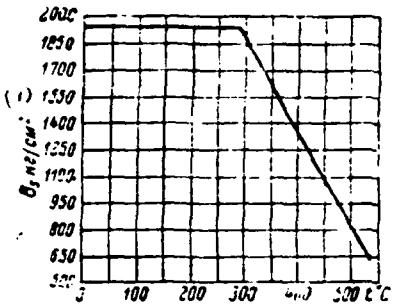
For manufacturing different parts of apparatuses and vessels are used extensively nonferrous metals and their alloys: copper, tin, aluminum, zinc, bronze, brass, etc.

The parts, working medium of which it is sea water, and also parts, which undergo the effect of sea water and air, which contains moisture, are manufactured from the red copper, the bronze, brasses, etc. For the welded or soldered parts is applied copper sheet M3 and

M4, rolled brasses and bronze LCo2, LS59-1, L62, L90, BrAMts9-2, etc.; for the castings - copper, bronze and brasses of the predominantly following brands/marks: BrCTs10-2, BrOTs8-4, BrAMts9-2, etc.

Tubes from the nonferrous metal are applied only pulled or seamless-rolled on GOST 494-52 and 617-53, and copper-nickel - on GOST 2203-43.

The basic mechanical properties of nonferrous metals and their alloys with normal and at different temperatures are given respectively in Tables 39 and 40.



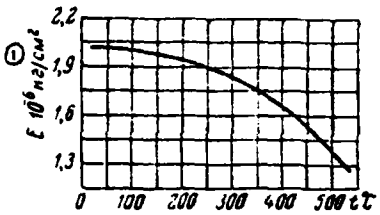


Fig. 66. Change in the yield point of common carbon steel.

Key: (1) kg/cm².

Fig. 67. Change in modulus of elasticity of common carbon steel in dependence on temperature.

Key: (1) kg/cm².

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Tables 39. Mechanical properties of nonferrous metals and alloys.

(1) Наименование и марка металла или сплава	(2) Предел прочности σ_b, кг/мм²	(3) Предел текучести σ_s, кг/мм²	(4) Относительное удлинение δ, %
(5) Медь	24 (м) 40—50 (т) 17 (л)	7,0 (м) 38 (т) —	50 (м) 6 (т) 8 (л)
(7) Никель	80—90 45—52 (от)	70 14—21 (от)	42—52 (л) 35—40 (м)
(9) Алюминий	8—11 (м) 15—25 (т) 9—12 (л)	5—8 (м) 12—24 (т) —	32—40 (м) 4—8 (т) 11—25 (л)
(10) Свинец	1,1	0,5	68
(11) Олово	2,5—4	—	45—60
(12) Цинк	2—7 (л) 10—12 (о)	7,5 (л) —	— 40—50 (о)

(5) Наименование и марка металла или сплава	(2) Предел прочности σ_b, кг/мм²	(3) Предел текучести σ_s, кг/мм²	(4) Относительное удлинение δ, %
(6) Томпак Л90	19 (л) 26 (м) 34 (п/т)	7 (л) 13 (м) 30 (п/т)	16 (л) 44 (м) 20 (п/т)
(8) Латунь Л68	28 (л) 33 (м) 52 (т)	— 10 (м) —	48 (л) 56 (м) 12 (т)
(8) Латунь Л62	32,8 (л) 36 (м) 68 (т)	12 (л) 11 (м) 48 (т)	35,5 (л) 49 (м) —
(8) Латунь ЛК80—3	30—50	16	15—16
(8) Латунь ЛМц58—2	36 (л) 44 (м) 55—65 (т)	24 (л) 36 (м) 5—10 (т)	15,6 (л) — —

Key: (1). Designation and brand/mark of metal or alloy. (2). Limit of strength kgf/mm². (3). Yield point kgf/mm². (4). Elongation per unit length δ, o/o. (5). Designation and brand/mark of metal or alloy. (6). Pinchbeck. (7). Nickel. (8). Brass. (9). Aluminum. (10). Lead. (11). Tin. (12). Zinc.

Continuation table 39.

(1) Наименование и марка металла или сплава	(2) Предел прочности σ_b, кг/мм²	(3) Предел текучести σ_s, кг/мм²	(4) Относительное удлинение δ, %
(8) Латунь ЛО70—1	25 (л) 35 (м) 58 (т)	18,4 (л) 16,2 (м) —	49 (м) 62 (м) 10 (т)
(8) Латунь ЛО62—1	35 (л) 38 (м) 44 (т)	— 15 (м) 18 (т)	25 (л) 37 (м) —
(8) Латунь ЛС59—1	34 (л) 42 (м) 62 (т)	15 (л) 14,5 (м) 42 (т)	27 (л) 36—50 (м) 4—6 (т)
(13) Бронза БрАЖ9—4	30—50 (л) — 55 (т)	20 (л) — 35 (т)	10—20 (л) 40 (м) 5 (т)
(13) Бронза БрАМц9—2	40 (л) 50 (п/т) 60 (т)	20 (л) 25 (п/т) 50 (т)	20 (л)
(13) Бронза БрОЦ4—3	20—30 (л) 55 (т)	6,5 (л) —	15 (л) 10 (т)
(13) Бронза БрОЦ10—2	20—25	18	2—10
(13) Бронза БрОЦ8—4	20—25	12	6—15
(13) Бронза БрОФ10—1	20	14	3
(14) Мельхиор НМ30	38	14	23—28

(15) Значение букв:

(м) — мягкий (п/т) — полутвердый
(т) — твердый (от) — отожженный
(л) — литой (о) — обработанный

Key: (8). Brass. (13). Bronze. (14). German silver. (15). Value of letters: (m) - soft; (t) - hard; (l) - cast; (p/t) - semihard; (ot) - annealed; (o) - machined.

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The strength of copper with an increase in the temperature considerably is depressed and according to experimental data comprises:

При температуре, °С	20	50	100	150	200	250	285	367	451	556
Прочность, %	100	98	95	91	85	79	75	66	51	33

Allowable stresses for copper and brass in the dependence on the temperature are given into tables 41.

For copper and brassing permissible tensile stresses compose approximately/exemplarily 67o/o of the allowable stress for rolled stock.

Allowable stresses on the bend for annealed copper in the dependence on the temperature are given into tables 42.

For the apparatuses and the parts, which work at temperature more than 250°C, use/application of copper and brasses is not recommended.

The results of the tensile tests of nonferrous metals at different temperatures are given in Table 43.

Table 41. Allowable stresses for copper and brass at different temperatures.

(1) Температура, °C	120	140	160	180	200	220	240	250
(2) Допускаемое напряжение для меди R_z, кг/см²	440	420	400	380	360	340	320	300
(3) Допускаемое напряжение для латуни R_z, кг/см²	500	475	450	425	400	375	350	325

Key: (1). Temperature. (2). Allowable stress for copper kg/cm². (3). Allowable stress for brass kg/cm².

Table 40. Mechanical Properties of Nonferrous Alloys at Different Temperatures

(1) Температура, °C	20		200		300		400	
(2) Марка материала	(3) Предел прочности σ_b, кг/мм²	(4) Предел текучести σ_s, кг/мм²	(3) Предел прочности σ_b, кг/мм²	(4) Предел текучести σ_s, кг/мм²	(3) Предел прочности σ_b, кг/мм²	(4) Предел текучести σ_s, кг/мм²	(3) Предел прочности σ_b, кг/мм²	(4) Предел текучести σ_s, кг/мм²
ОЦ10—2	25	18	20	15	15	14	14	13
БрАМц9—2	$40_а$, $60_в$	$20_а$	$53_в$	—	52	—	44	—
ЛО62—1	$38_г$	$20_е$	29	—	28	—	10	—
(5) Медь	22,9	—	—	—	13,2	—	8,5	—
ОЦ8—4	20	14	17	—	—	—	—	—

(6) Индексами обозначено: а — литой в землю; в — катаный; г — мягкий; е — литой в кокиль.

Key: (1) Temperature, °C; (2) Brand of material; (3) Tensile strength, kg/mm²; (4) Yield strength, kg/mm²; (5) Copper; (6) Subscripts denote: a - cast in earth; в - rolled; г - soft; e - chill cast.

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Table 42. Allowable stresses on the bend for annealed copper in the dependence on the temperature.

Температура стенки, °C (1)	Допускаемое напряжение на изгиб R_b, кг/мм² (2)
120—140	4,7
141—160	4,4
161—180	4,2
181—200	4,0
201—220	3,8
221—240	3,6
241—250	3,3

Key: (1). Temperature of wall. (2). Allowable bending stress kgf/mm².

Table 43. Results of the tensile tests of nonferrous metals at different temperatures.

(1) Металл	(2) Температура, °C	(3) Предел прочности σ_b, кг/см²	(4) Относительное удлинение δ, %	(5) Относительное сжатие ψ, %
(6) Латунь, отожженная при 500° C	20	3240	34	70
	200	2690	35	70
	400	1180	19	27
	600	280	14	17
	800	50	7	9
(8) Никель, отожженный при 900° C	20	4930	26	72
	195	4480	26	66
	309	4480	31	67
	455	3020	20	31
	593	2060	15	25
	800	920	11	18
	1000	400	11	15
(10) Цинк, отожженный при 200° C	20	1130	5	7
	112	725	8	15
	150	500	7	10
	247	225	6	11
	330	125	8	15
	405	3	2	2

(1) Металл	(2) Температура, °C	(3) Предел прочности σ_b, кг/см²	(4) Относительное удлинение δ, %	(5) Относительное сжатие ψ, %
(7) Алюминий, отожженный при 350° C	20	1160	19	79
	75	1000	24	83
	135	765	32	88
	310	260	39	97
	403	125	42	99
	510	55	45	99
	600	35	42	100
(9) Олово, отожженное при 50° C	20	275	40	74
	53	175	45	72
	100	105	45	82
	153	65	41	97
	180	45	10	12
	207	25	0	0
(11) Свинец, отожженный при 100° C	20	135	31	100
	82	80	24	100
	150	50	33	100
	195	40	20	100
	265	20	20	100

Key: (1). Metal. (2). Temperature. (3). Limit of strength kg/cm². (4). Elongation per unit length. (5). Contraction. (6). Brass, annealed at 500°C. (7). Aluminum, annealed at 350°C. (8). Nickel, annealed at 900°C. (9). Tin, annealed at 50°C. (10). Zinc, annealed at 200°C. (11). Lead, annealed at 100°C.

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For manufacturing the separate parts of apparatuses and vessels or for their coating are applied in the limited quantity nonferrous metals as, for example, nickel, aluminum, zinc, tin, lead and so forth, etc. Zinc is applied mainly for the protectors/treads of apparatuses, which undergo destruction under the action of galvanic currents. Aluminum is used for manufacturing of parts sufficiently strong ones and lungs and just as lead, it can be used as the sealing material.

§ 30. Iron casting.

Iron casting has sufficiently limited application in the manufacture of the parts of shipboard heat exchangers.

The cast iron in the majority of the cases are made from gray cast iron as densest and least subjected to action of corrosion, and also possessing good castabilities. Cast iron parts can be used for the apparatuses, which work under the pressure not more than 6 kg/cm², also, at temperature of working medium not more than 200°C. The use/application of cast iron parts for the apparatuses, which undergo the effect of sea water, is not allowed/assumed.

The sizes/dimensions of cast iron vessels must not exceed 600 mm in diameter and 400 l on the capacity/capacitance.

The cast cast iron covers/caps, the drains of condensate and other parts of apparatuses and different fittings are made from gray cast iron (on GOST 1412-54) whose basic properties are given into tables 44. A great use in the apparatus construction find cast irons of brands SCh18-36, SCh24-44 and SCh28-48.

Tables 44. Mechanical properties of castings from gray cast iron.

(1) Марка чугуна	(2) Предел прочности на разрыв, кг/мм², не менее	(3) Предел прочности на изгиб кг/мм², не менее	(4) Твердость по Бринелю H_B	(5) Стрела прогиба, мм при расстоянии между опорами, мм		(6) Предел прочности на сжатие, кг/мм²
				600	300	
СЧ12-28	12	28	143—229	6	2	50
СЧ15-32	15	32	163—229	8	2,5	65
СЧ18-36	18	36	170—229	8	2,5	70
СЧ21-40	21	40	170—241	9	2	75
СЧ24-44	24	44	170—241	9	3	83
СЧ28-48	28	48	170—241	9	3	100
СЧ32-52	32	52	197—248	9	3	110

Key: (1). Brand/mark of cast iron. (2). Yield strength, kgf/mm², is not less. (3). Ultimate breaking strength kgf/mm², is not less. (4). Hardness according to Brinell. (5). Bending deflection, mm with distance between supports, mm. (6). Ultimate compression strength, kgf/mm².

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A change of the limit of the strength of the bend of cast iron in the dependence on the temperature according to experimental data is given in table 45.

Allowable stress for the cast iron:

$$R_s = R_b = 200 \div 250 \ \text{кг/см}^2.$$

For cast iron of average/mean quality the allowable stress on

the bend can be accepted, in depending on the kind of load and surface condition, on Tables 46.

Allowable stress in cast iron on the compression:

$$R_d = 600 \text{ кг/см}^2.$$

Addition to cast iron wall thickness accept C=7-9 mm, for the centrifugal casting by C=5 mm.

Table 45. Ultimate breaking strength of cast iron in depending on temperature.

(1) Температура, °C	20	200	300	400	500	570
(2) Предел прочности на изгиб, кг/см²	2350	2380	2360	2190	1810	1230

Key: (1). Temperature, °C. (2). Ultimate breaking strength, kg/cm².

Table 46. Allowable stresses on the bend of cast iron in the dependence on load and surface condition.

(1) Род нагрузки	(2) Напряжение на изгиб $R_{б}$, кг/см²	
	(3) без литейной корки	(4) с литейной коркой
(5) Спокойная	510	420
(6) Возрастающая от нуля до максимального значения	340	280
(7) Меняющаяся от максимального отрицательного значения до максимального положительного значения	170	140

Key: (1). Kind of load. (2). Stress/voltage on bend kg/cm². (3) without the casting skin. (4) with the casting skin. (5). Steady. (6). Increasing from zero to maximum value. (7). Changing from maximum negative value to maximum positive value.

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§ 31. Jointing materials (packing).

As the jointing materials in the heat exchangers are applied different packing. When selecting of packing it is considered:

1) the character of the packed medium;

2) operating pressure in the apparatus;

3) operating temperature;

4) the duration of connection to the dismantling;

5) the quality of packing surfaces (smooth, rough);

6) the width of the packing;

7) the thickness of the packing;

8) the force of the tightening of the bolts;

9) the position of the packing;

10) external agency on the packing;

11) the property of sealing material (strength, elasticity, coefficient of friction).

In essence all sealing materials are subdivided into three groups:

1. Nonmetallic pads - rubber, paranite, cardboard, asbestos, etc.

2. Metallic packing, manufactured with pillar from metal or alloy - copper, brass, steel, lead, etc.

3. Submetallic packing, which have metallic mounting/case (brass, copper, lead, zinc) and nonmetallic center (asbestos, rubber), or vice versa.

The most popular include the following sealing materials.

Rubber of the 2nd group, average/mean hardness from 7.5 to 11 kg/cm². It is commonly used as the packing/seal for the smooth flange joints, which are contacted with the cold and hot sea and feed water, the aqueous solutions and the air at temperature from -30 to +60°C

and pressures to 3 kg/cm², and with the cloth packing - to 6 kg/cm².

Heat-resistant rubber of the 4th group of average/mean hardness with the cloth packing is applied for the temperatures to 150°C and the pressure to 10 kg/cm².

Oil-resistant rubber of the 6th group of average/mean hardness is applied for oils and fuel/propellant at temperatures to 60°C and pressures to 3 kg/cm².

Plastic rubber without the harmful impurities is applied for the everyday apparatuses, intended for the preparation of drinking water and food.

Sealing rubber is manufactured any form and any sizes/dimensions in the form of plates, cords or round, square, quadrangular and shaped sections/cuts. The thickness of rubber plates without the packing is from 1 to 40 mm and with the cloth packing from 2 to 15 mm.

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Paranite is the most general-purpose and widely used sealing material; it is applied for packing the surfaces, which are contacted

with the cold and hot fresh and sea water, the brine, the acids, the alkalies, the water saturated and superheated steam, the air and the flue gases at temperature to 400°C and pressure to 15 kg/cm². Paranite is manufactured in the form of sheets with size/dimension to 1500 mm and in thickness from 0.3 to 6 mm.

Cardboard is applied for packings/seals of surfaces, which are contacted with the liquid propellant, the lubricating oils, the air, the ventilation gases and the drinking water at temperature to 90°C and pressure to 6 kg/cm²; cardboard impregnated - for the surfaces, which are contacted with the kerosene and the gasoline at temperature to 30°C and pressure to 10 kg/cm².

Cardboard asbestos is applied for packing the surfaces, which are contacted with the hot gases, the gasoline and the kerosene at temperature to 180°C and pressure to 3 kg/cm².

By fabrics cotton, unbleached linen, by hemp cords with the greasings by the red lead oxide and different mastics pack the connections, intended for the low pressures, and the untreated or slightly machined surfaces.

Copper annealed is applied: brand M3 for packing the connections, which are contacted with the saturated and superheated

steam at temperature to 250°C and pressure to 35 kg/cm², brands M1 - at temperatures to 350°C and pressure to 45 kg/cm², and also for the Freon, carbonic acid, hot gases, fuel/propellant and oils at temperature to 200°C and pressure 200 kg/cm².

Iron soft of the type Armco is applied for the saturated and superheated steam at temperature to 450°C and pressure to 64 kg/cm² and for other corrode media at temperature to 450°C and pressure to 100 kg/cm².

Aluminum is applied for the media, in which is not dissolved oxide of aluminum, and at very high and low temperatures and high pressures.

Lead is applied for packing the connections, which are contacted with the acids, oils, liquid propellant, gasoline at temperature to 100°C and pressure to 40 kg/cm².

Submetallic and riffled metallic packing are applied in the dependence on their construction/design for packing the connections, which are contacted with the gases, the air, the water, the fuel/propellant by oil, acids and the like at temperatures of 60-250°C and pressure from 5 to 80 kg/cm², and they are established on smooth surfaces of the connections, which frequently undergo

dismantling.

Tentative widths and thicknesses of packing in depending on their diameter are given in Table 47.

The specific pressures, necessary for the deformation of packing and that maximum permissible, call their flattening, and also specific gravity/weight of the material of packing are given in Table 48.

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In order to determine the conditions of nonextrusion of the nonmetallic packing, pressed between the smooth flanges, they use the formula

$$(D_в + b)\, b\sigma_y f > D_в \delta p,$$

where $D_в$ — bore of packing, cm; b - width of packing, cm; δ - thickness of packing, cm; σ_y — the specific pressure on the packing, necessary for the deformation, kg/cm²; p - the design pressure of medium, kg/cm²; f - coefficient of the friction of pad, equal to; f=0.10-0.15 during treatment ∇ of the surface of the flanges; f=0.05-0.08 during treatment ∇∇ or the surface of flanges.

Table 47. Sizes/dimensions of packing.

(1) Диаметр прокладки, мм	(2) Неметаллические, мм		(3) Металлические, мм	
	(4) ширина	(5) толщина	(4) ширина	(5) толщина
(6) До 100	5—6	1—1,5	3—4	1—2
100—200	6—7	1—1,5	4—5	2—3
200—400	7—8	1,5—2	5—6	3—4
(7) 400—600	8—10	1,5—2,5	6—7	4—5
Свыше 600	12—20	2—3	8—12	5—6

Key: (1). Diameter of packing, mm. (2). Nonmetallic, mm. (3). Metallic, mm. (4) width. (5) thickness. (6). To. (7). It is more than.

Tables 48. Specific pressures on the packing.

(1) Прокладочные материалы	(2) Удельное давление на прокладку, кг/см²		(5) Удельный вес, т/м³
	(3) необходимое для деформации	(4) вызывающее расплющивание	
(6) Резина	(8) 2,6	35	1,5
(7) Паронит	30 и 60 (для газов)	315	1,9
(8) Картон	20	—	1,0
(9) Картон асбестовый	40	—	—
(10) Медь отожженная	750	980	8,9
(11) Железо мягкое	—	1260	7,85
Свинец (12)	110	—	11,3

Key: (1). Sealing materials. (2). Specific pressure on packing, kg/cm². (3) necessary for the deformation. (4) the calling flattening. (5). Specific gravity/weight, t/m³. (6). Rubber. (7).

Paranite. (8). Cardboard. (9). Cardboard asbestos. (10). Copper annealed. (11). iron (soft). (12). Lead. (13) 30 and 60 (for the gases).

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§ 32. Insulation.

Basic insulation, used for the insulation/isolation of heat exchangers, are given in Table 49, containing physical constants insulation/isolation.

Tables 49. Physical corstants of insulation/isclaticn.

(1) Материал	(2) Вес	(3) Формула коэффициента теплопроводности λ, ккал/м-час °С	(4) Температура устойчивости, °С
(5) Ньювель	(6) В порошке 200 кг/м³ (7) В изоляции 350 кг/м³ (8) В штукатурке 400 кг/м³	$\lambda = 0,0695 + 0,000083\ t_{ср}$ (14)	350
(9) Совелит	(6) В порошке 220 кг/м³ (7) В изоляции 420 кг/м³ (8) В штукатурке 440 кг/м³	$\lambda = 0,736 + 0,000162\ t_{ср}$	400
(10) Термаль	(11) Гладкий с асбестовыми кольцами (12) Гофрированный	$\lambda = 0,046 + 0,000218\ t_{ср}$ $\lambda = 0,051 + 0,000219\ t_{ср}$	400
(13) Ткань асбестовая (15) Картон асбестовый	1,6—2,0 кг/м² 3,3 кг/м² (14)	$\lambda = 0,106 + 0,000159\ t_{ср}$ $\lambda = 0,135 + 0,00016\ t_{ср}$	400 600
(17) Матрац, наполненный ньювелем	(16) При толщине 25 мм — 7,5 кг/м² 40 мм — 10,5 кг/м² 50 мм — 12,5 кг/м² (14)	$\lambda = 0,07 + 0,00012\ t_{ср}$	400
(18) Матрац, наполненный совелитом	(16) При толщине 25 мм — 7,5 кг/м² 40 мм — 11,2 кг/м² 50 мм — 13,4 кг/м² (14)	$\lambda = 0,075 + 0,00012\ t_{ср}$	450

(19) Здесь $t_{ср}$ — средняя арифметическая температура — складывается из температур теплоносителя и наружной поверхности стенки.

Key: (1). Material. (2). Weight. (3). Formula of coefficient of thermal conductivity λ, kcal/m-hour °C. (4). Temperature of stability, °C. (5). Newell. (6). In powder. (7). In insulation/isolation. (8). In plastering. (9). Scvelit [99sp07 - mixture of MgO, $CaCO_3$, and asbestos]. (10). Thermal. (11). Smcoth with asbestos rings. (12). Corrugated. (13). Fabric asbestos. (14)

kg/m². (15). Cardboard (asbestos. (16). With thickness. (17). Insulation blanket, filled by Newell. (18). Insulation blanket, filled with sovelit. (19). Here - arithmetic mean temperature - is composed of temperatures of heat carrier and external surface of wall.

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Recently ever more wide acceptance obtains the new means of the insulation/isolation of mechanisms, apparatuses and conduits/manifolds - so-called FOV - the formed fired vermiculite.

FOV is manufactured in the form of moldings - the rectangular plates/slabs with the size/dimension 1000x500x30-50 of mm and in the form of the rectilinear and curvilinear shells with a length of 500 mm, with thickness from 30 to 70 mm and in bore from 30 to 420 mm. For the diameters more than 130-150 mm to more expediently apply moldings in the form of the segments which can be established to the tubes of different diameters; furthermore, segments are transportable than shells.

The specific weight of the molded plates/slabs - 250 kg/m³, and shells - 230 kg/m³.

The coefficient of the thermal conductivity λ of articles, in depending on mean temperature t_{cp}, is determined from the formula

$\lambda = 0{,}07 + 0{,}0002 t_{cp}$

kcal/m•h°C.

Temperature stability of articles to 600°C.

The installation of insulation/isolation by the moldings, which have smaller specific weight, in comparison with Newell and scvelit of the isolated surfaces, is produced without the preheating and requires only the small smearing or welds and joints. Work on the insulation/isolation can be produced independent of the site of installation of the isolated articles.

The use/application of FOV as insulation in the form of moldings makes it possible to considerably reduce the labor consumption of installation works, and to also lower the weight of insulation/isolation.

As facing material for the insulation/isolation in the majority of the cases serve sheets made of galvanized iron with a thickness of 1 mm and sheets from aluminum-magnalium alloy.

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Chapter VI.

Calculations of strength.

Heat exchangers, as a rule, work under pressure or in vacuum. The parts of heat exchangers, which are subjected loads, are designed in essence for the strength in depending on their material, operating pressure, temperature and properties of medium.

In this section are given calculation formulas and methods of determining the strong sizes/dimensions of the basic parts of different apparatuses and vessels, relied on strength.

The calculation of vessels from the nonferrous metals and the alloys is produced by the same calculation procedure, as for the steel vessels, in this case necessary, just as for steel, to consider all mechanical properties of the material used.

The order of the presentation of material approximately/exemplarily corresponds to the sequence of the produced stress analyses of parts.

§ 33. Calculation of cylindrical walls.

Thin-walled steel cylinders, subjected to internal pressure.

The wall thickness of cylinder or tube

$$s = \frac{pD_в}{230\varphi R_z - p} + C \text{ мм}, \qquad (213)$$

where p - design pressure, kg/cm²; takes as the equal to the sum of the operating pressure of medium in the vessel and hydrostatic pressure, if it comprises more than 2.5o/c of the worker; $D_в$ - the cylinder bore, mm; φ - modulus of resistance of weld; it is accepted on Tables 50 in the dependence on the construction/design of weld and welding method; R_z - permissible tensile stress, kg /mm²; it is accepted in the dependence on the temperature of wall on Table 51, and the safety factors - in Table 52. C - addition to the calculated wall thickness, which considers corrosion, tolerances, ovality, etc., mm; C=0.18s with $s_{расч} > 6$ мм and C=1 mm when $s_{расч} \leq 6$ мм.

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Table 50. Values of moduli of resistance φ in depending on the form of weld.

(1) Вид шва и способ сварки	(2) Значения φ
(3) Ручная газо- или электросварка	
(4) Стыковые швы с подваркой со стороны вершины шва	0,95
(5) Стыковые швы, сваривaемые с одной стороны, но имеющие со стороны вершины подкладки или кольца, прилегающие к основному металлу по всей длине шва	0,9
(6) Стыковые швы, свариваемые только с одной стороны	
(7) а) продольные	0,7
(8) б) поперечные	0,8
(9) Автоматическая сварка под слоем флюса	
(10) Стыковые швы с двусторонним проваром	1,0
(11) Стыковые швы, свариваемые только с одной стороны	0,8
(12) Коэффициент прочности шва для меди	
(13) При паянном шве твердым припоем или сварке медью	0,8

Key: (1). Form of weld and welding method. (2). Values. (3). Manual gas- or electric welding. (4). Butt welds with auxiliary welding from the side of apex/vertex of weld. (5). Butt welds, welded on one hand, but which have on the side of the top of backing/block or rings, adjacent to base metal all over weld length. (6). Butt welds, welded only on the one hand. (7). longitudinal. (8). transverse. (9). Automatic submerged-arc welding. (10). Butt welds with bilateral penetration. (11). Butt welds, welded only on the one hand. (12). Modulus of resistance of weld for copper. (13). With soldered weld by brazing metal or to welding by copper.

Table 51. Values of permissible tensile stresses during the calculation of cylindrical walls.

(1) Температура стенки, °C	R_p, кг/мм (2)	(3) Примечание
(4) Менее 250	$\frac{\sigma_b}{n_b}$	
(5) От 250 (6) до 400	$\frac{\sigma_s^t}{n_T}$	(8) Берется наименьшее значение отношений
(7) Более 400	$\frac{\sigma_s^t}{n_T}$; $\frac{\sigma_n^t}{n_n}$	

The designations: σ_b - the limit of the strength of metal to the elongation at temperature of 20°C, kg /mm²; σ_s^t - yield stress of metal at temperature t, kg /mm²; σ_n^t - creep limit of metal at temperature t, kg /mm²; n_b, n_T and n_n - safety factors in the relation respectively to the limits of strength, viscosity/yield and creep (they are taken according to Table 52).

Key: (1). Temperature of wall. (2). kg/mm. (3). Note. (4). It is less. (5). From. (6). to. (7). It is more. (8). Is taken small value of relations.

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Formula (213) is applied for calculating thick-walled vessels, which refer outside diameter to the internal not more than value 1.5.

During the calculation of the wall thickresses of the cylindrical containers, subjected to internal pressure at normal temperature (cistern and other vessels, which work under conditions, close to the body constructions/designs), permissible tensile stress is received as equal to

$$R_z = 0{,}6\sigma_s \text{ kg/mm}^2 \qquad (214)$$

where σ_s - yield stress of metal with the normal temperature, kg /mm².

Thin-walled steel cylinders, subjected to ambient pressure.

The wall thickness of cylinder or tube

$$s = \frac{pD}{4R_d}\left(1 + \sqrt{1 + \frac{al}{p(l+D)}}\right) + C \text{ см}, \qquad (215)$$

where p - external overpressure, kg/cm²; D - diameter of cylinder in light/world, cm; R_d -allowable compression stress, kg/cm²; l - length of cylinder (between the effective rigid attachments), cm; C - addition, cm; a - factor, obtained experimentally.

Table 52. Values of the safety factors during the calculation of cylindrical walls.

(1) Цилиндры сварные	(2) Коэффициенты запаса		
	$n_в$	$n_т$	$n_п$
(3) Обогреваемые газом при наличии или отсутствии отверстий	4,5	2,0	1,15
(4) Необогреваемые газом при наличии отверстий под трубки, лючки и т. п.	4,25	1,9	1,10
(5) Необогреваемые газом при наличии надежно укрепленных отверстий либо при их отсутствии	4,0	1,8	1,0
(6) Для бесшовных труб	3,8	1,7	1,1
(7) Для трубопроводов	4,0	1,8	1,15

Key: (1). Cylinders are welded. (2). Safety factors. (3). Warmed by gas in presence or absence of holes. (4). Nonheated by gas in presence of holes under tubes, small hatches, etc. (5). Unheated by gas in presence of reliably fastened/strengthened holes or in their absence. (6). For seamless pipes. (7). For conduits/manifolds.

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For the horizontal cylinders: a=100 - with the longitudinal seam overlapping; a=80 - with the longitudinal seam welded or with the cover plates from both sides.

For the vertical cylinders: a=70 - with the longitudinal seam overlapping; a=50 - with the longitudinal seam welded or with the cover plates from both sides.

Breaking stress in the cylindrical containers. cylindrical containers without rings of rigidity whose breaking stress is lower than the yield point, and the ovality of less than 0.05 $D_н$, rely on stability with respect to the formula

$$p_{кр} = \frac{E}{4(1-\mu^2)}\left(\frac{s}{r}\right)^2 \text{ кг/см}^2. \qquad (216)$$

Cylindrical containers without rings of rigidity whose breaking stress is higher than the yield point, and ovality less than 0.1 $D_н$, they are designed from the formula

$$p_{кр} = \frac{s}{r}\,\frac{\sigma_т}{1+\frac{4\sigma_т}{E}\left(\frac{r}{s}\right)^2} \text{ кг/см}^2 \qquad (217)$$

Here E - modulus of elasticity of material, кг/см²; s - the wall thickness of vessel (without addition C), см; r - the mean radius of vessel, см; μ - Poisson ratio; $\sigma_т$ - yield point of material, кг/см².

The margin of the stability of the vessel:

$$m = \frac{p_{кр}}{p}.$$

where p - external overpressure of medium, кг/см²; m≥4 - for the vertical vessels; m≥5 - for the horizontal vessels.

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Thick-walled steel cylinders, subjected to internal pressure.

If the wall thickness of cylinder exceeds 10o/o of the cylinder bore, then its calculation is produced according to the formula of the thick-walled vessels:

$$s = \frac{r}{\varphi}\left(\sqrt{\frac{R_z + p}{R_z - p}} - 1\right) + C \text{ см}, \qquad (218)$$

where r - an inside radius of apparatus, cm; φ - modulus of resistance of the weld; R_z - permissible tensile stress, kg/cm²; p - internal overpressure, kg/cm²; C - addition which during the calculation of the thick-walled cylinders can be placed of the equal to zero.

If calculation is produced on allowable stress R_z, selected on the yield point σ_s, then the wall thickness of cylinder will be determined according to the formula

$$s = r\left(\sqrt{\frac{100\varphi R_z}{100\varphi R_z - \sqrt{3}p}} - 1\right) \text{ мм}, \qquad (219)$$

where σ_s - yield point of material, kg /mm².

Remaining designations the same as in formula (218).

Cylindrical wall, included between the rings of rigidity.

If the apparatus, which works under the external overpressure, is equipped with the rings of rigidity, then the cylindrical wall between them works on the bend.

Stress/voltage on the bend in the cylindrical wall between the rings of the rigidity:

$$R_b = \frac{1.5p\sqrt{Ds_1}}{0.643 + \frac{s_1\sqrt{Ds_1}}{F}} \sqrt{\frac{D^2 s_1^2}{3(1-\mu^2)}} \ kg/cm^2 \qquad (220)$$

where p - external overpressure, kg/cm²; D - diameter of cylinder in the light/world, cm. s_1 - wall thickness without addition C, cm: for valve apparatuses $s_1=s-C$, for welded joints $s_1=\phi(s-C)$; F - cross-sectional area of the ring of rigidity (cm²) without taking into account addition C; μ - Poisson ratio (Table 38).

Rings of the rigidity of cylindrical wall.

Load on 1 running cm of the length of the circumference of the ring of the rigidity:

$$q = \frac{p\sqrt{Ds_1}}{0.643 + \frac{s_1\sqrt{Ds_1}}{F}} \ kg/cm. \qquad (221)$$

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Critical load on 1 running cm of the circumference of the ring

$$p_{кр} = \frac{3EI}{R} \text{ kg/cm} \qquad (222)$$

where E - modulus of elasticity, kg/cm²; I - moment of the inertia of the transverse ring of rigidity, cm⁴; R - radius of ring on the neutral line, cm.

Critical load on 1 running cm of the circumference of the ring of rigidity, supported at several points (considering its part as circular arch with the supported ends):

$$p_{кр} = \frac{EI}{R^3}\left(\frac{4\pi^2}{a^2} - 1\right) \text{ kg/cm} \qquad (223)$$

where a - a central angle between the supports of ring in the portions π

$$\pi = \angle a = 180°.$$

Reserve of resistance to the indentation of the ring:

$$m = \frac{p_{кр}}{q} > 5.$$

Compression stress in the ring over the diametric section/cut:

$$R_d = \frac{qD_н}{2F} \text{ kg/cm}^2 \qquad (224)$$

where $D_н$ - outside diameter of ring, cm.

If ring is carried out with the ellipticity, which does not exceed 1o/o of its nominal bore, then the maximum bending moment in the ring can be determined according to Fedotov's formula:

$$M = 66pl\left(\frac{r}{100}\right)^2 \text{ kg}\bullet\text{cm} \qquad (225)$$

where p - external overpressure, kg/cm²; l - distance between rings, cm; r - inside radius of apparatus, ~~see~~ cm.

Stress/voltage on the bend in the ring of the rigidity:

$$R_b = \frac{M}{W} \text{ kg/cm}^2. \qquad (226)$$

where W - a general/common/total modulus of section of the ring of rigidity and adjacent to it shell (with a length ~15 cm), cm³.

Strength bending of the remaining part of the shell can be disregarded/neglected.

Total stress/voltage in the ring of the rigidity:

$$R_{сум} = R_d + R_b \text{ kg/cm}^2. \qquad (227)$$

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Tolerances for the ovality of welded cylinders are given in Table 53.

Table 53. Tolerances for the ovality of welded cylinders (according to the data of practice).

При (1) диаметре цилиндра D, мм	до 200	201—300	301—500	501—1000
(2) Допуск на овальность, % от D	1,5	1,0	0,75	0,5

Key: (1). With the diameter of cylinder. (2). Tolerance for ovality c/c from D.

§ 34. Calculation of the dished bottoms and covers/caps.

Bottoms must have a profile/airfoil of ellipse or curve, close one to the ellipse. The diagram of construction by this curve is given in Fig. 68.

Outside radius of the transfer arc of the bottom

$$r_н = \frac{\sqrt{(0,5D_н)^2 + h} \cdot \sqrt{(0,5D_н)^2 + h^2} - 0,5D_н + h}{D_н} \text{ мм.} \quad (228)$$

An outside radius of the convex part of the bottom

$$R_н = \frac{(0,5D_н)^2 + h^2 - 0,5D_н r_н}{h} \text{ мм,} \quad (229)$$

where $D_н$ - outside diameter of bottom, mm; h - height/altitude of the convex part of the bottom on external surface, mm.

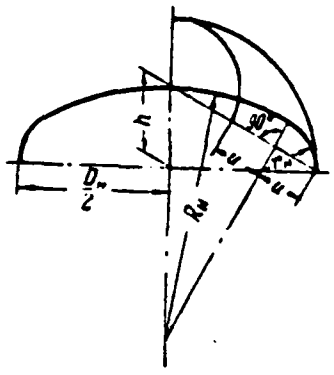

Fig. 68. Diagram of the plotting of curves of the dished bottom.

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The dished bottoms whose different types are shown in Figs. 69, 70 and 71, must satisfy also the requirements, indicated in Table 54.

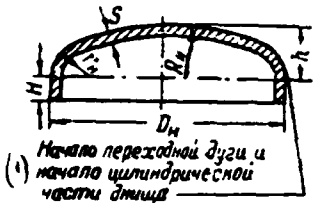

Fig. 69.

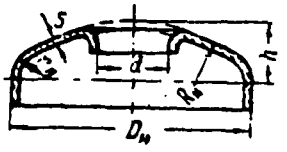

Fig. 70.

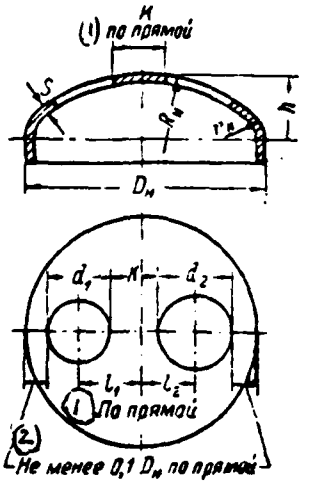

Fig. 71.

Fig. 69. Anechoic dished bottom.

Key: (1). Began transfer arc and the beginning of the cylindrical part of the bottom.

Fig. 70. Dished bottom with access.

Fig. 71. Dished bottom with holes.

Key: (1). On the straight line. (2). Not less than 0.1 D_H on straight line.

Table 54. Design specifications for the bottoms.

(1) Высота выпуклой части днища по наружной поверхности h	(2) Внутренний радиус выпуклой части днища $R_в - s$	(3) Наружный радиус переходной дуги днища $r_н$	(4) Расстояние от края отверстия		
			(5) до края днища (по проекции) a	(6) до края другого отверстия (по проекции) k	(7) до начала отбортовки лазового отверстия
(8) Не менее $0{,}2\ D_н$	(9) Не более $D_в$	(8a) Не менее $0{,}1\ D_н$ и не менее $\frac{2h^2}{D_н}$	(8) Не менее $0{,}1\ D_н$	(10) Не менее диаметра меньшего отверстия (при неукрепленных отверстиях)	(8) Не менее s

Notes: 1. Through hole must be arranged/located centrally.

2. Is not allowed/assumed arrangement of holes on transfer arc of bottom.

3. On cylindrical part is allowed/assumed drilling unit holes.

Key: (1). Height/altitude of the convex part of the bottom over the external surface of h. (2). Inside radius of convex part of bottom. (3). Outside radius of transfer arc of bottom. (4). Distance from edge of hole. (5). to edge of bottom (on projection) a. (6). to edge of another hole (on projection) k. (7). prior to beginning of flanging of through hole. (8). Not less. (8a). and. (9). Not more. (10). Not less than diameter of smaller hole (with unfastened/unstrengthered holes).

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The wall thickness of the dished bottom is determined from the formula

$$s = \frac{D_н p y}{200 R_z} + C \text{ мм}, \qquad (230)$$

where $D_н$ - outside diameter of housing, mm; p - design pressure, kg/cm² [see value of p to the formula (213)]; y - form factor of the bottom; values y in depending on the value of relation $\frac{h}{D_н}$ and of character of weakening bottom by holes $\frac{l+d}{D_н}$ are given in Table 55; in the latter/last relation l - a distance from the axis/axle of bottom to the axis/axle of hole, mm; d, d_1, d_2 (Figs 70 and 71) - diameters of holes, mm; is accepted greatest; R_z - permissible tensile stress; it is selected in depending on the temperature of wall according to the data of Table 56; C - addition to the calculated thickness: C=3 mm; for the anechoic bottoms in calculated wall thickness to 17 mm C=2 mm and for the bottoms, manufactured from steel casting, C=5 mm.

Table 55. Value of the form factor of bottom in depending on its sizes/dimensions and arrangement of holes.

(1) Отношение высоты днища к его диаметру $\frac{h}{D_н}$	(2) Фактор формы y							
	(3) днища глухого или рассматриваемого как глухое	(4) днища с лазовыми или иными отверстиями с отношением $\frac{l+d}{D_н}$, (5) равным						
		0,1	0,2	0,3	0,4	0,5	0,6	0,7
0,20	2,00	2,05	2,20	2,40	2,50	2,75	2,90	3,10
0,22	1,65	1,80	2,00	2,15	2,30	2,50	2,70	2,85
0,24	1,40	1,60	1,75	1,95	2,10	2,30	2,50	2,65
0,25	1,30	1,50	1,65	1,85	2,05	2,20	2,40	2,60
0,26	1,25	1,40	1,60	1,75	1,95	2,15	2,30	2,50
0,28	1,10	1,30	1,45	1,60	1,80	2,00	2,20	2,40
0,30	1,00	1,15	1,35	1,50	1,70	1,90	2,05	2,25
0,40	0,75	0,90	1,05	1,20	1,40	1,60	1,75	1,95
0,50	0,75	0,90	1,05	1,20	1,40	1,60	1,75	1,95

Notes: 1. "Anechoic" is called the bottom, which has no holes (cutouts).

2. For intermediate values $\frac{h}{D_н}$ and $\frac{l+h}{D_н}$ form factor is determined by interpolation.

Key: (1). Ratio of the height/altitude of bottom to its diameter. (2). Form factor. (3). bottom anechoic or of that considered as anechoic. (4). bottom with through or other holes with relation. (5). equal.

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The wall thickness of the spherical bottom

$$s = \frac{pr}{200\,R_z} + C \text{ мм},$$

where r - an inside radius of sphere, mm; p, R_z and C - the same as in formula (230).

During the calculation of the wall thickness of the bottoms, subject to internal pressure at normal temperature (cistern and other vessels, which work under conditions, close to body constructions/designs), the allowable stress takes as the equal to:

$$R_z = 0{,}6\sigma_s \quad \text{kg/cm}^2$$

where σ_s - yield point of material at normal temperature, kg/cm².

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Table 56. Values of allowable stresses for calculating the thickness of bottoms and covers/caps, subjected to internal pressure.

(1) Температура стенки $t_{ст}$, °C	(2) Допускаемое напряжение R_z, кг/мм²		
	(3) для штампованных днищ	(4) для литых днищ	(5) для плоских крышек
(6) Менее 250	$\frac{\sigma_b}{2,9}$	$\frac{\sigma_b}{4,4}$	$\frac{\sigma_b}{3,2}$
(7) От 250 (8) до 400	$\frac{\sigma_s^t}{1,25}$	$\frac{\sigma_s^t}{1,9}$	$\frac{\sigma_s^t}{1,4}$
(9) Более 400	$\frac{\sigma_s^t}{1,25}$; $\frac{\sigma_n^t}{0,9}$ *1	$\frac{\sigma_s^t}{1,9}$; $\frac{\sigma_n^t}{1,4}$ *1	$\frac{\sigma_s^t}{1,4}$; $\frac{\sigma_n^t}{0,9}$ *1

The designations: σ_b - the limit of the strength of metal to the elongation at temperature of 20°C, kg /mm²; σ_s^t - yield stress of metal at temperature t, kg /mm²; σ_n^t - creep limit of metal at temperature t, kg /mm².

Key: (1). Temperature of wall. (2). Allowable stress R_z kg /mm². (3). for stamped/die-forged bottoms. (4). for cast bottoms. (5). for flat/plane covers/caps.

FOOTNOTE [1]. Is taken small value. ENDFOOTNOTE.

Additional requirements for the dished bottoms.

1) Bottoms are considered as "anechoic" in the following cases:

a) when the maximum size of the unfastened/unstrengthened cutouts it does not exceed 4s with the condition that the distance between the edge of cutout and the edge of bottom (on the projection) comprises less than 0.2 D_n;

b) when the maximum size of the completely fastened/strengthened cutouts it does not exceed 8s and the distance between the edge of cutout and the edge of bottom (on the projection) exceeds 0.2 D_n;

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c) when the maximum size of the completely fastened/strengthened cutouts does not exceed 6s and the distance between the edge of cutout and by the edge of bottom (on the projection) it exceeds 0.1 D_n;

2. The stamped edges of through hole reinforcement are not considered.

3. Holes in bottoms can be arranged/located out of zone of transfer arc at a distance not less than s from end of this arc.

4. Hole in center of flanged bottom outside can be carried out by diameter to 450 mm without special strengthening.

5. Height of cylindrical side of bottom H must be equal at thickness of bottom: to 10 mm - not less than 25 mm, from 10 to 20 mm - not less than 40 mm, more than 20 mm - according to thickness of bottom, but not less than 50 mm.

6. Thickness of cylindrical part of bottom must correspond to calculated thickness of cylindrical housing of vessel of the same diameter. In this case the turned edge must comprise not less than 0.9 thickness of bottom.

7. For welded bottoms into denominator of formula (230) is introduced modulus of resistance of weld ϕ, taken on Table 50.

Dished bottoms, subjected to ambient pressure.

The wall thickness of the bottom

$$s = \frac{1.4pD_{w}y}{200R_{d}} + C \text{ мм}, \qquad (231)$$

where R_d - permissible compression stress, kg /mm².

Remaining designations and structural/design requirements are the same as for the bottoms, subjected to internal pressure.

Breaking stress in the bottoms, which work under the ambient pressure, relies on stability.

For the spherical bottoms

$$p_{кр} = \frac{2E}{\sqrt{3(1-\mu^2)}}\left(\frac{s}{r}\right)^2 \text{ kg/cm}^2. \qquad (232)$$

For the hemispheric ends

$$p_{кр} = \frac{k_1 k_2 \sigma_s}{\frac{r}{s} + \frac{\sigma_s}{k_2 E}\left(\frac{r}{s}\right)^2} \text{ kg/cm}^2. \qquad (233)$$

Here E - modulus of elasticity of material, kg/cm²; μ - Poisson ratio; s - the wall thickness of bottom, cm; r - the mean radius of bottom, cm; k_1=1.5; k_2=40 - for the stamped/die-forged bottoms from the whole sheet; k_1=1.1; k_2=20 - for the stamped/die-forged bottoms from the welded segments; k_1=0.75; k_2=12 - for the tapped bottoms of the welded segments; σ_s - yield point of material, kg/cm².

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The margin of the stability of the bottom

$$m = \frac{p_{кр}}{p} > 5,$$

where p - external overpressure, kg/cm².

Plate covers/caps, subjected to internal pressure.

The plate covers/caps, subjected to internal pressure (Fig. 72), are designed from the formula

$$\sigma = \frac{3}{\pi (s-C)^2}\left[\frac{0{,}18P_б(r^2-a^2)}{d^2} + 1{,}48P_б \lg\frac{r}{a}\right] + \\ + \frac{pR}{2\varphi(s-C)}\ \text{кг/см}^2, \qquad (234)$$

where σ - stress/voltage in the cover/cap, kg/cm²; s - thickness of cover/cap, cm; r - radius of a circle of bolts, cm; C - addition, cm; $P_б$ - load on all bolts, kg; a - distance from the axis/axle of cover/cap to the line of centers of packing, cm; d - external radius of the flange of cover/cap, cm; p - design pressure, kg/cm²; R - radius of the spherical segment of cover/cap, cm; φ - modulus of resistance of weld.

Allowable stress in the cover/cap is selected on the basis of the safety factors to the elongation; for the limit of strength $n_в = 4$, for the yield point $n_т = 1{,}8$.

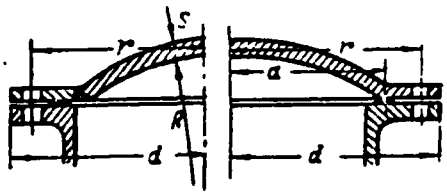

Fig. 72. On the calculation of plate covers/caps.

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In the plate covers/caps the cutouts in diameter to 50 mm do not require reinforcement with the condition of the sufficient clearance (not less than s) between the edge of cutout and weld, which connects spherical segment to the flange or cover/cap. Holes whose diameter is more than 50 mm are subject to reinforcement.

Conical bottoms, subjected to internal pressure.

1. Vessel is found under internal pressure of vapors or gases. Maximum tensile stress along the generatrix of the cone:

$$R_s' = \frac{pD}{2\varphi'(s-C)\cos\alpha} \quad \text{kg/cm}^2. \qquad (235)$$

Maximum tensile stress on the circular weld of the cone:

$$R_z^{\circ} = \frac{pD}{4\varphi''(s-C)\cos\alpha} \quad \text{kg/cm}^2. \qquad (236)$$

2. Vessel is filled with liquid to specific maximum altitude. Fig. 73 depicts vessel with a bore of D, conical bottom with a height/altitude of h_2 and central by angle 2α, filled with liquid on the height/altitude of cylindrical part, equal to h_1.

Maximum tensile stress along the generatrix of the cone:

$$R_z^{\circ} = \frac{\gamma D}{2\varphi'(s-C)\cos\alpha} h_1 \quad \text{kg/cm}^3. \qquad (237)$$

Maximum tensile stress on the circular weld of the cone:

with $h_1 < h_2/3$

$$R_z^{\circ} = \frac{3}{32}\frac{\gamma D}{\varphi'(s-C)\cos\alpha}(h_1 + h_2) \quad \text{kg/cm}^3 \qquad (238)$$

with $h_1 > h_2/3$

$$R_z^{\circ} = \frac{\gamma D}{12\varphi'(s-C)\cos\alpha}(3h_1 + h_2)^2 \quad \text{kg/cm}^2. \qquad (239)$$

In formulas (235)-(239): p - internal pressure in the vessel, kg/cm²; D - bore of vessel, cm; s - the wall thickness of conical bottom with the addition, cm; C - addition to the corrosion, etc.,

cm; ϕ' - modulus of resistance of weld along the generatrix of the cone; ϕ'' - the modulus of resistance of weld across the generatrix of the cone; α - halves central angle in the degrees; γ - the specific gravity/weight of liquid, kg/cm^2; h_1 - the maximum altitude of liquid in the cylindrical part, cm; h_2 - height/altitude of conical bottom from the apex/vertex to the base/root, cm.

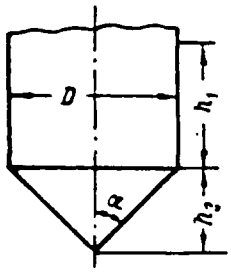

Fig. 73. On the calculation of conical bottoms.

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3. Vessel is filled with liquid above mirror of which occurs pressure of vapors or gases. In this case the calculation is conducted according to formulas (235) and (236), only instead of p in them is substituted the total pressure of liquid column and pressure in the vessel (kg/cm²).

§ 35. Calculation of flat/plane walls, covers/caps and bottoms.

Flat/plane walls and covers/caps without the reinforcements.

The thickness of the rectangular wall, attached on the perimeter (Fig. 74),

$$s = 0{,}53b\sqrt{\frac{p}{R_b\left(1+\frac{b^2}{a^2}\right)}} + C, \text{ мм}, \qquad (240)$$

where p - pressure on the wall, kg/cm²; b - smaller side of

rectangle, mm; R_b - allowable stress on the bend, kg/cm², equal to $\frac{\sigma_b}{4}$ for steel and $\frac{\sigma_b}{5}$ for the nonferrous alloys; here σ_b - the limit of the strength of material at operating temperature, kg/cm²; a - large side of rectangle, mm; C - addition, mm.

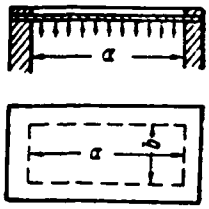

Fig. 74.

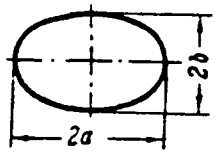

Fig. 75.

Fig. 74. On calculation of rectangular wall.

Fig. 75. On calculation of elliptical or oval wall.

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The thickness of the elliptical or oval wall, attached on the perimeter (Fig. 75),

$$s = b\sqrt{\frac{1{,}8p}{R_b\left(1+\frac{2}{3}\frac{b^2}{a^2}+\frac{b^4}{a^4}\right)}} + C \text{ мм}, \qquad (241)$$

where a - a semimajor axis of ellipse, mm; b - semiminor axis of ellipse, mm.

Remaining designations the same as in formula (240).

Thickness of circular flat/plane covers/caps and bottoms (Fig. (76)

$$s = d\sqrt{\mu\frac{p}{R_b}} + C \text{ см}, \qquad (242)$$

where d - a diameter of cover/cap or bottom, cm; p - maximum operating pressure, kg/cm²; R_b - allowable stress on the bend, kg/cm² [see formula (240)]; C - addition to corrosion, cm [see formula (230)]; μ - coefficient, equal to:

For the covers/caps, rigidly connected or the bolts or attached to the flanges of housing (Fig. 76a), and also for flat/plane bottoms, which compose one whole with the housing of apparatus (Fig. 76b) ... 0.162.

For the plates, rigidly attached on their contour/outline ... 0.187.

For the forged (pulled) bottoms, which compose one whole with the housing or welded with it butt (Figs. 76c and d) ... 0.250.

For the covers/caps, which undergo preliminary bend from the tightening of bolts, with the presence of the sealing projection on the cover/cap or the flange of housing (Fig. 76e) ... 0.300.

For the covers/caps, welded all over thickness to the internal surface of housing (Fig. 76f); in this case weld throat it must be not less than 1.25 the thinnest wall thicknesses of housing or bottom ... 0.500.

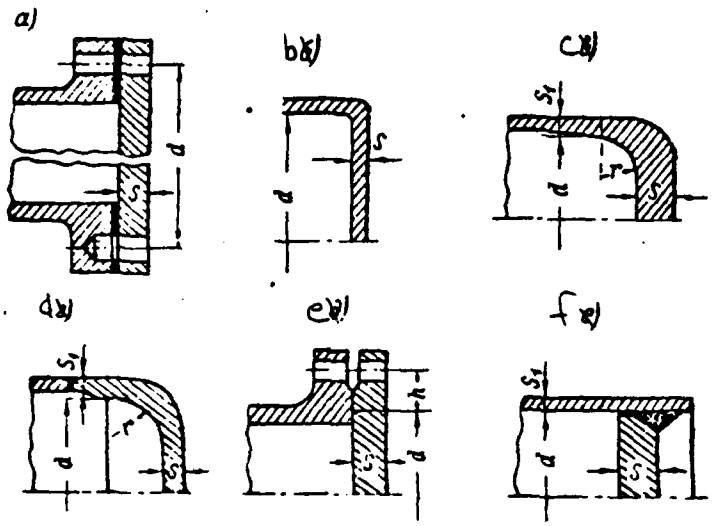

Fig. 76. On the calculation of the thicknesses of circular flat/plane covers/caps and bottoms.

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The thickness of the flat/plane stamped/die-forged bottom with the bent back edges, subjected to internal pressure (Fig. 77),

$$s=\sqrt{\frac{3p}{800\sigma_b}}\left[d-r_i\left(1+\frac{2r_i}{d}\right)\right]\text{мм}, \tag{243}$$

where p - great design pressure, kg/cm²; σ_b - limit of the strength of material, kg /mm²; d - bore of bottom, mm; r_i - inside radius of transfer arc from cylindrical part to the flat/plane, mm. Value r_i must be not less than 1/15 d.

Round plate with the hole in the center, attached on the

external and internal contours/outlines and subjected to bending by the evenly distributed load.

Maximum stress/voltage in the plate:

$$R_{max} = k_1 \frac{q r_n}{s^2} \text{ kg/cm}^2. \qquad (244)$$

Greatest sagging of the plate:

$$f_{max} = k_2 \frac{q r_n^2}{E s^3} \text{ cm}. \qquad (245)$$

Here q - intensity of load, kg/cm²; r_n - outside radius of plate, cm; s - thickness of plate, cm; E - modulus of elasticity of material, kg/cm²; k_1 - dimensionless voltage ratio, it is determined on Fig. 78, in depending on the ratio of an outside radius of plate r_n to a radius of hole r_m; k_2 - a dimensionless coefficient of the sagging/deflection; it is determined on Fig. 79 in depending on ratio r_n and r_m.

Initial data for the plotting of curves of the dimensionless voltage ratios and sagging are the fundamental equations of the theory of the bend of plates:

1) momental equation for the meridian cut;

2) the equation of the angle of the tangent inclination of the elastic line;

3) the equation of elastic line (equation of sagging).

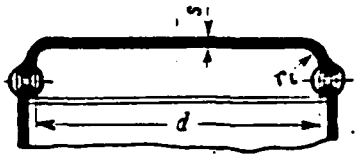

Fig. 77. On the calculation of the flat/plane stamped/die-forged bottoms with the bent back edges.

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Flat/plane walls, fastened by spacing or anchor bolts.

Wall thickness during the even distribution of the fastenings

$$s = C\sqrt{p(a^2 + b^2)} \text{ мм.} \qquad (246)$$

Wall thickness during the nonuniform distribution of the fastenings

$$s = 0{,}5C(d_1 + d_2)\sqrt{p} \text{ мм,} \qquad (247)$$

where C - the calculated coefficient, taken on Table 57; p - great design pressure, kg/cm²; a - distance between spacing or anchor bolts in one series/row (Fig. 80), mm; b - distance between the series/rows of spacing or anchor bolts (Fig. 80), mm; d_1, d_2 - distance between fastenings (Fig. 81), mm.

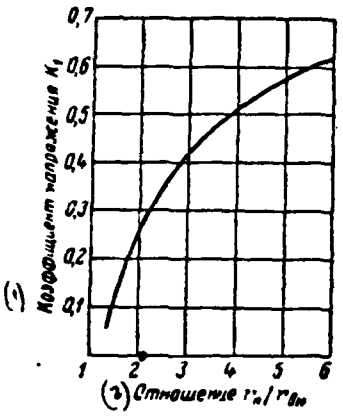

Fig. 78.

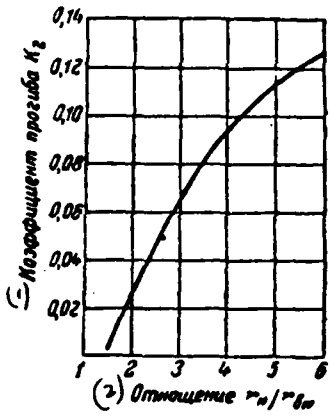

Fig. 79.

Fig. 78. Value of coefficient of k_1 in depending on relation of radii $\frac{r_н}{r_{вн}}$.

Key: (1). Coefficient of stress/voltage. (2). Relation.

Fig. 79. Value of coefficient of k_2 in depending on relation of radii $\frac{r_н}{r_{вн}}$.

Key: (1). Coefficient of sagging/deflection. (2). Ratio.

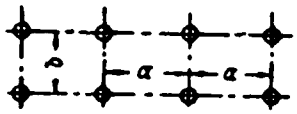

Fig. 80.

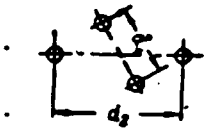

Fig. 81.

Fig. 80. Evenly distributed fastenings.

Fig. 81. Unevenly distributed fastenings.

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Formulas (246) and (247) are derived into the assumptions that the walls made of steel have limit of the strength of material $\sigma_b = 36$ kg /mm². With accomplishing of walls with the large limit of the strength of material their thickness must be reduced by the multiplication of value s on $\sqrt{\frac{36}{\sigma_b}}$.

If the temperature of the medium, which washes wall, is more than 230°C, calculation is conducted taking into account the temperature.

Flat/plane wall, reinforced by stiffening ribs (Fig. 82). A number of transverse and longitudinal edges/fins, and also their

size/dimension and profile/airfoil are selected from the conditions of allowable stresses in the material of wall and edges/fins. Usually as the edges/fins are considered angle plates.

Calculation is conducted according to the greatest side of flat/plane wall.

Let us introduce the following designations: p - design pressure on the wall, kg/cm²; a - large side of the rectangle of wall, included between the edges/fins, cm; b - smaller side of the same rectangle of wall, cm; h - height of edge/fin, cm; l - length of edge/fin along the greatest side of wall, cm; B - width of band, equal to side of rectangle, arranged/located along the length of edge/fin l, ~~sec~~ cm.

Table 57. Values coefficient C.

(1) Значения C	(2) Условия работы плоских стенок
0,017	(3) Для омываемых горячими газами и водой стенок, в которые ввертываются на резьбе распорные или анкерные болты и расклепываются
0,015	(4) Для таких же стенок, но не омываемых горячими газами
0,0155	(5) Для омываемых горячими газами и водой стенок, в которые ввертываются на резьбе распорные или анкерные болты с наружными гайками или точеными головками.
0,0135	(6) Для таких же стенок, но не омываемых горячими газами
0,014	(7) Для стенок, скрепленных только анкерными трубками
0,013	(8) Для неомываемых горячими газами стенок, имеющих анкеры, снабженные гайками и скрепляющими шайбами, при этом диаметр наружной скрепляющей шайбы равен $^2/_5$ расстояния между анкерами и толщина шайбы равна $^2/_3$ толщины стенки
0,012	(9) Для таких же стенок, но диаметр наружной скрепляющей шайбы равен $^3/_5$ расстояния между анкерами и толщина шайбы равна $^5/_9$ толщины стенок
0,011	(10) Для таких же стенок, но диаметр наружной скрепляющей шайбы равен $^4/_5$ расстояния между анкерами и шайбой, толщина которой равна толщине стенки и которая приклепана к этой стенке

Key: (1). Values. (2). Working conditions of flat walls. (3). For washed by hot gases and water walls, into which are screwed in on thread spacing or anchor bolts and are unriveted. (4). For the same walls, but not washed by hot gases. (5). For washed by hot gases and water walls, into which are screwed in or thread spacing either anchor bolts with external nuts or exact heads. (6). For walls, fastened only by stay tubes. (7). For walls unreached by hot gases, which have anchors, equipped with nuts and fastening washers, in this case diameter of external fastening washer is equal to 2/5 distances between anchors and thickness of washer is equal to 2/3 wall thicknesses. (8). For the same walls, but diameter of external fastening washer is equal to 3/5 distances between anchors and

thickness of washer is equal to 5/6 wall thicknesses. (9). For the same walls, but diameter of external fastening washer is equal to 4/5 distances between anchors and washer whose thickness is equal wall thickness and which is riveted to this wall.

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F_1 - cross-sectional area of edge/fin, cm²; X_1X_1 - centroidal axis of the section/cut of the edge/fin; X_2X_2 - centroidal axis of the section/cut of the band of the flat/plane wall; XX - centroidal axis of section of band and edge/fin; OO - axis/axle of the base/root of the band; I_{X_1} - second moment of area of edge/fin relative to axis/axle X_1X_1, cm⁴; it is determined from the tables for the profile/airfoil accepted and the size/dimension of the edge/fin; Z_0 - distance of the apex/vertex of edge/fin from axis/axle X_1X_1, cm; s - thickness of rectangular wall, included between the stiffening ribs, it is determined by formula (240), cm;

Y_1 - distance of axis/axle X_1X_1 from axis/axle OO

$$Y_1 = h + s - Z_0 \text{ см};$$

Y_2 - distance of axis/axle X_2X_2 from axis/axle OO

$$Y_2 = 0{,}5s \text{ см};$$

F_2 - cross-sectional area of the band

$$F_2 = Bs \text{ см};$$

Z - distance of the neutral axis/axle XX from axis/axle OO

$$Z = \frac{F_1 Y_1 + F_2 Y_2}{F_1 + F_2} \text{ см};$$

a_1 - distance between centers X_1X_1 and XX

$$a_1 = Y_1 - Z \text{ см};$$

a_2 - distance between centers X_2X_2 and XX

$$a_2 = Z - Y_2 \text{ см};$$

Y_3 - distance of the outermost filament from axis/axle XX

$$Y_3 = s + h - Z \text{ см}.$$

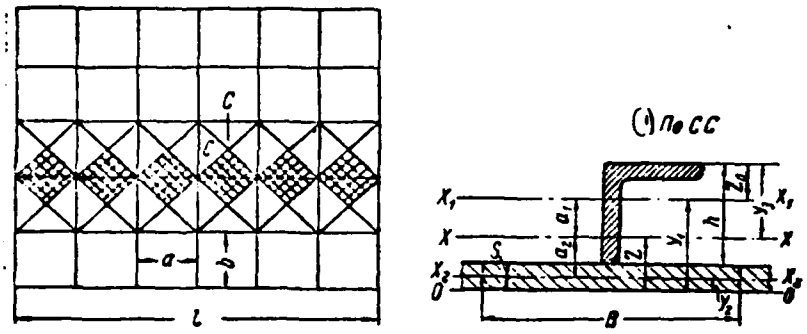

Fig. 82. On the calculation of the flat/plane wall, reinforced by stiffening ribs.

Key: (1). On.

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Load, which effects on the edge/fin and the band,

$$Q = lBp \text{ kg.} \tag{248}$$

Greatest bending moment, which effects on the edge/fin and the band,

$$M = \frac{Ql}{12} \text{ kg}\cdot\text{cm.} \tag{249}$$

Second moment of area of band relative to axis/axle X_2X_2

$$I_{x_1} = \frac{Bs^3}{12} \text{ см}^4. \tag{250}$$

Second moment of area of edge/fin relative to axis/axle XX

$$I_1 = I_{X_1} + a_1^2 F_1 \ cм^4. \qquad (251)$$

Second moment of area of band relative to axis/axle XX

$$I_2 = I_{X_2} + a_2^2 F_2 \ cм^4. \qquad (252)$$

Total moment of the inertia of edge/fin and band relative to axis/axle XX

$$I = I_1 + I_2 \ cм^4. \qquad (253)$$

Stress/voltage, which appears in the edge/fin from the action of moment/torque M,

$$R_s = \frac{MY_s}{I} \ \text{kg/cm}^2. \qquad (254)$$

Stress/voltage, which appears in the band from the action of moment/torque M,

$$R_z = \frac{MZ}{I} \ \text{kg/cm}^2. \qquad (255)$$

Walls and reinforcements of rectangular vessels.

During determining of the dimensions of rectangular vessels they use predominantly the relationships/ratios

$$B = \sqrt{V}; \ L = \frac{3}{2} B; \ H = \frac{2}{3} B,$$

where B - the width; L - length; H - height/altitude; V - volume.

The pressure of liquid on the wall of the vessel

$$p = 0{,}85\gamma H \quad \text{kg/cm}^2 \qquad (256)$$

where γ - the specific gravity/weight of liquid, kg/cm³; H - height of liquid column, cm.

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The wall thickness of the vessel:

$$s=\sqrt{\frac{3pL^2H^2}{8R_b(H^2+L^2)}}+C \text{ см}, \qquad (257)$$

where L - length of wall, or distance between upright struts, cm;

H - height/altitude of wall, or distance between horizontal stiffeners, cm;

R_b — allowable stress on the bend, kg/cm²;

C - addition to the corrosion, see

The moment of resistance of the upright strut:

$$W=\frac{\gamma LH^2}{16R_b} \text{ см}^3, \qquad (258)$$

where γ - the specific gravity/weight of liquid, kg/cm³;

L - distance between struts, cm;

H - height of vertical wall, cm;

R_b — allowable stress on the bend of the material of strut, kg/cm².

At the calculated moment of resistance is selected the corresponding section/cut of strut.

Length of horizontal stiffener or distance between connections/communications, which fasten horizontal stiffeners, in the presence of one series/row of horizontal reinforcements on the height/altitude:

$$L = \frac{4}{H}\sqrt{\frac{R_b W}{\gamma}}\ \text{см.} \qquad (259)$$

Length of lower horizontal stiffener or distance between connections/communications, which fasten lower horizontal stiffener, in the presence of two series/rows of horizontal reinforcements on the height/altitude:

$$L_1 = 4\sqrt{\frac{R_b W}{\gamma\left(H - \frac{h_1 + h_2}{4}\right)(h_1 + h_2)}}\ \text{см.} \qquad (260)$$

Length of upper horizontal stiffener or distance between connections/communications, which fasten upper stiffener, in the presence of two series/rows of horizontal reinforcements on the height/altitude:

$$L_2 = \frac{4}{H - \frac{h_1 + h_2}{2}}\sqrt{\frac{R_b W}{\gamma}}\ \text{см.} \qquad (261)$$

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Here W - moment of resistance of horizontal reinforcements, cm^3;

h_1 - distance from the bottom to the lower horizontal element/cell, cm;

h_2 - distance from the bottom to the upper horizontal element/cell, cm;

R_b, γ and H - the same as in formula (258).

The distance between the beams/gullies under the bottom of the vessel:

$$l = 1{,}254s\sqrt{\frac{R_b}{\gamma H}}\ \text{см}, \qquad (262)$$

where s - the wall thickness of bottom without additive C, cm;

R_b, γ and H - the same as in formula (258).

During the calculation of the thicknesses of walls and bottom of welded rectangular vessel the modulus of resistance of weld ϕ it is possible not to consider under the condition for the arrangement of weld at a distance of 1/4 flight/span between the struts or the beams/gullies where the bending moment has minimum absolute value.

Rectangular chambers/cameras, subjected to internal pressure.

The thickness of wall s of rectangular chamber/camera is determined on the stresses/voltages, which appear in the angle of chamber/camera, and on the stresses/voltages, which appear in the most weakened section/cut of wall (Fig. 83).

For the first case

$$s = \frac{p}{200R}\sqrt{m^2 + l^2} + \sqrt{6M_0 \frac{p}{100R}} \text{ мм.} \quad (263)$$

For the second case

$$s = \frac{p}{200R}\frac{l}{\varphi} + \sqrt{\frac{6M_0}{\varphi'}\frac{p}{100R}} \text{ мм.} \quad (264)$$

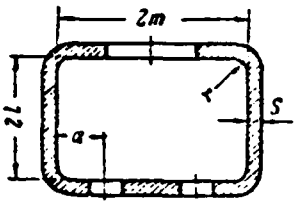

Fig. 83. On the calculation of rectangular chambers/cameras.

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Here p - design pressure of medium, kg/cm²;

R - allowable stress, kg/cm² (it is accepted on Tables 56);

M_a — conditional bending moment in the angle of chamber/camera (referred to the unit of length and to the pressure 100 kg/cm²), determined according to the formula

$$M_a = \frac{1}{3}\,\frac{m^2 + l^2}{m + l}\ мм^2;$$

M_b — the conditional bending moment in any place of the designed side of chamber/camera (referred to the unit of length and to the pressure 100 kg/cm²), determined according to the formula

$$M_b = ma - \frac{a^2}{2} - \frac{1}{3}\,\frac{m^2 + l^2}{m +}\ мм^2.$$

m - half-width in the light/world of the designed side of

chamber/camera, mm;

l — half-width in the light/world of the side, perpendicular to that designed, mm;

a - small distance from the internal surface of side wall to the axis/axle of weakening (hole or weld), mm;

ϕ - coefficient of strength of weld, it is accepted on tables 50;

ϕ' - coefficient of weakening bore surface, equal to

$$\varphi' = \frac{t-d}{t},$$

where t - pitch of holes, mm;

d - diameter of holes, mm.

836. Calculation of the unfastened/unstrengthened and fastened/strengthened holes.

Unfastened/unstrengthened holes.

Unfastened/unstrengthened are considered: a) hole under the rolling-out and the thread; b) hole packed with access or other

gates; c) the holes, intended for the connection of tubes, branches, bushings and the like on the victuals, if the construction/design of welds does not provide the joint operation of the welded elements/cells with the vessel.

The permissible greatest diameter of unfastened/unstrengthened holes $d_н$ will be determined according to the formula

$$d_н = 8{,}1\sqrt[3]{D_в s(1-k)}\ мм, \qquad (265)$$

where $D_в$ — bore of housing, mm;

s - the wall thickness of housing, mm;

k - real modulus of resistance of vessel, determined in the formula

$$k = \frac{pD_в}{(230R_z - p)s} \leqslant 0{,}99,$$

where p - design pressure in the housing, kg/cm²;

R_z — permissible tensile stress, kgf/mm².

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In all cases the greatest diameter of the

unfastened/unstrengthened hole must not exceed

$d_н \leqslant 0{,}6D_в$ и $d_н \leqslant 200$ мм.

Key: (1). and.

For the elongated holes value $d_н$ must be replaced by the length of the large axis/axle of oval.

In the presence in vessel of the unfastened/unstrengthened holes the hydraulic test must be produced under the pressure, which does not exceed 1.5p, otherwise of hole preliminarily they must be fastened/strengthened.

Fastened/strengthened holes.

The sizes/dimensions of the reinforcements of holes usually are selected from the following relationships/ratios:

$$D > 2d; \quad b > 2s; \quad s \leqslant 2{,}5s_1,$$

where D - an outside diameter of fastening ring, cm;

d - bore of fastening ring, cm;

b=0.5(D-d) - the width of the fastening ring, cm;

s - thickness of the fastening ring, cm;

s_1 - the wall thickness of housing, ~~see~~ cm

The outside diameter of the fastening ring is determined by the formula:

$$D = \frac{d_1(s_1 - C - C_1)\varphi}{s} + d \text{ см}, \qquad (266)$$

where d_1 - a diameter of hole in housing, cm;

C - addition to corrosion, cm;

C_1 - structural/design or production addition, cm;

ϕ - modulus of resistance of weld.

1. If reinforcement of hole is fastened to rivets, then diameter of reinforcing ring, determined according to formula (266), must be increased to $n\delta$, where n - number of holes under rivets, intersected by critical section/cut of reinforcement, and δ - diameter of rivet holes, cm.

2. If housing of apparatus is carried out unwelded or if with welded housing weld intersects by hole, then in this case into

formula (266) is substituted modulus of resistance of weld $\phi=1$.

3. If to small hole is connected thick-walled branch connection without fastening finger/pin, then satisfactoriness of reinforcement, imparted by branch connection to hole, can be checked according to formula (266), in this case instead of size/dimension of d_1 is substituted bore of branch connection d_{max}, and for size/dimension of s_1 - height/altitude of branch connection, equal to 2.5 (s_1-C), cm.

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4. If hole has not circular, but elliptical or rectangular form, then instead of diameter of hole d_1 into formula (266) is substituted its greatest size/dimension (with exception of case, presented in p. 5) and respectively is determined greatest outside dimension of reinforcement of hole.

5. If on cylindrical housing is arranged/located elliptical or rectangular hole whose major axis perpendicular to axis/axle of cylinder (Fig. 84), then instead of maximum size of hole is substituted either its width b or half length $l/2$, in depending on that which of values is more.

§37. Calculation of the riveted seams.

The diameter of rivets is determined on the empirical formulas for the single-sheet welds (overlapping or with one cover plate):

$$d = \sqrt{5s} - 0{,}4 \text{ см}, \qquad (267)$$

where s - a thickness of sheets, see

Spacing of the rivets:

1) for the single-row weld (Fig. 85a)

$$t = 2d + 0{,}8 \text{ см};$$

2) for the double-row weld with bussing arrangement of rivets (Fig. 85b)

$$t = 2{,}6d + 1{,}0 \text{ см};$$

3) for the double-row weld with the staggered arrangement of rivets (Fig. 85c)

$$t = 2{,}6d + 1{,}5 \text{ см}.$$

Distance from the edge of sheet to the center of the rivet:

$$a = 1{,}5d \div 1{,}6d \text{ см}.$$

Distance between the rows of rivets with their bussing arrangement:

$$a_1 = 0{,}8t \text{ см}.$$

Distance between the rows of rivets with their staggered arrangement:

$$a_2 = 0{,}6t \text{ см}.$$

Coefficient of weakening the sheets:

$$\varphi = \frac{t-d}{t}.$$

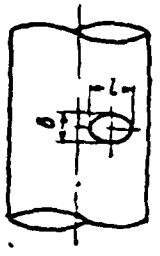

Fig. 34. On the calculation of the reinforcements of holes.

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The force, which falls on 1 cm of weld length:

$$P = \frac{p_0 D}{2} \text{ кг/см}, \qquad (268)$$

Key: (1). the kg/cm

where p_0 - high design pressure in the housing, kg/cm²;

D - bore of housing, cm.

The permissible force P must not exceed:

For the single-row welds kg/cm P<500

For the double-row welds with the staggered arrangement of

rivets P=390-950

For the double-row welds with bussing arrangement of rivets P=390-1000.

Specific sliding resistance:

$$k = \frac{Pt}{0.7K_{\text{м}}l^2} \text{ кг см}^2. \qquad (269)$$

Key: (1). kg/cm².

Permissible specific sliding resistance for single-row welds

$$k \leqslant 700 \text{ kg/cm}^2.$$

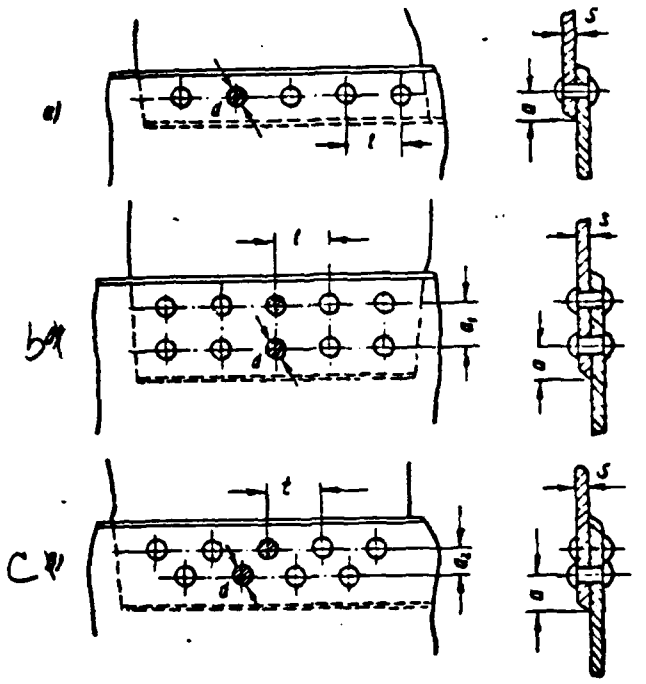

Fig. 85. On the calculation of the riveted seams.

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§38. Calculation of tubes.

The wall thickness of the tube

$$s = \frac{p\,l\,n}{2\sigma_{bp}\varphi} + C \text{ см}, \qquad (270)$$

where p - maximum operating pressure, kg/cm²;

d - bore of tube, cm;

σ_b — limit of the strength of the material of tube, kg/cm^2;

ϕ - modulus of resistance of weld;

C - addition to the ovality, the corrosion, etc.;

n - safety factor, equal to:

For the liquids..... 4.5.

For vapor..... 5.6.

For superheated steam..... 7.1.

Tubes in wall thickness of less than 1 mm for the shipboard heat exchangers are not applied.

Thicknesses and outside diameters of tubes are accepted on the standards in the dependence on the internal diameters and the pressures.

The recommended tubes for the heat exchangers are shown in Table

58.

The passes of branch connections, welds, branches and the like for the connection of tubes to the apparatuses take as the equal to the internal diameters for the fittings, the fittings and the conduits/manifolds (according to GOST 355-53, Table 59) whose strength must be selected in depending on conditional pressures according to GOST 356-52.

Table 58. Recommended tubes for the heat exchangers.

Назначение трубок (1)	Диаметры, мм (2)	Материал (3)	ГОСТ
Для подогревателей топлива (4)	17/13	Сталь (5)	301—50
Для конденсаторов и охладителей воды (6)	16/14 16/13	Мельхиор (7) Латунь (9)	2203—43 494—52
Для маслоохладителей (8)	10/8 16/14	Мельхиор (7) Латунь (9)	2203—43 494—52
Для подогревателей воды и масла (10)	10/8 16/14 16/13	Латунь (9)	494—52
Для испарителей (11)	36/32	Медь (12)	617—53
Для воздухонагревателей (12)	10/8	Латунь (9)	494—52
Для воздухоохладителей (13)	10/8	Мельхиор (7)	2203—43
Для бытовых аппаратов и цистерн с подогревом (14)	16/13	Медь (12)	617—53
Для змеевиков подогрева масла и топлива (15)	26/20	Медь (12)	617—53
Для манометров (16)	9/6	Медь (12)	617—[illegible]

Key: (1). Designation/purpose of tubes. (2). Diameters, mm. (3). Material. (4). For fuel heaters. (5). Steel. (6). or capacitors/condensers and coolants of water. (7). German silver. (8). For oil coolers. (9). Brass. (10). For preheaters of water and oil. (11). For vaporizers/evaporators. (12). For air heaters. (13). For air coolers. (14). For everyday apparatuses and cisterns with preheating. (15). For coils of preheating oil and fuel/propellant. (16). For manometers.

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For the fittings and the connecting pieces of the conduits/manifolds, manufactured from steel, pressure conditional, workers and test are given in Table 60, and from the nonferrous metals - in Table 61.

Table 61. Passes conditional for the reinforcement, the fittings and the conduits/manifolds GOST 355-52 with the limitation on a VN-C1-1158-52.

Диаметры условных проходов, мм (1)							
3	20	50	100	200	300	400	700
6	25	60	125	(225)	(325)	450	800
10	32	70	150	250	350	500	900
15	40	80	175	(275)	(375)	600	1000

Note. The values of the internal diameters, included in the brackets, it is permitted to apply only in the exceptional cases for the steam line.

Key: (1). Diameters of internal diameters, mm.

Table 60. Pressures for the reinforcement and the connecting pieces of the conduits/manifolds made of the carbon steel (according to GOST 356-52).

Давления, кг/см² (1)		Давления рабочие наибольшие при температурах среды в С, кг/см² (2)						
условные p_y (3)	пробные (водой при температуре ниже 100° С) (4) $p_{пр}$	до 200 (5) p_{20}	250 p_{25}	300 p_{30}	350 p_{35}	400 p_{40}	4 5 p_{42}	450 p_{45}
1	2	1	1,0	1,0	0,7	0,6	0,6	0,5
2,5	4	2,5	2,3	2,0	1,8	1,6	1,4	1,1
4	6	4	3,7	3,3	2,9	2,6	2,3	1,[illegible]
6	9	6	5,5	5,0	4,4	3,8	3,5	2,7
10	15	10	9,2	8,2	7,3	6,4	5,8	4,5
16	24	16	15	13	12	10	9	7
25	38	25	23	20	18	16	14	11
40	60	40	37	33	30	28	23	18
64	96	64	59	52	47	41	37	29
100	150	100	92	82	73	64	58	45
160	240	160	147	131	117	102	93	72
200	300	200	184	164	146	128	116	99
[illegible]	350	250	230	205	182	160	145	112
[illegible]	430	320	294	262	234	205	185	144
[illegible]	520	400	368	328	292	256	232	180
[illegible]	625	500	460	410	365	320	290	225

Key: (1). Pressures, kg/cm². (2). Pressures working greatest at temperatures media in C, kg/cm². (3). conditional. (4). test (by water at temperature lower than 100°C). (5). to.

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Testing the wall thickness of tube to the thinning with the bend with a radius of is less $3{,}5 d_н$

$$s_1 = s - \frac{s d_н}{2r + d_н} \text{ мм}, \qquad (271)$$

where s_1 - the wall thickness of tube after bend, mm;

s - the wall thickness of tube to bend, mm;

$d_н$ — outside diameter of tube, mm;

r - bending radius of tube, mm.

Testing tube to the bend. The bending deflection of the tube:

$$y_0 = \frac{5}{384}\frac{Gl^3}{EI} \text{ см}, \qquad (272)$$

where G - weight of tube with liquid, kg;

l — distance between supports (diaphragms, tube plates), cm; l is accepted not more than 1.5 m;

E - modulus of elasticity of the material of tube, kg/cm²;

I - the moment of the inertia of tube, cm⁴:

$$I = \frac{\pi}{64}(d_н^4 - d_в^4);$$

where $d_н$ — outside diameter of tube, cm;

$d_в$ — bore of tube, ~~sec~~ cm

Table 61. Pressures for the reinforcement and the connecting pieces of the conduits/manifolds from the bronze, brass and copper.

Давления, кг/см² (1)		Давления рабочие наибольшие при температурах среды в °С, кг/см² (4)		
условные $p_у$ (2)	пробные (водой при температуре ниже 100° С) $p_{пр}$ (3)	до 120 (5) p_{17}	200 p_{20}	250 p_{25}
1	2	1	1	0,7
2,5	4	2,5	2	1,7
4	6	4	3,2	2,7
6	9	6	5	4
10	15	10	8	7
16	24	16	13	11
25	38	25	20	17
40	60	40	32	27
64	96	64	—	—
100	150	100	—	—
160	240	160	—	—
200	300	200	—	—
250	350	250	—	—

Key: (1). Pressures, kg/cm². (2). conditional. (3). test (by water at temperature lower than 100°C). (4). Pressures working greatest at temperatures media in °C, kg/cm². (5). to.

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Maximum permissible bending deflection of tube $y_{max} = 2$ ~~with~~ mm.

Number of free oscillations/vibrations of the tube:

$$m = \frac{1}{2\pi}\sqrt{\frac{g}{y_0}}\ \text{кол/сек},^{(1)} \qquad (273)$$

Key: (1). osc./s.

where y_0 - a maximum bending deflection of tube, cm; g=981 cm/s² - acceleration of gravity.

Test hydraulic pressure of the heating and cooling tubes of apparatuses and quite heat exchangers is designated according to GOST 2029-52.

§39. Calculation of bolts and pins.

Complete effort/force, which effects on all bolts from the internal pressure of medium,

$$Q = pF\ \text{кг},^{(1)} \qquad (274)$$

Key: (1). kg.

where p - the design pressure of medium, kg/cm²;

F - area, limited by the centerline of packing, cm².

Calculated effort for one bolt with the arrangement of bolts in

the circumference (Fig. 86):

$$P_0 = \frac{kQ}{z} \text{ кг.} \qquad (275)$$

Key: (1). kg.

Calculated effort/force to the most loaded bolt during the arrangement of bolts on the ellipse or rectangle with the relation of the sides of rectangle $a/b<1.5$ (Fig. 87):

$$P_0 = \frac{kptF}{2\pi r} \text{ кг.} \qquad (276)$$

Key: (1). kg.

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Calculated effort for one bolt during the arrangement of bolts on rectangle with the relation of its sides $a/b \geqslant 1.5$:

$$P_0 = kptr \text{ кг,} \qquad (277)$$

Key: (1). kg.

where k - the coefficient of the tightening of bolt, which ensures the density of connection with the compression of the packing; k=1.8-2.0 at temperature of medium is less than 300°C; k=2.0-2.5 at temperature of medium is less than 300°C; k=2.0-2.5 at temperature of medium is more than 300°C;

z - number of bolts

$$z = \frac{U}{t},$$

where U - a perimeter or the line of the arrangement of bolts, cm:

for the circumference

$$U = \pi D_6;$$

for the rectangle

$$U = 2(a' + b');$$

for the ellipse

$$U = \pi\sqrt{2(a^2 + b^2)};$$

t - distance (space) between the bolts, cm, taken $t=(3.5-4.0)d_0$ - for oils; $t=(4.0-5.0)d_0$ - for the vapor, the water, the air, the fuel/propellant;

a - large side of rectangle (semi-axis of ellipse) between the centerlines of packing, cm;

a' - the same between the centerlines of the arrangement of bolts, cm;

b - smaller side of rectangle (semi-axis of ellipse) between the axial lines of packing, cm;

b' - the same between the centerlines of the arrangement of bolts, cm;

$D_б$ — diameter of a circle of the arrangement of bolts, cm;

r - small distance from the center of surface to the axis/axle of packing, cm;

d_0 - nominal diameter of the bolt

$$d_0 = 1{,}13\sqrt{\frac{P_{ин}}{\sigma_b}} + 0{,}5 \text{ см}, \qquad (278)$$

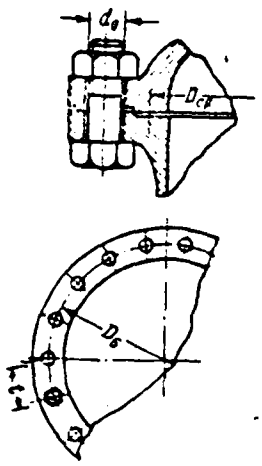
where σ_b — limit of the strength of the material of bolts, kg/cm²;

n - safety factor, taken:

For the precisely executed bolts and the bearing surfaces and the soft jointing material, and also for the cases when it is known that the material of bolts satisfies the technical specifications 5

For the well machined bolts and the surfaces and the soft jointing material 6.5

for the bolts, not not completely which do not satisfy the conditions, presented with $n=6.5$ 8



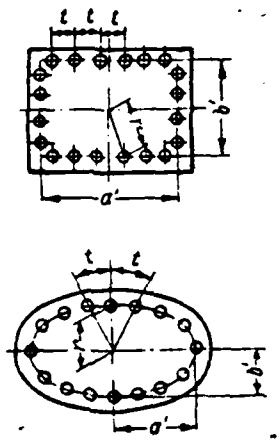


Fig. 86. On the calculation of the bolts, arranged/located in the circumference.

Fig. 87. On calculation of bolts, arranged/located in ellipse or rectangle.

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Stress/voltage in the stream of the bolt:

$$R_z = 1{,}27\frac{P_0}{d_0^2}\ \text{кг/см}^2, \qquad (279)$$

Key: (1). kg/cm².

where d_0 — diameter of bolt on the female thread, ~~see~~ cm

The permissible loads and stresses/voltages for the sealing bolts with the metric thread (without taking into account the coefficient of the tightening of bolts) are given in Table 62.

Table 62. Permissible loads and stresses/voltages for the sealing bolts with the metric thread.

Диаметр болта, d_0 (1)	Допускаемая нагрузка в кг при n, равном (2)			Допускаемое напряжение в кг/см² при n, равном (3)		
	5	6,5	8	5	6,5	8
M8	12	9	6	37	29	20
M10	58	46	31	114	90	60
M12	140	110	74	188	148	99
M14	256	202	135	251	198	133
M16	441	319	233	313	226	165
M18	595	470	314	348	275	184
M20	863	682	457	391	309	207
M22	1182	934	625	428	338	226
M24	1425	1126	754	449	355	238
M27	2048	1618	1083	489	386	258
M30	2615	2088	1383	514	406	272
M36	4162	3288	2201	558	441	295
M42	6067	4793	3209	591	467	313
M48	8329	6581	4405	616	486	326

Notes: 1. Table is given for the bolts from the common bolt material St.4 and Steel 20. With the use of other materials the permissible loads and stresses/voltages for the bolts must be changed with respect to a change in the limits of the strength of materials.

2. With increase in temperature allowable stress in bolts and pins must descend in accordance with incidence/drop in limit of strength of material.

3. Sealing bolts in diameter less than 12 mm for shipboard

apparatuses are not applied.

4. Upon consideration of force of tightening of bolts permissible loads and stresses/voltages, indicated in table, must be increased to coefficient of tightening of bolts accepted.

Key: (1). Diameter of bolt d_0. (2). Permissible load in kg with n, equal. (3). Allowable stress in kg/cm² with n, equal.

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Calculation of the fillet/shoulder of pin (Fig. 88):

Thickness of the fillet/shoulder of the pin

$$\delta = \frac{P_0}{\pi d_0 R_{cp}} \text{ см.} \qquad (280)$$

Key: (1). cm.

Diameter of the fillet/shoulder of the pin

$$d_6 = \sqrt{d_0^2 + \frac{1{,}27 P_0}{R_{см}}} \text{ см.} \qquad (281)$$

Key: (1). cm.

Of uniform strength conditions of fillet/shoulder and pin the

sizes/dimensions of fillet/shoulder must not be less

$$\delta > \frac{d_0}{3}; \; d_б > 1{,}4 d_0.$$

Here $R_{ср}$ — allowable stress in the fillet/shoulder on the shear/section, kg/cm², are accepted $R_{ср} = 0{,}6\ R_z$;

$R_{см}$ — allowable stress in the fillet/shoulder on the warping, kg/cm²; it is received $R_{см} = 1{,}8\ R_z$;

R_z — permissible tensile stress, kg/cm².

Remaining designations the same as in the calculation of bolts.

The minimum distances between the bolts for the unscrewing of nuts normal flat/plane open-end wrenches are given in Table 63.

§40. Calculation of flanges.

Thickness of the circular cast flange (Fig. 89)

$$s = \sqrt{\frac{6P_{п}az}{\pi D_f R_b k}} + C \text{ см.} \qquad (282)$$

Key: (1). cm.

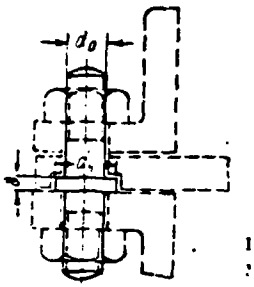

Fig. 88. On the calculation of the fillet/shoulder of pin.

Table 63. Minimum distances between the bolts.

d_0, мм	6	8	10	12	14	16	(18)	20	(22)	24	27	30	36	42	48
t_1	26	31	35	42	45	52	60	60	74	74	82	92	106	119	132
t_2	30	35	39	48	52	56	67	67	80	80	89	98	114	130	145
c	12	13	15	18	20	21	25	25	30	30	33	36	41	46	50

The designations: d_0 - nominal diameter of bolt, mm;

t_1 - distance between centers during the removal/taking of the key/wrench upward, mm;

t_2 - distance between centers of bolts during the removal/taking of key/wrench to the side, mm;

c - distance from axis/axle of bolt to the wall, mm.

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Thickness of circular welded flange (Fig. 90)

$$s = \beta \sqrt{\frac{P_0 (r_0 - r) t}{R_b (t - d) d}} + 1{,}2 \text{ см.} \qquad (283)$$

Key: (1). cm.

Formula (283) should be applied only for mean pressures and diameters, for other cases it is necessary to use formula (282).

Thickness of the rectangular (Fig. 91) or oval flange

$$s = \sqrt{\frac{6 P_0 a}{R_b (t - d) k}} + C \text{ см.} \qquad (284)$$

Key: (1). cm.

Thickness of the floating flange (Fig. 92)

$$s = 1{,}225 d_1 \sqrt{\frac{P_1 a}{R_b (D - d_f - 2d)}} + C \text{ см.} \qquad (285)$$

Testing bending stresses in the critical section/cut of flange (Fig. 93) can be produced according to the following formulas.

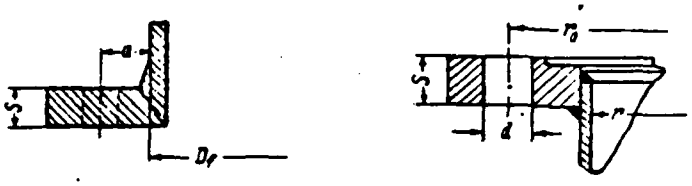

Fig. 89. On the calculation of the circular cast flange.

Fig. 90. On calculation of circular welded flange.

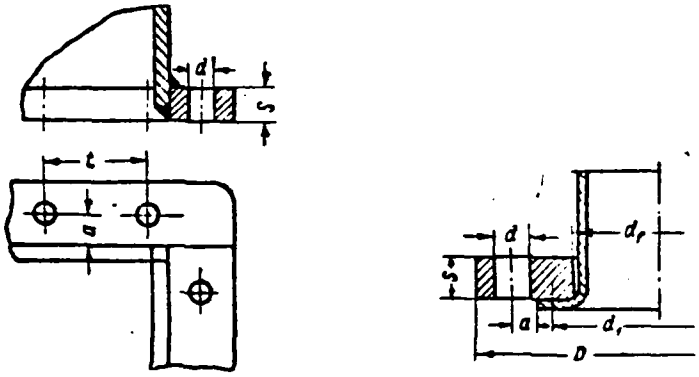

Fig. 91. On calculation of rectangular flange.

Fig. 92. On calculation of floating flange.

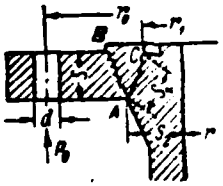

Fig. 93. On calculation of critical section/cut of flange.

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Bending stress in section/cut AB on the flange ridge

$$R_b = \frac{3P_0 z\,[r_0 - (r + s_2)]}{\pi (r + s_1)\, s^2}\ \text{кг/см}^2. \qquad (286)$$

Key: (1). kg/cm².

Bending stress in section/cut AC on the groove of the flange

$$R_b = \frac{3P_0 z\,[2r_0 - (r + s_1 + r_1)]}{\pi (r + s_2 + r_1)\, s_1^2}\ \text{кг/см}^2. \qquad (287)$$

Key: (1). kg/cm².

Testing flange joint to the density is determined from the formula

$$\alpha = t\sqrt[4]{\frac{P}{s^3}}, \qquad (288)$$

where $\alpha \leqslant 10$ - for steel and bronze;

$\alpha \leqslant 7$ - for cast iron;

Here s - thickness of flange, cm (in the presence of groove in the critical section/cut the calculated thickness of flange must be increased at the depth of groove);

p - the design pressure of medium, kg/cm²;

a - distance from the center of bolt hole to the wall (flanging or ring) of tube (arm of bend), or cm;

P_0 - calculated effort/force per one bolt, kg;

z - number of bolts;

D_1 - diameter of a circle of coupling flanged tube (critical section/cut), cm;

k - coefficient of the tightening of the bolts (see §39);

r_1 - radius of the outer edge of groove, cm;

s_1 - thickness of flange in the section/cut throughout the groove, cm;

s_2 - thickness of tube in the place of its coupling with the flange, cm;

r_0 - radius of a circle of the centers of bolt holes, cm;

r - inside radius of housing (tube), of cm;

D - outside diameter of flange, cm;

d_1 - diameter of the center line of packing, cm;

d_1 - bore of flange, cm;

d - diameter of bolt hole, cm;

C - addition, cm;

t - distance between the bolts (space of bolts), cm;

β=0.43 - coefficient for the flanges, which are not subjected load from the pressure of the packing/seal (flanges with the packing, which pass all over end surface from the action of the tightening of bolts do not test stress/voltage on the bend);

β=0.6 - coefficient for the flanges, loaded on the bend with the action of the sealing pressure (flanges with the packing on the part of the end surface);

$R_b = \frac{\sigma_b}{n}$ - allowable stress on the bend, kg/cm^2;

where σ_b — limit of the strength of material, kg/cm²;

n - safety factor, taken

For the steel flanges . . . . . 5—6

For the bronze and brass flanges . . . . . 6—7

For the steel and bronze casting. 8

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The calculation of flanges for rolling-out, for thread, for rivets or combinations of them is produced according to formula (283) for the welded flanges.

Flanges for the branch connections of heat exchangers are accepted according to GOST to the flanges in the dependence on the internal diameter and the conditional pressure (GOST 355-52 and GOST 356-52).

§41. Calculation of the tube plates.

The tube plates are one of the most critical parts of tubular heat exchangers. Working conditions of the tube plates depend in essence on designation/purpose and construction/design of heat exchangers.

In the practice found use the stated below procedure of calculation of different tube plates, based on the theory of the bend of plates taking into account the basic special features/peculiarities of the design concepts of heat exchangers and working conditions for their.

Let us introduce the following conventional designations:

p - design pressure of medium, kg/cm²;

s - thickness of the tube plate, cm;

r - calculated parameter of the attachments of the tube plate, cm;

r_1 - radius of a circle of bolt holes, cm;

b - smaller side of the rectangle, limited by the centerline of bolt holes, cm;

b_1 - smaller semi-axis of the ellipse, limited by the centerline of bolt holes, cm;

a - large side of the rectangle, limited by the centerline of bolt holes, cm;

a_1 - semimajor axis of the ellipse, limited by the centerline of bolt holes, cm;

D_1 — diameter of the center line of packing, cm;

d_n — outside diameter of tubes, cm;

n - number of tubes;

t - space of tubes with their laying out on equilateral triangle, cm;

t_1 - space of the arrangement of tubes in the series/row, cm;

t_2 - space between the series/rows of tubes, cm;

d_0 - diameter of connection/communication on the female thread, cm;

z - number of connections/communications;

r_c — radius of a circle of the arrangement of connections/communications;

c_1 - distance between the centerline of bolt holes and extreme series/row of connections/communications, arranged/located along the large side of rectangle or ellipse, cm;

c_2 - distance between the series/rows of connections/communications, arranged/located along the large side of rectangle or ellipse, cm;

c_3 - distance between connections/communications in the series/row, cm;

L - calculated bond length (distance between the planes of framing), cm ~~sec~~

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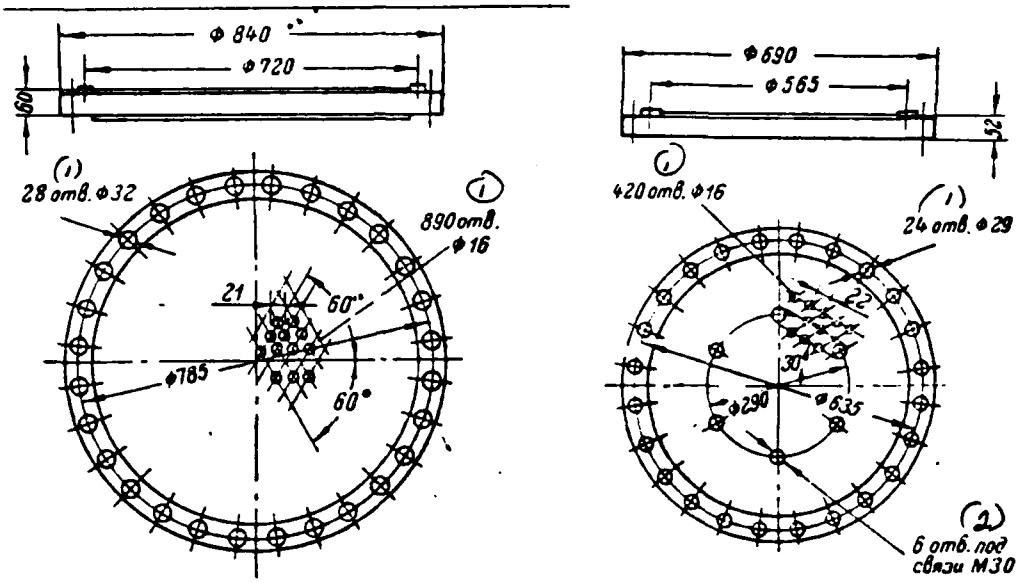

Fig. 94. On calculation of circular tube plate, not reinforced by connections/communications.

Key: (1). openings.

Fig. 95. On calculation of circular tube plate, reinforced by connections/communications.

Key: (1). openings. (2). openings for connections/communications.

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The thickness of the circular, rectangular and elliptical tube plates, not reinforced and reinforced by connections/communications,

is determined from the formula:

$$s = r\sqrt{\frac{\psi e p}{\eta R_b}} + C \text{ см.} \qquad (289)$$

The calculated parameter of the attachment of tube plate r is selected on Tables 64 in depending on form and method of attachment.

Coefficient ψ, which considers the method of the attachment of the tube plate in depending on its form, is selected on Tables 65 and 66.

Table 64. Value of the calculated parameter r.

Форма и способ закрепления трубной доски (1)	r
Для круглой доски, не подкрепленной (рис. 94) и подкрепленной (рис. 95) связями (2)	r_1
Для прямоугольной доски, не подкрепленной связями (рис. 96) (3)	b
Для эллиптической доски, не подкрепленной связями (4)	b_1
Для прямоугольной (рис. 97) или эллиптической доски, подкрепленной анкерными или распорными связями (принимается большая величина) (5)	(6) c_1 или c_2

Key: (1). Form and method of the attachment of the tube plate. (2). For circular panel, not reinforced (Fig. 94) and reinforced (Fig. 95) by connections/communications. (3). For rectangular panel, not reinforced by connections/communications (Fig. 96). (4). For elliptical of panel, not reinforced by connections/communications. (5). For rectangular (Fig. 97) or elliptical panel, reinforced by anchor or stays-bolt (is accepted high value). (6). or.

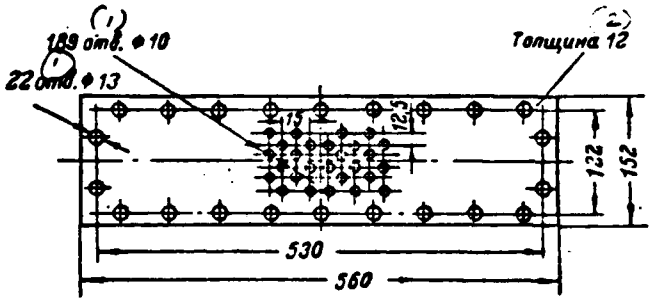

Fig. 96. On calculation of rectangular tube plate, not reinforced by connections/communications.

Key: (1). openings. (2). Thickness.

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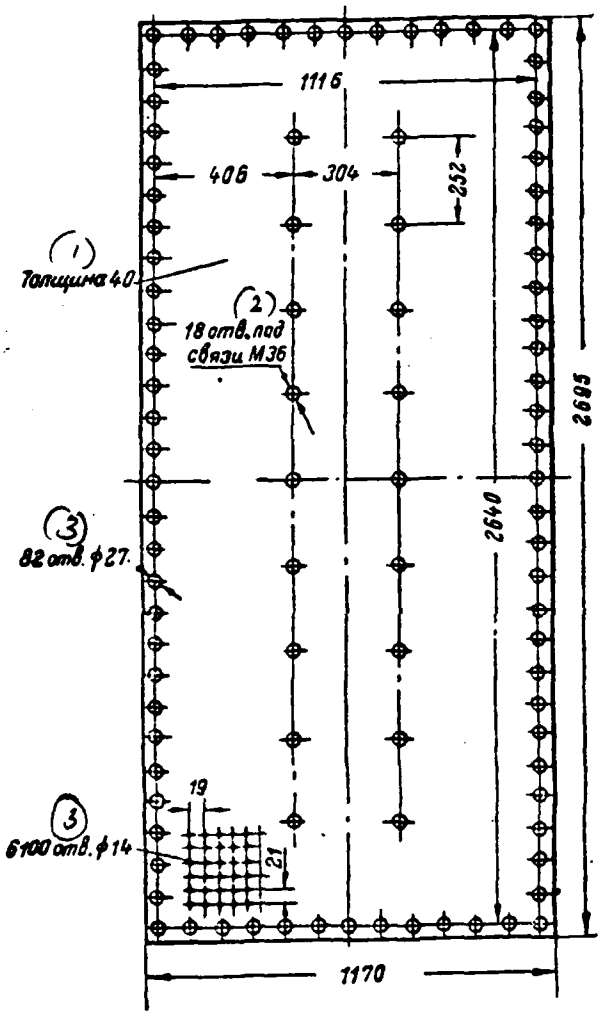

Fig. 97. On calculation of rectangular tube plate, reinforced by connections/communications.

Key: (1). Thickness. (2). openings for connections/communications.

(3). openings.

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The values of coefficient of ϕ are given as average values for the supported and jammed plate.

The coefficient of weakening the tube plate φ is determined from the following formulas.

During the laying cut of tubes on equilateral triangle

$$\varphi = 1 - 0{,}905 \frac{d_н^2}{t^2}. \qquad (290)$$

During the corridor or checkered laying cut of the tubes

$$\varphi = 1 - 0{,}785 \frac{d_н^2}{t_1 t_2}. \qquad (291)$$

The values of coefficient φ in depending on the diameter of tubes and their space, that have great use/application, are given in Table 67.

Coefficient ε, considering a change of the specific load on the tube plate in the dependence on the diagram of heat exchanger, is determined on Tables 68.

Table 65. Value of coefficient of ψ.

Форма и способ крепления трубной доски (1)	(2) Значение ψ
Для круглой доски, не подкрепленной связями (рис. 94) (3)	0,5
Для круглой доски, подкрепленной анкерными или распорными связями (рис. 95) (4)	0,75
Для прямоугольной доски, не подкрепленной связями, значение ψ выбирается в зависимости от отношения сторон прямоугольника a/b (рис. 96) (5)	(6) По табл. 66
(7) Для эллиптической доски, не подкрепленной связями	$\psi = \dfrac{1,8}{1 + \dfrac{2}{3}\dfrac{b_1^2}{a_1^2} + \dfrac{b_1^4}{a_1^4}}$
Для прямоугольной и эллиптической доски, подкрепленной анкерными или распорными связями, значение ψ выбирается в зависимости от отношения стороны прямоугольника a или полуоси эллипса a_1 к расстоянию c_1 или c_2 (к большей величине), рис. 97 (8)	По табл. 66 (6)

Key: (1). Form and method of fastening the tube plate. (2). Value. (3). For circular panel, not reinforced by connections/communications (Fig. 94). (4). For circular panel, reinforced by anchor or brace connections/communications (Fig. 95). (5). For rectangular panel, not reinforced by connections/communications, value of ψ is selected in depending on relation of sides of rectangle a/b (Fig. 96). (6). On tables. (7). For elliptical panel, not reinforced by connections/communications. (8). For rectangular and elliptical panel, reinforced by anchor or stays-bolt, value of ψ is selected in depending on ratio of side of rectangle a or semi-axis of ellipse a_1 to distance of c_1 or c_2 (to larger value), Fig. 97.

Table 66. Value of coefficient of ψ for the rectangular and elliptical panels in depending on the relation of their sides or semi-axes.

$\frac{a}{b}; \frac{a}{c}; \frac{a_1}{c_1}$	1,0	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	2,0	3,0	4,0	5,0	∞
ψ	0,30	0,33	0,37	0,41	0,44	0,47	0,49	0,51	0,53	0,55	0,56	0,60	0,62	0,63	0,63

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Table 67. Value of coefficient φ.

$d_н$, мм		17		16		10		
$\varphi = 1 - 0,905 \frac{d_н^2}{t^2}$	t	22	20	21	22	12,5	13	13,5
	φ	0,46	0,42	0,474	0,52	0,42	0,465	0,517
$\varphi = 1 - 0,785 \frac{d_н^2}{t_1 t_2}$	t_1	22	26	26	26	15	15	15
	t_2	19	20	21	22	12,5	13	13,5
	φ	0,46	0,615	0,635	0,65	0,583	0,595	0,61

Table 68. Value of coefficient

Схема теплообменника и приложение нагрузки (1)	Значение ε (2)
Для трубных досок любой формы с пучком V-образных трубок (рис. 98) или пучком прямых трубок, один конец которых закреплен в неподвижной, а второй — в плавающей трубной доске (рис. 99) при действии нагрузки с любой стороны (3)	$\varepsilon = 1$
Для круглых трубных досок с пучком прямых трубок, один конец которых закреплен в неподвижной, а второй — в подвижной в сальнике трубной доски, скрепленной с крышкой (рис. 100)	
а) при действии нагрузки со стороны крышек (4)	$\varepsilon = 1$
б) при действии нагрузки со стороны межтрубного пространства	$\varepsilon = 1 - \frac{d_н^2 n}{D_f^2}$
Для круглых трубных досок с пучком прямых трубок, закрепленных в двух неподвижных трубных досках (рис. 101) или одной из них, подвижной в сальнике, но не скрепленной с крышкой (рис. 102), при действии нагрузки с любой стороны (5)	$\varepsilon = 1 - \frac{d_н^2 n}{D_f^2}$
Для прямоугольных трубных досок с прямыми трубками, закрепленными в двух неподвижных трубных досках (рис. 101), при действии нагрузки с любой стороны (6)	$\varepsilon = 1 - 0{,}785 \frac{d_н^2 n}{ab}$
Для эллиптических трубных досок с прямыми трубками, закрепленными в двух неподвижных трубных досках (рис. 101), при действии нагрузки с любой стороны (7)	$\varepsilon = 1 - \frac{d_н^2 n}{4a_1 b_1}$

The designations: a and b - side of the rectangle; a_1 and b_1 - semi-axis of ellipse, they are accepted to the center line of packing.

Key: (1). Diagram of heat exchanger and load application. (2). Value. (3). For tube plates of any form with beam of V-shaped tubes (Fig. 98) or by pencil of straight lines tubes whose one end is attached in fixed, and by the second - in floating tube plate (Fig. 99) under

effect of load from any side. (4). For circular tube plates with pencil of straight lines tubes whose one end is attached in fixed, and by the second - in mobile in gasket tube plate, fastened with cover/cap (Fig. 100).

a) under the effect of load from the side of covers/caps.

b) under the effect of load from the side of inter-tube space. (5). For circular tube plates with pencil of straight lines tubes, attached in two fixed tube plates (Fig. 101) or one of them, mobile ones in gasket, but not fastened with cover/cap (Fig. 102) under effect load from any side. (6). For rectangular tube plates with straight/direct tubes, attached in two fixed tube plates (Fig. 101), under effect of load from any side. (7). For elliptical tube plates with straight/direct tubes, attached in two fixed tube plates (Fig. 101) under effect of load from any side.

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For the design pressure of medium p is accepted the larger pressure of working medium, which effects on one of the sides of the tube plate.

For vacuum capacitors the design pressure increases by 1 kg/cm^2,

which considers the greatest possible vacuum in the capacitor/condenser.

For the vertical tube banks at their relatively larger dimensions and weight and low pressures of working media the design pressure increases by the total weight of tubes, if it comprises more than 10o/o of the load, created a pressure of medium.

For the circular tube plates, reinforced by anchor or stays-bolt, design pressure p takes as the equal to the given specific load p'_2, determined according to formula (296). For the preliminary determination of the thickness of the tube plate from formula (289) tentatively it is accepted:

$$p'_2 = (0{,}5 \div 0{,}6)\, p \text{ кг/см}^2. \qquad (292)$$

Key: (1). kg/cm².

Full load from the pressure of working medium on the circular tube plate

$$Q = 0{,}785 D_{ip}^2 p \text{ кг}. \qquad (293)$$

by Key: (1). kg.

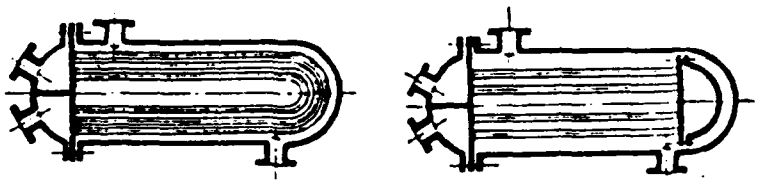

Fig. 98. Diagram of heat exchanger with the V-shaped tubes.

Fig. 99. Diagram of heat exchanger with floating tube plate.

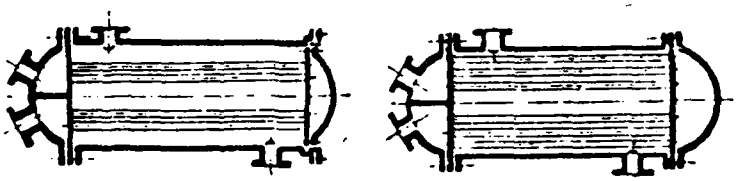

Fig. 100. Diagram of heat exchanger with mobile tube plate and cover/cap.

Fig. 101. Diagram of heat exchanger with two securely fastened tube plates.

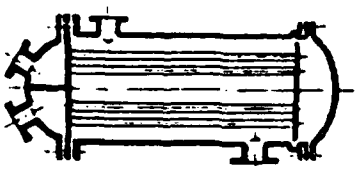

Fig. 102. Diagram of heat exchanger with mobile tube plate and fixed cover/cap.

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Load, which falls to the arcnor stays, arranged/located on the circular tube plate,

$$P_1 = \frac{\pi p (r_1^2 - r_c^2)^2}{8\left\{\left[-2r_c^2 \ln\frac{r_1}{r_c} + \frac{1}{2}\left(1 + \frac{r_c^2}{r_1^2}\right)(r_1^2 - r_c^2)\right] + \frac{8s^2\varphi L}{3d_0^2 z(1-\mu^2)}\right\}} \text{ кг.} \quad (294)$$

Load, which falls to tube plate,

$$P_2 = Q - P_1 \text{ кг.} \quad (295).$$

Key: (1). kg.

Given specific load on the circular tube plate

$$P_2' = \frac{P_2}{0{,}785 D_f^2} \text{ кг/см}^2. \quad (296)$$

Key: (1). kg/cm².

Load, which falls to one connection/communication,

$$P_1' = \frac{P_1}{z} \text{ кг.} \quad (297)$$

Key: (1). kg.

The advantageous relation of the radii of a circle of the arrangement of connections/communications r_c and bolts r_1 is within the limits $\frac{r_c}{r_1} \approx 0{,}45 \div 0{,}5.$

Poisson ratio μ is accepted:

for steels..... 0.3

For brasses. 0.33

For the bronze. 0.34

The spacing or anchor stays, which faster rectangular tube plates, are designed from the smallest section/cut of connection/communication for the load, which falls to the area, supported by connection/communication.

One series/row of connections/communications along the line of centers to establish/install is not recommended.

Allowable stress on the bend in the tube plate is designated according to the formula

$$R_b = \frac{\sigma_b}{n_b}. \qquad (298)$$

Safety factor n_b with respect to the lower limit of the strength of material σ_b of the tube plate at operating temperature of medium to 200°C is accepted

$$n_b > 4.$$

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At higher temperatures the value of ultimate strength is accepted at a prescribed/assigned calculated temperature with the subsequent testing of stresses/voltages on the yield point of material σ_s; safety factor in this case must be not less than 1.8.

Addition C to the minus tolerances of rolled stock, treatment and for the corrosion of the tube plates, etc.:

	CM
for the thickness of panels to 2.0 cm.	0.1
For the thickness of panels from 2.1 to 4.0 cm.	0.3
For the thickness of panels from 4.1 to 6.0 cm.....	0.3
For the thickness of panels are more than, 6.0 cm.	0.4

The smallest thickness of the tube plate in the place of the rolling of tubes, from the conditions of guaranteeing of strength and density of their rolling-out, must not be the less outside diameter of the tubes:

$$s > d_w$$

The smallest thickness of the tube plate in the place of weakening by its grooves, grooves and its envelopment under the

packing/seal flanges must not be less:

$$s_{min} > s\sqrt{1,5\varphi}.$$

The thickness of the sealing part of the welded tube plate must be designed just as flange.

Testing strasses/voltages in the bridge of tube plate, Fig. 103 (between four tubes), is produced according to the formula

$$R_b > \frac{p}{3,6\left(1-\frac{d_n}{t}\right)\left(\frac{s}{t}\right)^2} \text{ кг/см}^2,(1) \qquad (299)$$

Key: (1). kg/cm².

where t — half-sum of the sides of the rectangle, formed by four tubes:

$$t = 0,5(t_1 + t_2).$$

The determination of values t_1 and t_2 see in Fig. 103.

Testing the reliability of fastening the ends of the tubes against their extraction is produced according to the formula

$$R > \frac{pf}{\pi d_n s}. \qquad (300)$$

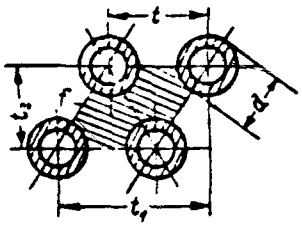

Fig. 103. On the calculation of the bridge of the tube plate.

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The area between four tubes f (in Fig. 103 cross-hatched) is determined:

for the tubes, arranged/located on equilateral triangle,

$$f = 0{,}866t^2 - 0{,}785d_н^2 \ см^2;$$

for the tubes, arranged/located in the corridor or checkered order,

$$f = t_1 t_2 - 0{,}785d_н^2 \ см^2.$$

Allowable stresses on the extraction of tubes must be not more:

$R_{max} \leqslant 40$ kg/cm² - for the tubes, rolled in the cylindrical holes;

$R_{max} \leqslant 50$ kg/cm² - for the tubes, rolled and flanged from one end;

$R_{max} \leqslant 70$ kg/cm² - for the tubes, rolled and flanged from two

ends.

Stress/voltage in the anchor stays is determined

$$R_z = \frac{P_1}{0{,}785 d_0^2 z} \quad \text{или}^{(1)} \quad R_z = \frac{P_1'}{0{,}785 d_0^2} \ кг/см^2. \qquad (301)$$

by Key: (1). or kg/cm².

Allowable stress in the anchor stays during the hydraulic test must not exceed

$$R_z' \leqslant \frac{\sigma_t}{1{,}6} \ кг/см^2, \qquad (302)$$

Key: (1). kg/cm².

where σ_t — yield point of material, kg/cm².

Breaking stress on the buckling in stays-bolt:

$$R_{кр} = \frac{\pi^2 E}{\left(\frac{L}{i}\right)^2} \ кг/см^2. \qquad (303)$$

Key: (1). kg/cm².

Radius of inertia of connection/communication of the round cross-section

$$i = \frac{d_0}{4} \ см.$$

The modulus/module of the normal elasticity E is accepted:

for steels kg/cm². ..... $(2.0-2.2)\cdot 10^6$

For brasses..... $(0.65-1.0)\cdot 10^6$

For the bronze. ..... $(0.9-1.2)\cdot 10^6$

Stability margin in stays-bolt with the buckling

$$x = \frac{R_{\text{пр}}}{R_z} > 4.$$

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Here by R_z is implied permissible compression stress, equal to permissible tensile stress.

For the purpose of a reduction/descent in the thermal stresses, which appear in the tube plates, and also the tubes in the places of their rolling in the housings of the heat exchangers, which have rigidly by them is more than 1 m the silt of the working under conditions relatively high temperatures, it is necessary to produce testing the compensation capacity of apparatus and in the necessary cases to provide for the installation of compensators.

§42. Calculation of the compensation capacity of apparatus.

If in the tube system of apparatus straight/direct tubes are rolled in two tube plates, rigidly fastened with the housing of apparatus, then in this case should be manufactured the verifying calculation of the compensation capacity of apparatus.

The elongation of the housing of apparatus under the action of a difference in the temperatures:

$$\Delta l_1 = \alpha_1 l_1 (t'_{ст} - t_0) \text{ см}, \qquad (304)$$

where α_1 - a coefficient of the linear expansion of the material of housing on 1°C;

l_1 — length of housing (usually is accepted the distance between the tube plates), cm;

$t'_{ст}$ — mean temperature of the wall of housing, °C;

t_0 - temperature of apparatus during the assembly (it usually takes as the equal to 15-20°C), °C.

The elongation of the tubes of apparatus under the action of a difference in the temperatures:

$$\Delta l_2 = \alpha_2 l_2 (t'_{ст} - t_0) \text{ см}, \qquad (305)$$

where α_2 - a coefficient of the linear expansion of the material of tubes on 1°C;

l_1 — length of tubes (distance between the tube plates), mm;

$t_{ст}$ — mean temperature of the wall of tube, °C;

t_0 - temperature of apparatus during the assembly, °C.

Difference in the elongations between the elongations of housing and tube (amount of strain):

$$\Delta l = \Delta l_1 - \Delta l_2 \text{ см.} \qquad (306)$$

In obtaining Δl of positive the tubes additionally are dilated/extended under the action of the elongation of housing. In obtaining $\overline{\Delta l}$ of negative the housing additionally is dilated/extended under the effect of the elongation of tubes.

end section.

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The effort/force which appears in the tube (housing), called by the elongation of housing (tubes), according to the law of Hooke:

$$P_1 = \frac{\Delta l F E}{l} \text{ kg}, \qquad (307)$$

where E - modulus of elasticity of the material of tube (housing), kg/cm²;

F - cross-sectional area of tube (housing):

$$F = 0{,}785\,(d_н^2 - d_в^2) \text{ см}^2,$$

where $d_н$ - outside diameter of tube (housing), cm;

$d_в$ - bore of tube (housing), cm.

The effort/force, which appears in the tube (housing), called by the internal pressure:

$$P_2 = 0{,}785 d_в^2 p \text{ кg}, \qquad (308)$$

where p - internal pressure in the tube (housing), kg/cm².

Total effort/force in the tube (housing) from the action of a difference in the temperatures and internal pressure:

$$P_{сум} = P_1 + P_2 \text{ кg}. \qquad (309)$$

Total stress/voltage on the breakage in the wall of tube (housing):

$$R_{сум} = \frac{P_{сум}}{F} \text{ кg/cm}^2. \qquad (310)$$

If obtained values $P_{сум}$ and $R_{сум}$ are insignificant, then compensator on the apparatus it is not required.

Compensator on the apparatus is established in such a case, when:

1) total stress/voltage on the breakage in the tube or the housing exceeds allowable stress, i.e.

$$R_{сум} > R_{доп},$$

where $R_{доп}$ - allowable stress in the wall of tube (housing), of kg/cm²;

2) the effort/force, which appears in the tube, exceeds the permissible load on the extraction of the ends of the tubes, i.e.

$$P_{сум} > P_{max},$$

where P_{max} - permissible load on the extraction of the ends of the tubes: $P_{max} = R_{max} \pi d_н y$ kg;

R_{max} - allowable stresses on the extraction of the ends of the tubes (see page 206), of kg/cm²;

$d_н$ - the outside diameter of tubes, cm,

y - depth of the rolling-out of tubes, cm.

According to the experimental data the safety factor of rolling-out n, i.e., the ratio of force $P_{вмп}$, which extracts the rolled tube, to permissible load P_{max} on the extraction of the ends of the tubes composes 2-2.5.

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For the approximate computations of efforts/forces and the stresses/voltages, which appear in the tube from the temperature elongations, can be recommended the following simplified formulas.

The force, which appears in the tube, in the absence of the compensation for temperature elongations approximately is determined:

for the steel tubes

$$P = 75\Delta t d s \text{ kg}; \qquad (311)$$

for the brass tubes

$$P = 57\Delta t d s \text{ kg}. \qquad (312)$$

The compression stress or elongation in the tube from the action of temperature elongations in the absence of the compensation for tube is determined:

for the steel tubes

$$R = 24\Delta t \text{ kg/cm}^2; \tag{313}$$

for the brass tubes

$$R = 18\Delta t \text{ kg/cm}^2. \tag{314}$$

The bending deflection of tube in depending on its elongation approximately shares

$$y = \sqrt{0{,}375 l \Delta l + y_0} - y_0 \text{ мм}. \tag{315}$$

Here Δt - increase in the temperature against the assembling, °C;

d - the mean diameter of tube, cm;

s - the wall thickness of tube, cm;

l - length of tube, mm;

Δl - difference in the elongations of housing and tube, mm;

y_0 - initial sagging/deflection of tube, mm.

§ 43. Calculation of the expansion bellows.

The expansion bellows with the necessary calculated values is depicted in Fig. 104.

The wall thickness of the lens

$$s = 0{,}67H\sqrt{\frac{p}{R_b}}\ \text{см}, \qquad (316)$$

where H - a projection of sizes/dimensions r_1, r_2, l lens (Fig. 104), cm;

p - internal pressure in the compensator kg/cm²;

R_b - allowable stress on the bend, kg/cm².

The complete effort/force from the internal pressure, received by the walls of the lens

$$P_0 = 0{,}785p(d_1^2 - d_2^2)\ \text{kg}, \qquad (317)$$

where d_1 - diameter of the lens of compensator in section/cut AA, cm;

d_2 - diameter of lens in section/cut BB, cm.

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Force from the internal pressure, which disrupts the wall of the lens of compensator according to the diameter of lens d_1 in section/cut AA:

$$P_A = P_0 \frac{d_1}{d_1 + d_2} \text{ kg}. \qquad (318)$$

The reaction, compressive the wall of the lens of compensator according to diameter d_2 in section/cut BB:

$$P_B = P_0 - P_A \text{ kg}. \qquad (319)$$

The force, which appears in the compensator from the deformation of one lens to value $+-\Delta x \sim -0.5\Delta l$ (with the precompression or the elongation of lens on $+-\Delta x$):

$$P_x = \pm \frac{EI_{cp}\Delta x}{\Sigma b - \frac{\Sigma a^2}{4\Sigma s_n}} \text{ kg}, \qquad (320)$$

where Δx - an amount of the deformation of one lens of the compensator;

E - modulus of elasticity of the material of lens, kg/cm²;

$I_{cp} = 0{,}262\, d_{cp} s^3$ - moment of the inertia of the cross section of the wave of lens, rectified on its average/mean diameter, cm⁴;

$d_{cp} = 0{,}5(d_1 + d_2)$ - the mean diameter of the lens of compensator, cm;

Σb - coefficient of the configuration of lens, cm^3;

Σa - coefficient of the configuration of lens, cm^2;

Σs_n - the reduced length of the wall of lens, cm.

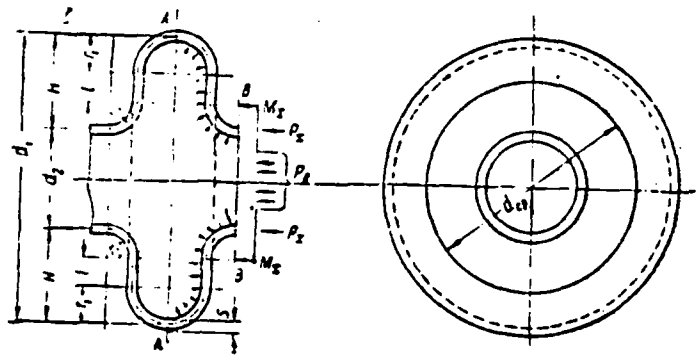

Fig. 104. On the calculation of the expansion bellows.

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Values of the coefficients of configuration and reduced length:

1. For case of $r_1 \neq r_2$; $l \neq 0$:

$$\Sigma b = n\left\{\frac{(3\pi-8)}{4} r_2^3 + \left[r_2(r_2+l) + \frac{1}{3} l^2\right] + r_1\left[\frac{\pi}{2}(r_2+l)^2 + \right.\right.$$
$$\left.\left. + 2(r_2+l) r_1 + \frac{\pi}{4} r_1^2\right]\right\};$$

$$\Sigma a = n\{(\pi-2) r_2^2 + (2r_2+l) + r_1[\pi(r_2+l) + 2r_1]\};$$

$$\Sigma s_n = n\left[\frac{\pi}{2}(r_2+r_1) + l\right].$$

2. For case of $r_1 = r_2 = r$; $l \neq 0$:

$$\Sigma b = n\left\{\frac{(3\pi-8)}{4} r^3 + \left[r(r+l) + \frac{1}{3} l^2\right] l + r\left[\frac{\pi}{2}(r+l)^2 + \right.\right.$$
$$\left.\left. + 2(r+l) r + \frac{\pi}{4} r^2\right]\right\};$$

$$\Sigma a = n\{(\pi-2) r^2 + (2r+l) l + r[\pi(r+l) + 2r]\};$$

$$\Sigma s_n = n(\pi r + l).$$

3. For case of $r_1 \neq r_2$; $l=0$:

$$\Sigma b = n\left[\frac{(3\pi-8)}{4} r_2^3 + r_1\left(\frac{\pi}{2} r_2^2 + 2r_2 r_1 + \frac{\pi}{4} r_1^2\right)\right];$$

$$\Sigma a = n\left[(\pi-2) r_2^2 + r_1(\pi r_2 + 2r_1)\right];$$

$$\Sigma s_n = n\frac{\pi}{2}(r_2 + r_1).$$

4. For case of $r_1 = r_2 = r$; $l=0$;

$$\Sigma b = 4{,}71 nr^3;$$
$$\Sigma a = 6{,}28 nr^2;$$
$$\Sigma s_n = 3{,}14 nr,$$

where n - number of half-lenses in compensator.

Pinching moment/torque, called by the deformation of the lenses:

$$M_x = \pm \frac{\Sigma a P_x}{2\Sigma s_n} \text{ kgcm.} \qquad (321)$$

Bending moment in the critical section/cut of lens (section/cut AA):

$$M_a = P_x H - M_x \text{ kgcm.} \qquad (322)$$

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Bending stress from the action of moment/torque in the critical section/cut:

$$\pm R_b' = \frac{M_\sigma s}{2 I_A} \text{ kg/cm}^2, \qquad (323)$$

where $I_A = 0{,}262\, d_1 s^3$ - moment of the inertia of lens in critical section/cut, cm⁴.

Bending stress from the internal pressure:

$$R_b'' = \frac{0{,}45 p H^2}{s^2} \text{ kg/cm}^2. \qquad (324)$$

Total bending stress:

$$\pm R_b = R_b' + R_b'' \text{ kg/cm}^2, \qquad (325)$$

Plus sign is - with the work of compensator on elongation.

Minus sign is - with the work of compensator on compression.

Stress/voltage on the breakage from the internal pressure:

$$R_z = \frac{pd_1}{2s} \text{ kg/cm}^2. \tag{326}$$

Resulting stress/voltage in the critical section/cut

$$R_{рез} = \sqrt{R_b^2 + R_z^2} \text{ kg/cm}^2. \tag{327}$$

Axial force in the housing of the apparatus:

$$P' = P_B + P_x \text{ kg}. \tag{328}$$

Stress/voltage in the wall of lens in the place of fastening to the housing (section/cut EE):

$$R_{z_E} = \frac{P'}{\pi d_2 s} \text{ kg/cm}^2. \tag{329}$$

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Chapter VII.

EXAMPLES OF THE CALCULATIONS OF THE STRENGTH OF PARTS.

§ 44. Calculation of the strength of the walls of housing.

Cylindrical wall.

Initial data for the calculation.

Material of the housing of fuel heater: steel st. 3.

Calculated (working) pressure of saturated steam in the housing $p = 26$ kg/cm^2.
Bore of housing $D_в = 283$ мм.

We accept.

$\varphi = 0{,}8$ - the modulus of resistance of weld (on Table 50);

$\sigma_b = 38$ kg/mm^2 - limit of the strength of steel St. 3 (on Table 33);

$n_b = 4{,}25$ - safety factor with $t_p < 250°C$ (on Table 52);

C=1 mm - addition.

The allowable stress

$$R_s = \frac{\sigma_b}{n_b} = \frac{38}{4,25} = 8,9 \text{ kg/mm}^2.$$

The wall thickness of the cylinder

$$s = \frac{pD_n}{230R_s\varphi - p} + C = \frac{26 \cdot 283}{230 \cdot 8,9 \cdot 0,9 - 26} + 1 = 5,6 \text{ мм}.$$

We accept s=6 mm.

Flat/plane wall with the stiffening ribs.

Initial data for the calculation.

Material of the flat/plane wall: copper M3.

Material of stiffening ribs (angle plate): steel st. 3.

Design pressure on the wall: p=1 kg/cm².

Large side of the flat/plane wall: l=1500 mm.

Smaller side of the flat/plane wall: c=1300 mm.

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We accept.

Number of edges/fins along the larger side $n_1=5$.

Number of edges/fins along the smaller side $n_2=4$.

Profile/airfoil of angle plate on OCT 10015-39 N 6/4.

We determine (on the tables).

Limit of the strength of copper $\sigma_b=2000$ kg/cm².

Yield point of copper $\sigma_t=700$ kg/cm².

Limit of the strength of steel St. 3 $\sigma_b'=3800$ kg/cm².

Yield point of steel St. 3 $\sigma_t'=2400$ kg/cm².

Side of the rectangle, included between the stiffening ribs:

$$a=\frac{c}{n_2+1}=\frac{1300}{4+1}=260 \text{ мм.}$$

Second side of the rectangle

$$b = \frac{l}{n_1 + 1} = \frac{1500}{5+1} = 250 \text{ мм},$$

The thickness of the flat/plane wall, included between the stiffening ribs

$$s = 0{,}53b\sqrt{\frac{p}{R_b\left(1+\frac{b^2}{a^2}\right)}} + C = 0{,}53 \cdot 25\sqrt{\frac{1}{440\left(1+\frac{25^2}{26^2}\right)}} + \\ + 0{,}3 = 0{,}755 \text{ см},$$

where $R_b = 440$ kg/cm² - the allowable stress of copper (on Table 41);

C=03 cm - addition taking into account weakening of bore surface.

We accept s=8 mm.

Let us designate (see Fig. 82).

X_1X_1 - centroidal axis of the section/cut of edge/fin (elbow);

X_2X_2 - centroidal axis of the section/cut of the band of the flat/plane wall;

XX - centroidal axis of the section/cut of band and edge/fin;

OO - axis/axle of the base/root of band.

From the table of assortment for angle plate N 6/4 we determine:

Height/altitude of edge/fin (angle plate) h=6 cm.

Cross-sectional area of edge/fin F_1=5.72 cm².

Distance of the apex/vertex of edge/fin from axis/axle X_1X_1 equal to Z_0=2 cm.

Second moment of area of edge/fin relative to axis/axle X_1X_1 $I_{x_1}=20{,}3$ см⁴.

Distance of axis/axle X_1X_1 from axis/axle CC:

$$Y_1=h+s-Z_0=6+0{,}8-2=4{,}8 \text{ см}.$$

Distance of axis/axle X_2X_2 from axis/axle CC:

$$Y_2=0{,}5s=0{,}5\cdot 0{,}8=0{,}4 \text{ см}.$$

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Width of the band of wall, which receives loads along the larger side l of rectangle,

$$B=\frac{a}{2}=\frac{26}{2}=13 \text{ см}.$$

Cross-sectional area of the band

$$F_2=Bs=13\cdot 0{,}8=10{,}4 \text{ см},$$

Distance of the neutral axis/axle XX from axis/axle OO

$$Z=\frac{F_1Y_1+F_2Y_2}{F_1+F_2}=\frac{5,72\cdot4,8+10,4\cdot0,4}{5,72+10,4}=1,96\ см.$$

Distance between centers X_1X_1 and XX

$$a_1=Y_1-Z=4,8-1,96=2,84\ см.$$

Distance between centers X_2X_2 and XX

$$a_2=Z-Y_2=1,96-0,4=1,56\ см.$$

Distance of the outermost filament from axis/axle XX

$$Y_3=s+h-Z=0,8+6-1,96=4,84\ см.$$

Load, which effects on the edge/fin and the band,

$$Q=Blp=13\cdot150\cdot1=1950\ kg.$$

Greatest bending moment, which effects on the edge/fin and the band,

$$M=\frac{Ql}{12}=\frac{1950\cdot150}{12}=24400\ kgcm.$$

Second moment of area of band relative to axis/axle X_2X_2

$$I_{x_2}=\frac{Bs^3}{12}=\frac{13\cdot0,8^3}{12}=0,55\ см^4.$$

Second moment of area of edge/fin relative to axis/axle XX

$$I_1=I_{x_1}+a_1^2F_1=20,3+2,84^2\cdot5,72=66,6\ см^4.$$

The second moment of area of band relative to axis/axle XX

$$I_2=I_{x_2}+a_2^2F_2=0,55+1,56^2\cdot10,4=25,95\ см^4.$$

Total moment of the inertia of edge/fin and band relative to axis/axle XX

$$I = I_1 + I_2 = 66{,}6 + 25{,}95 = 92{,}55 \text{ см}^4.$$

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Stress/voltage, which appears in the edge/fin from the action of moment/torque M,

$$R_1 = \frac{MY_3}{I} = \frac{24400 \cdot 4{,}84}{92{,}55} = 1275 \text{ kg/cm}^2.$$

Stress/voltage, which appears in the band from the action of moment/torque M,

$$R_2 = \frac{MZ}{I} = \frac{24400 \cdot 1{,}96}{92{,}55} = 516 \text{ kg/cm}^2.$$

Safety factor in the edge/fin

$$n_1 = \frac{\sigma_s'}{R_1} = \frac{2400}{1275} = 1{,}88.$$

Safety factor in the band

$$n_2 = \frac{\sigma_s}{R_2} = \frac{700}{516} = 1{,}36.$$

§ 45. Calculation of the strength of covers/caps and bottoms.

Convex stamped/die-forged bottom.

Initial data for the calculation.

Material of convex bottom of the housing of the preheater of the water: steel st. 3.

Calculated (working) pressure of vapors in the housing $p=2$ kg/cm².

Outside diameter of housing $D_н = 558$ мм.

We accept.

$\sigma_b = 38$ kg /mm² - limit of the strength of steel St. 3 (on table 33):

C=3 mm - addition;

y=1.65 - coefficient or factor of shape of bottom (on table 55); for the anechoic bottom in the ratio of the height/altitude of bottom h to its outside diameter $D_н$ i.e. when $\frac{h}{D_н} = 0{,}22$.

Allowable stress with t<250°C (on table 56)

$$R_z = \frac{\sigma_b}{2,9} = \frac{38}{2,9} = 13,1 \text{ kg/cm}^2.$$

The wall thickness of the dished bottom

$$s = \frac{D_н p y}{200 R_z} + C = \frac{558 \cdot 2 \cdot 1,65}{200 \cdot 13,1} + 3 = 3,71 \text{ мм}.$$

We accept s=4 mm.

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Flat/plane circular cover/cap.

Initial data for the calculation.

Material of the flat/plane cover/cap: steel st. 3.

Calculated (it is working) pressure p=2 kg/cm².

Diameter of a circle of the arrangement of bolts d=620 mm.

We accept.

$\sigma_b = 38$ kg /mm² - limit of the strength of steel St. 3.

μ=0.3 - for the covers/caps, which undergo preliminary bend from the tightening of the bolts [see formula (242)].

C=2 mm - addition.

Allowable stress on the bend (on table 56)

$$R_b = \frac{\sigma_b}{3,2} = \frac{38}{3,2} = 11,9 \text{ kg/mm}^2.$$

Thickness of the flat/plane circular cover/cap

$$s = d\sqrt{\mu \frac{p}{R_b}} + C = 62\sqrt{0,3\frac{2}{1190}} + 0,2 = 1,595 \text{ см}.$$

We accept s=16 mm.

Plate cover/cap.

Initial data for the calculation.

Material of cover/cap (cast): steel 55L.

Calculated (it is working) pressure in the cover/cap p=32 kg/cm².

We accept (on the made drawing/draft).

Radius of the spherical segment of cover/cap R=70 cm.

External radius of the flange of cover/cap d=42.5 cm.

Radius of a circle of the arrangement of bolts r=39.25 cm.

Distance from the axis/axle of cover/cap to the line of centers of packing a=36 cm.

Load on the bolt (from the calculation of bolts) P_0=8350 kg.

Number of bolts z=28.

The wall thickness of cover/cap s=5.5 cm.

Addition for the cast cover/cap C=0.5 cm.

The modulus of resistance of weld (it is absent) ϕ=1.

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Bending stress in the cover/cap

$$R_0 = \frac{3}{\pi(s-C)^2}\left[\frac{0{,}18P_0z(r^2-a^2)}{d^2} + 1{,}48P_0z\lg\frac{r}{a}\right] + \frac{pR}{2\varphi(s-C)} =$$

$$= \frac{3}{3{,}14(5{,}5-0{,}5)^2}\left[\frac{0{,}18\cdot 8350\cdot 28(39{,}25^2-36^2)}{42{,}5^2} + \right.$$

$$\left. + 1{,}48\cdot 8350\cdot 28\lg\frac{39{,}25}{36}\right] + \frac{32\cdot 70}{2\cdot 1\cdot(5{,}5-0{,}5)} = 940 \text{ кг/см}^2.$$

(1)

Key: (1). kg/cm².

Safety factor in the cover/cap on ultimate strength

$$n = \frac{\sigma_b}{R_b} = \frac{6000}{940} = 6{,}4,$$

where $\sigma_b = 6000$ kg/cm² - limit of the strength of steel 55L (on Table 29).

§ 46. Calculation of bolts and pins.

Calculation of the shank of bolt.

Initial data for the calculation.

Material of the bolts: steel 35X.

Design pressure in the cylindrical chamber/camera p=32 kg/cm².

Diameter of a circle of the arrangement of bolts $D_б = 78{,}5$ см.

Diameter of the centerline of packing $D_{пр} = 72$ см.

Complete effort/force, which effects on all bolts from the internal pressure of medium,

$$Q = 0{,}785 D_{пр}^2 p = 0{,}785 \cdot 72^2 \cdot 32 = 130000 \text{ кg.}$$

We accept.

Quantity of bolts z=28.

Coefficient of the tightening of bolt k=1.8.

Calculated effort for one bolt

$$P_0 = \frac{kQ}{z} = \frac{1{,}8 \cdot 130000}{28} = 8350 \text{ kg}.$$

Distance between the bolts (space of bolts)

$$t = \frac{\pi D_б}{z} = \frac{3{,}14 \cdot 78{,}5}{28} = 8{,}8 \text{ см.}$$

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The nominal diameter of the bolt

$$d_0 = 1{,}13 \sqrt{\frac{P_1 n}{\sigma_b}} + 0{,}5 = 1{,}13 \sqrt{\frac{8350 \cdot 6{,}5}{9500}} + 0{,}5 = 3{,}2 \text{ см.}$$

where $\sigma_b = 9500$ kg/cm² - limit of the strength of steel 35Kh (on Table 37)

n=6.5 - a safety factor for the well machined bolts.

We accept d_0=3 cm.

Stress/voltage in the rod of the bolt

$$R_s = 1{,}27\frac{P_0}{d_0^2} = 1{,}27\frac{8350}{2{,}56^2} = 1620 \text{ kg/cm}^2,$$

where $d_0 = 2{,}56$ cm - diameter of bolt along the female thread.

Calculation of the fillet/shoulder of pin.

Initial data for the calculation (from the calculation of the shank of bolt).

Material of the pin: steel 35Kh.

Calculated effort for one pin P_0=8350 kg.

Nominal diameter of pin d_0=3.0 cm.

The thickness of the fillet/shoulder of the pin

$$\delta = \frac{P_0}{\pi d_0 R_{cp}} = \frac{8350}{3.14 \cdot 3 \cdot 875} = 10{,}08 \text{ см},$$

where R_{cp} - permissible shear stress:

$$R_{cp} = 0{,}6 R_s = 0{,}6 \frac{\sigma_b}{n} = 0{,}6 \frac{9500}{6{,}5} = 875 \text{ kg/cm}^2;$$

$\sigma_b = 9500$ kg/cm² - permissible tensile stress;

n=6.5 - safety factor for the well machined pins.

We accept $\delta = \frac{d_0}{3} = \frac{30}{10} = 10$ мм.

The diameter of the fillet/shoulder of the pin

$$d_6 = \sqrt{d_0^2 + \frac{1{,}27 P_0}{R_{см}}} = \sqrt{3^2 + \frac{1{,}27 \cdot 8350}{2630}} = 3{,}63 \text{ см},$$

where $R_{см}$ - permissible crumpling stress

$$R_{см} = 1{,}8 R_s = 1{,}8 \frac{\sigma_b}{n} = 1{,}8 \frac{9500}{6{,}5} = 2630 \text{ kg/cm}^2.$$

We accept $d_6 = 1{,}4 d_0 = 1{,}4 \cdot 30 = 42$ мм.

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§ 47. Calculation of flanges.

Round cast flange.

Initial data for the calculation.

Material of the flange: steel 45L.

Limit of the strength of steel 45L: $\sigma_b = 5500$ kg/cm².

Calculated effort for one bolt (from the calculation of bolts) $P_0 = 8350$ kg.

Diameter of the critical section/cut of flange (from the made drawing/draft) $D_f = 74$ см.

Arm of bend a=4.25 cm.

Number of bolts z=28.

The thickness of the cast flange

$$s = \sqrt{\frac{6P_0az}{\pi D_f R_b k}} + C = \sqrt{\frac{6 \cdot 8350 \cdot 4,25 \cdot 28}{3,14 \cdot 74 \cdot 690 \cdot 1,8}} + 0,5 = 5 \text{ см},$$

where R_b - allowable stress on the bend:

$$R_b = \frac{\sigma_b}{n_b} = \frac{5500}{8} = 690 \text{ кg/cm}^2;$$

$n_b = 8$ - safety factor for steel casting;

k=1.8 - coefficient of the tightening of bolts;

C=0.5 cm - addition.

Circular welded flange.

Initial data for the calculation.

Material of the flange: steel st. 4.

Limit of the strength of steel St. 4 on Table 33 $\sigma_b = 4200$ kg/cm².

Calculated effort/force on pin P_0=208 kg.

Radius of a circle of the arrangement of pins r_0= 31.75 cm.

Internal radius of housing r= 27.5 cm.

Space of pins t=8.3 cm.

Diameter of hole under the pin d=2.9 cm.

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The thickness of the welded circular flange

$$s=\beta\sqrt{\frac{P_0(r_0-r)t}{R_b(t-d)d}}+1{,}2=$$

$$=0{,}43\sqrt{\frac{208(31.75-27{,}5)8{,}3}{840(8{,}3-2{,}9)2{,}9}}+1{,}2=1{,}52\ см,$$

where R_b - allowable stress on the bend:

$$R_b=\frac{\sigma_b}{n}=\frac{4200}{5}=840\ \text{kg/cm}^2;$$

n=5 - safety factor of the flange;

β=0.43 - coefficient for the flanges, which are not subjected load from the tightening of bolts.

We accept s=16 mm.

Rectangular flange.

Initial data for the calculation.

Material of the flange: steel St. 4.

Limit of the strength of material on Table 33 $\sigma_b=4200$ kg/cm².

Calculated effort/force to the bolt P_0=324 kg.

Space of bolts t=5.9 cm.

Diameter of bolt hole d=1.3 cm.

Arm of bend a=1.5 cm.

The thickness of rectangular flange will be determined

$$s=\sqrt{\frac{6P_0a}{R_b(t-d)k}}+C=\sqrt{\frac{6\cdot 3.24\cdot 1,5}{840(5,9-1,3)1,8}}+0,1=0,75\ cм,$$

where $R_b=840$ kg/cm² - allowable stress on the bend;

k=1.8 the coefficient of the tightening of the bolts;

C=0.1 cm - addition.

We accept s=8 mm.

§ 48. Calculation of the tube plates.

Circular panel without the aronors.

Initial data for the calculation.

Material of the tube plate: brass LC62-1.

Design pressure p=32 kg/cm².

Radius of a circle of the arrangement of bolts r_1=39.25 cm.

The mean diameter of packing D_{np} = 72 cm.

Outside diameter of tubes $d_н$ = 1.6 cm.

Space of the arrangement of tubes on the triangle t=21 cm.

Number of tubes n=890.

We determine.

Limit of the strength of material (on Table 39) σ_b=3800 kg/cm².

Coefficient of the attachment of the tube plate (on Table 65) ψ=0,5.

Coefficient of weakening the tube plate (on Table 67) ϕ=0.474.

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Coefficient of a change in the specific load for the circular tube plate with the pencil of straight lines tubes (on Table 68)

$$\varepsilon = 1 - \frac{d_н^2 n}{D_{пр}^2} = 1 - \frac{1,6^2 \cdot 890}{72^2} = 0,563.$$

The safety factor of panel is taken n=4.

Allowable stress in the tube plate

$$R_b = \frac{\sigma_b}{n} = \frac{3800}{4} = 950 \text{ kg/cm}^2.$$

The thickness of the tube plate

$$s = r_1 \sqrt{\frac{\psi_{ср}}{\varepsilon R_b}} + C = 39,25 \sqrt{\frac{0,5 \cdot 0,563 \cdot 32}{0,474 \cdot 950}} + 0,3 = 5,85 \text{ см},$$

where C=0.3 cm - an addition.

We accept s=60 mm.

Circular panel with the anchors.

Initial data for the calculation.

Material of the tube plate: steel 30.

Material of connections/communications: steel 35 Kh

Design pressure p=36 kg/cm². Radius of a circle of the arrangement of bolts r_1=31.75 cm.

Radius of a circle of the arrangement of anchors r_c = 14.5 cm.

The mean diameter of packing $D_{пр}$ = 56.5 cm.

Diameter of connection/communication along the female thread d_0=2.54 cm.

Calculated bond length is L=13.5 cm.

Number of connections/communications z=6.

Outside diameter of tubes d_H = 1.6 cm.

Space of tubes on the triangle t=2.2 cm.

We determine.

Ultimate strength material (on Table 34) $\sigma_b = 4800$ kg/cm².

Poisson ratio for steel (on Table 38) $\mu = 0.3$.

Coefficient of the attachment of the tube plate with the anchors (on Table 65) $\psi = 0.75$.

Coefficient of weakening the tube plate (on Table 67) $\phi = 0.52$.

Coefficient of a change in specific load of V-shaped tube (on Table 68) $\varepsilon = 1$.

The safety factor of the tube plate is taken n=4.

Permissible stress in the tube plate

$$R_b = \frac{\sigma_b}{n} = \frac{4800}{4} = 1200 \text{ kg/cm}^2.$$

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Specific load on the tube plate we preliminarily accept

$$p_2' = 0{,}55p = 0{,}55 \cdot 36 = 19{,}7 \text{ kg/cm}^2.$$

The thickness of the tube plate preliminarily will be determined

$$s_0 = r_1 \sqrt{\frac{\psi_2 p_2}{\varphi R_b}} = 37{,}75 \sqrt{\frac{0{,}75 \cdot 1 \cdot 19{,}8}{0{,}52 \cdot 1200}} = 4{,}94 \text{ см} \approx 5 \text{ см}.$$

Load, which falls on connection/communication,

$$P_1 = \frac{\pi p (r_1^2 - r_c^2)^2}{s\left\{\left[-2r_c^2 \ln \frac{r_1}{r_c} + \frac{1}{2}\left(1 + \frac{r_c^2}{r_1^2}\right)(r_1^2 - r_c^2)\right] + \frac{8 s_0^3 \varphi L}{3 d_0^2 z (1 - \mu^2)}\right\}} =$$

$$= \frac{3{,}14 \cdot 36 (31{,}75^2 - 14{,}5^2)^2}{8\left\{\left[-2 \cdot 14{,}5^2 \ln \frac{31{,}75}{14{,}5} + \frac{1}{2}\left(1 + \frac{14{,}5^2}{31{,}75^2}\right)(31{,}75^2 - 14{,}5^2)\right] + \frac{8 \cdot 5^3 \cdot 0{,}52 \cdot 13{,}5}{3 \cdot 2{,}54^2 \cdot 6 (1 - 0{,}3^2)}\right\}} =$$

$$= 41\,000 \text{ кг}.$$ (1)

Key: (1). kg.

Full load on the tube plate and the anchor stays

$$Q = 0{,}785 D_{пр}^2 p = 0{,}785 \cdot 56{,}5^2 \cdot 36 = 90\,300 \text{ kg}.$$

Load, which falls to the tube plate,

$$P_2 = Q - P_1 = 90\,300 - 41\,000 = 49\,300 \text{ kg}.$$

Given specific load on the tube plate

$$p_2' = \frac{P_2}{0{,}785 D_{пр}^2} = \frac{49300}{0{,}785 \cdot 56{,}5^2} = 19{,}7 \text{ kg/cm}^2.$$

The thickness of the tube plate

$$s = r_1 \sqrt{\frac{\psi_2 p_2}{\varphi R_b}} + C = 31{,}75 \sqrt{\frac{0{,}75 \cdot 1 \cdot 19{,}7}{0{,}52 \cdot 1200}} + 0{,}3 \approx 5{,}2 \text{ см}.$$

where C=0.3 - an addition.

We accept s=52 mm.

Stress/voltage in the anchor stays

$$R_z' = \frac{P_1}{0{,}785 \cdot d_0^2 \cdot z} = \frac{41000}{0{,}785 \cdot 2{,}54^2 \cdot 6} = 1350 \text{ kg/cm}^2.$$

Safety factor in anchor in the anchor stays

$$n' = \frac{\sigma_b'}{R_z'} = \frac{9500}{1350} = 7,$$

where $\sigma_b' = 9500$ kg/cm² - limit of the strength of the material of connections/communications.

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Rectangular panel without the anchors.

Initial data for the calculation.

Material of the tube plate: brass LS59-1.

design pressure p=5 kg/cm².

Large side of rectangle, limited by the centerline of bolts,

a=53 cm.

Smaller side of rectangle, limited by the centerline of bolts, b=12.2 cm.

Outside diameter of tubes d_H = 1.0 CM.

Space of the arrangement of tubes in the series/row t_1=15 cm.

Space between the series/rows of the tubes with t_2=1.25 cm.

Number of tubes n=189.

We determine.

Limit of the strength of material (on Table 39) σ_b=3500 kg/cm².

Relation $\frac{a}{b}=\frac{53}{12.2}=4,34.$

Coefficient of the attachment of tube heel pads (in Table 66 in depending on relation a:b) ψ=0,625.

Coefficient of weakening the tube plate (on Table 67) ϵ=0.583.

The coefficient of a change in the specific load for the rectangular tube plate with the pencil of straight lines tubes (on Table 68):

$$\varepsilon = 1 - 0{,}785\frac{d_n^2 n}{ab} = 1 - 0{,}785\,\frac{1{,}0^2 \cdot 189}{53 \cdot 12{,}2} = 0{,}77.$$

The safety factor of the tube plate is taken $n_b = 4{,}5$.

Allowable stress in the tube plate

$$R_b = \frac{\sigma_b}{n_b} = \frac{3500}{4{,}5} = 780 \text{ kg/cm}^2.$$

The thickness of the tube plate

$$s = b\sqrt{\frac{2\varepsilon p}{\varphi R_b}} + C = 12{,}2\sqrt{\frac{0{,}625 \cdot 0{,}77 \cdot 5}{0{,}583 \cdot 780}} + 0{,}1 = 0{,}99$$

where C=0.1 cm - allowance.

We accept s=12 mm.

Rectangular panel with the archers.

Initial data for the calculation.

Material of the tube plate: steel alloyed.

Material of connections/communications: steel 35 KA

Design pressure $p=10$ kg/cm^2.

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Large side of rectangle, limited by the centerline of bolts, $a=264$ cm.

Smaller side of rectangle, limited by the centerline of bolts, $b=111.6$ cm.

Number of series/rows of connections/communications $n_1=2$.

Number of connections/communications in series/row $n_2=9$.

Distance between the axial bolt holes and the extreme series/row of connections/communications $c_1=40.6$ cm.

Distance between the series/rows of connections/communications $c_2=30.4$ cm.

Distance between connections/communications in the series/row $c_3=25.2$ cm.

Diameter of connection/communication along the female thread

$d_0 = 3.08$ cm.

Outside diameter of tubes $d_н = 1{,}4$ *см.*

Space of the arrangement of tubes in the series/row $t_1 = 2.1$ cm.

Space between the series/rows of the tubes with $t_2 = 1.9$ cm.

Number of tubes n=6100.

The width (greatest) of the designed section of panel is $r = c_1 = 40.6$ cm.

Relation $\frac{a}{c_1} = \frac{264}{40{,}6} = 6{,}5.$

Coefficient of the attachment of the tube plate (on tables 66 in depending on $a:c_1$), $\psi = 0{,}63.$

Coefficient of weakening the tube plate

$$\varphi = 1 - 0{,}785 \frac{d_н^2}{t_1 t_2} = 1 - 0{,}785 \frac{1{,}4^2}{2{,}1 \cdot 1{,}9} = 0{,}614.$$

Coefficient of a change in the specific load for the rectangular tube plate with the pencil of straight lines tubes (on Table 68)

$$\varepsilon = 1 - 0{,}785 \frac{d_н^2 n}{ab} = 1 - 0{,}785 \frac{1{,}4^2 \cdot 6100}{264 \cdot 111{,}6} = 0{,}682.$$

We determine (on the tables).

Limit of the strength of alloy steel at temperature of wall $t_{ст} = 400°C$, $\sigma_b^t = 3600$ kg cm².

Ultimate strength stopped 35X: $\sigma_b = 9500$ kg/cm².

The safety factor of the tube plate is taken $n_b = 4$.

Allowable stress in the tube plate

$$R_b = \frac{\sigma_b^t}{n_b} = \frac{3600}{4} = 900 \text{ kg/cm}^2.$$

The thickness of the tube plate

$$s = c_1 \sqrt{\frac{\psi_{вр}}{\varphi R_b}} + C = 40{,}6 \sqrt{\frac{0{,}63 \cdot 0{,}682 \cdot 10}{0{,}614 \cdot 900}} + 0{,}2 = 3{,}8 \text{ см},$$

where C=0.2 cm - an addition.

We accept s=40 mm.

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Load, which falls to one connection/communication,

$$P_1' = 0{,}5(c_1 + c_2) c_3 p = 0{,}5(40{,}6 + 30{,}4) 25{,}2 \cdot 10 = 8900 \text{ kg}.$$

Stress/voltage in the anchor stays

$$R'_z = \frac{P'_1}{0,785 \cdot d_0^2} = \frac{8900}{0,785 \cdot 3,08^2} = 1200 \text{ kg/cm}^2.$$

Safety factor in connections/communications

$$n'_b = \frac{\sigma_b}{R'_z} = \frac{9500}{1200} = 7,9.$$

§ 49. Calculation of the compensation capacity of apparatus.

Initial data for the calculation.

Pressure within the housing of apparatus p=0.8 kg/cm².

Temperature of medium in the intertube space t_1=116.3°C.

Mean temperature of medium in the tubes of apparatus t_2=75°C.

Temperature of apparatus during assembly t_3=15°C.

Temperature of surrounding air t_4=30°C.

Material of the housing: steel St. 3.

Material of the tures: brass.

The length of tubes and housings is $l=1.8$ m.

Diameter of housing $D_в=0{,}55$ м.

The wall thickness of the tubes with $s_1=1$ mm.

The wall thickness of housing is $s_2=4$ mm.

We determine (on Table 38). The coefficient of the linear expansion of the material of housing on 1°C, $\beta_1=1.25\cdot10^{-5}$.

Coefficient of the linear expansion of the material of tubes on 1°C, $\beta_2=1.9\cdot10^{-5}$.

For determining the temperature of wall we accept.

Heat-transfer coefficient from the vapor to the walls of housing and tubes with $\alpha_1=6600$ kcal/m²h °C.

Heat-transfer coefficient from the wall of housing to the

surrounding air α_2=10 kcal/m²h °C.

Heat-transfer coefficient from the wall of tubes to the water α_3=4000 kcal/m²-hour °C.

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Coefficient of the thermal conductivity of brass λ_1=90 kcal/m-h°C.

Coefficient of the thermal conductivity of steel λ_2=50 kcal/m-h°C.

Temperature of the internal surface of the wall of the tube

$$t'_{ст_1} = \frac{\alpha_3 t_2 + A_1 t_1}{\alpha_3 + A_1} = \frac{4000 \cdot 75 + 6150 \cdot 116,3}{4000 + 6150} \approx 100° \text{C},$$

where

$$A_1 = \frac{1}{\frac{s_1}{\lambda_1} + \frac{1}{\alpha_1}} = \frac{1}{\frac{0,001}{90} + \frac{1}{6600}} = 6150.$$

Temperature of the external surface of the wall of the tube

$$t'_{ст_2} = \frac{t_2 + t_1 \alpha_1 B_1}{1 + \alpha_1 B_1} = \frac{75 + 116,3 \cdot 6600 \cdot 0,000261}{1 + 6600 \cdot 0,000261} \approx 101° \text{C},$$

where

$$B_1 = \frac{1}{\alpha_3} + \frac{s_1}{\lambda_1} = \frac{1}{4000} + \frac{0,001}{90} = 0,000261.$$

Mean temperature of the wall of the tube

$$t_{ст_1} = 0,5(t'_{ст_1} + t'_{ст_2}) = 0,5(100 + 101) \approx 100° \text{C}.$$

Temperature of the internal surface of the wall of the housing

$$t^{\circ}_{ст_1} = \frac{\alpha_1 t_1 + A_2 t_4}{\alpha_1 + A_2} = \frac{6600 \cdot 116,3 + 10 \cdot 30}{6600 + 10} = 116,2^{\circ}\,C,$$

where

$$A_2 = \frac{1}{\frac{s_2}{\lambda_2} + \frac{1}{\alpha_2}} = \frac{1}{\frac{0,004}{50} + \frac{1}{10}} = 10.$$

Temperature of the external surface of the wall of the housing

$$t^{\circ}_{ст_2} = \frac{t_1 + t_4 \alpha_2 B_2}{1 + \alpha_2 B_2} = \frac{116,3 + 30 \cdot 10 \cdot 0,000232}{1 + 10 \cdot 0,000232} = 116^{\circ}\,C,$$

where

$$B_2 = \frac{1}{\alpha_1} + \frac{s_2}{\lambda_2} = \frac{1}{6600} + \frac{0,004}{50} = 0,000232.$$

Mean temperature of the wall of housing

$$t_{ст_2} = 0,5(t^{\circ}_{ст_1} + t^{\circ}_{ст_2}) = 0,5(116,2 + 116) \approx 116^{\circ}\,C.$$

Elongation of tube under the action of a difference in the temperatures

$$\Delta l_1 = \beta_2 l (t_{ст_1} - t_3) = 1,9 \cdot 10^{-5} \cdot 1,8(100 - 15) = 0,0029\,м = 2,9\ мм.$$

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Elongation of housing under the action of difference of temperatures

$$\Delta l_2 = \beta_1 l (t_{ст_2} - t_3) = 1,25 \cdot 10^{-5} \cdot 1,8(116 - 15) = 0,00227 = 2,27\ мм.$$

Difference in the elongations of tubes and housing

$$\Delta l = \Delta l_1 - \Delta l_2 = 2,9 - 2,27 = 0,63\ мм.$$

The effort/force, which appears in the housing, called by the elongation of the tubes

$$P_1 = \frac{\Delta l F_к E}{l} = \frac{0,63 \cdot 69,5 \cdot 2,2 \cdot 10^6}{180} = 53\,500\ kg,$$

where $F_в$ - cross-sectional area of housing, equal to

$$F_в = \pi(D_в + s_3)s_3 = 3{,}14(55 + 0{,}4)0{,}4 = 69{,}5 \text{ см}^2;$$

$E = 2.2 \cdot 10^6$ kg/cm² - modulus of elasticity of steel (on Table 38).

Effort/force, which appears in the housing from the internal pressure

$$P_2 = 0{,}785 \cdot D_в^2 p = 0{,}785 \cdot 55^2 \cdot 0{,}8 = 1900 \text{ кг}.$$

Total effort/force, which appears in the housing,

$$P_в = P_1 + P_2 = 53\,500 + 1900 = 55\,400 \text{ кг}.$$

Total stress/voltage on the breakage in the wall of the housing

$$R_1 = \frac{P_в}{F_в} = \frac{55400}{69{,}5} \approx 800 \text{ кг/см}^2.$$

Effort/force, which appears in the tube, called by its compression,

$$P_4 = \frac{\Delta l F_т E_1}{l} = \frac{0{,}053 \cdot 0{,}47 \cdot 1 \cdot 10^6}{180} = 165 \text{ кг}.$$

where $F_т$ - cross-sectional area of tube, equal (with its average/mean diameter $d_c = 1{,}5$ см)

$$F_т = \pi d_c s_1 = 3{,}14 \cdot 1{,}5 \cdot 0{,}1 = 0{,}47 \text{ см}^2;$$

$E_1 = 1.0 \cdot 10^6$ kg/cm² - the modulus of elasticity of brass on Table 38.

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The permissible load on the extraction of the ends of the tubes

$$P_{max} = R_{max} \pi d_н y = 40 \cdot 3{,}14 \cdot 1{,}6 \cdot 2 = 400 \text{ kg},$$

where $R_{max} = 40$ kg/cm² - allowable stress for the rolled tubes (see page 206);

$d_н = 1{,}6$ см - outside diameter of the tubes;

y=2 cm - depth of rolling/lapping tube.

The need of applying the compensator is determined from the following relationships/ratios

$$R = 800 < R_{доп} = 900 \text{ kg/cm}^2,$$

where $R_{доп} = 900$ kg/cm² - allowable stress in the wall of the housing

$$P_4 = 165 < P_{max} = 400 \text{ kg}.$$

On the allowable stresses and the loads on this apparatus of compensator it is not required.

§ 50. Calculation of the expansion bellows.

Initial data for the calculation.

Material of the lenses: steel st. 3.

Pressure of medium in the compensator $p=4$ kg/cm².

Diameter of the housing of apparatus (over the mean section) $d_2=55.4$ cm.

Amount of the deformation of compensator $\Delta l=0.126$ cm.

Sizes/dimensions of compensator we accept.

Number of lenses in compensator $z=1$.

Diameter of the lens of compensator (over the mean section) d_1=69.6 cm.

Radii of bending of lenses $r_1=r_2=r=3$ cm.

Wave height of the lens

$$H=0{,}5(d_1-d_2)=0{,}5(69{,}6-55{,}4)=7{,}1\ см.$$

The straight portion of the lens

$$l=H-2r=7{,}1-2\cdot 3=1{,}1\ см.$$

The wall thickness of the lens

$$s=0{,}67\cdot H\sqrt{\frac{p}{R_b}}=0{,}67\cdot 7{,}1\sqrt{\frac{4}{900}}=0{,}32\ см,$$

where $R_b=900$ kg/cm² - the allowable stress accepted for steel St. 3.

We accept s=4 mm.

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The amount of the deformation of one lens during its preliminary compression on $-\frac{\Delta l}{2}$

$$\Delta x=\pm\frac{\Delta l}{2z}=\pm\frac{0{,}126}{2\cdot 1}=\pm 0{,}063\ см,$$

where plus sign is - work of lens on the elongation;

minus sign is - operation of lens on compression.

Effort/force from the internal pressure, received by the walls of lens,

$$P_0 = 0{,}785p(d_1^2 - d_2^2) = 0{,}785 \cdot 4(69{,}6^2 - 55{,}4^2) = 5500 \text{ kg}.$$

Effort/force from the internal pressure, which disrupts the wall of lens according to diameter d_1,

$$P_A = P_0 \frac{d_1}{d_1 + d_2} = 5500 \frac{69{,}6}{69{,}6 + 55{,}4} = 3060 \text{ kg}.$$

The reaction, compressing the wall of lens along diameter d_2,

$$P_B = P_0 - P_A = 5500 - 3060 = 2440 \text{ kg}.$$

The mean diameter of the lens of the compensator

$$d_{cp} = 0{,}5(d_1 + d_2) = 0{,}5(69{,}6 + 55{,}4) = 62{,}5 \text{ см}.$$

Moment of the inertia of the cross section of the wave of lens, rectified according to its mean diameter,

$$I_{cp} = 0{,}262 d_{cp} s^3 = 0{,}262 \cdot 62{,}5 \cdot 0{,}4^3 = 1{,}05 \text{ см}^4.$$

Coefficients of the configuration of lens for case of $r_1 = r_2 = r$ and $l \neq 0$ according to the data of § 43:

$$\Sigma b = n\left\{\frac{(3\pi-8)}{4}r^2+\left[r(r+l)+\frac{l^2}{3}\right]l+\right.$$
$$\left.+r\left[\frac{\pi}{2}(r+l)^2+2(r+l)r+\frac{\pi}{4}r^2\right]\right\}=2\left\{\frac{(3\cdot3,14-8)}{4}3^2+\right.$$
$$+\left[3(3+1,1)+\frac{1,1^2}{3}\right]1,1+3\left[\frac{3,14}{2}(3+1,1)^2+2(3+1,1)3+\right.$$
$$\left.\left.+\frac{3,14}{4}3^2\right]\right\}=403,2\ см^2;$$

$$\Sigma a = n\{(\pi-2)r^2+(2r+l)l+r[\pi(r+l)+2r]\}=$$
$$=2\{(3,14-2)3^2+(2\cdot3+1,1)1,1+3[3,14(3+1,1)+$$
$$+2\cdot3]\}=149,2\ см^2.$$

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The reduced length of wall of lens for the same case

$$\Sigma s_n = n(\pi r+l)=2(3,14\cdot3+1,1)=21,04\ см.$$

Here n=2 - number is half lens in the compensator.

The force, appearing in the compensator from the deformation of one lens to value +-Δx, is determined from the formula

$$P_x=\frac{EI_{cp}\Delta x}{\Sigma b-\frac{\Sigma a^2}{4\Sigma s_n}}=\frac{2,2\cdot10^6\cdot1,05\cdot0,063}{403,2-\frac{149,2^2}{4\cdot21,04}}=1040\ \text{кг},\ (1)$$

Key: (1). kg.

where $E=2.2\cdot10^6$ kg/cm² - modulus of elasticity of the material of lens.

Pinching moment/torque, caused by the deformation of lens,

$$M_x = \frac{\Sigma a P_x}{2\Sigma s_n} = \frac{149,2 \cdot 1040}{2 \cdot 21,04} = 3680 \text{ kgcm}.$$

Bending moment in the critical section/cut of the lens (section/cut AA, Fig. 104)

$$M_A = P_x H - M_x = 1040 \cdot 7,1 - 3680 = 3720 \text{ kgcm}.$$

Moment of the inertia of lens in the critical section/cut

$$I_A = 0,262 d_1 s^3 = 0,262 \cdot 69,6 \cdot 0,4^3 = 1,16 \text{ cm}^4.$$

Bending stress from the action of moment/torque in the critical section/cut

$$R_b' = \frac{M_A s}{2 I_A} = \frac{3720 \cdot 0,4}{2 \cdot 1,16} = 640 \text{ kg/cm}^2.$$

Bending stress from the internal pressure

$$R_b'' = \frac{0,45 \cdot p \cdot H^2}{s^2} = \frac{0,45 \cdot 4 \cdot 7,1^2}{0,4^2} = 566 \text{ kg/cm}^2.$$

Total bending stress

$$R_b = R_b' + R_b'' = 640 + 566 = 1206 \text{ kg/cm}^2,$$

where the plus sign - with the work of compensator on the elongation;

minus sign is - with the work of compensator on compression.

Stress/voltage on the breakage from the internal pressure

$$R_z = \frac{pd_1}{2s} = \frac{4 \cdot 69,6}{2 \cdot 0,4} = 348 \text{ kg/cm}^2.$$

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Resulting stress/voltage in the critical section/cut

$$R_{res} = \sqrt{R_b^2 + R_z^2} = \sqrt{1206^2 + 348^2} = 1250 \text{ kg/cm}^2.$$

Axial force in the housing of the apparatus

$$P_c = P_B + P_z = 2440 + 1040 = 3480 \text{ kg}.$$

Stress/voltage in the wall of lens in the place of fastening to the housing of the apparatus

$$R_z' = \frac{P_c}{\pi d_2 s} = \frac{3480}{3,14 \cdot 55,4 \cdot 0,4} \approx 50 \text{ kg/cm}^2.$$

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[redacted] appendices.

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Table 1. Saturated water vapor (according to the temperatures).

(1) Температура t °C	(2) Давление насыщения p ата	(3) Удельный объем воды при давлении насыщения $v_в$ м³/кг	(4) Удельный объем пара v м³/кг	(5) Удельный вес пара γ кг/м³	(6) Энтальпия (теплосодержание) (7) жидкости q ккал/кг	(8) пара i ккал/кг	(9) Теплота испарения r ккал/кг
0	0,006228	0,001000	206,3	0,00485	0	597,3	597,3
2	0,007193	0,001000	172,9	0,00556	2,0	598,2	596,2
4	0,008289	0,001000	157,3	0,00636	4,0	599,1	595,1
6	0,009532	0,001000	137,8	0,00726	6,0	599,9	593,9
8	0,010932	0,001000	121,0	0,00826	8,0	600,8	592,8
10	0,012513	0,001000	106,42	0,00940	10,0	601,7	591,7
12	0,014292	0,001001	93,84	0,01066	12,0	602,6	590,6
14	0,016289	0,001001	82,90	0,01206	14,0	603,5	589,5
16	0,018528	0,001001	73,39	0,01363	16,0	604,3	588,3
18	0,02103	0,001002	65,09	0,01536	18,0	605,1	587,1
20	0,02383	0,001002	57,84	0,01729	20,0	606,0	586,0
22	0,02695	0,001002	51,50	0,01942	22,0	606,9	584,9
24	0,03041	0,001003	45,93	0,02177	24,0	607,8	583,8
26	0,03426	0,001003	41,04	0,02437	26,0	608,6	582,6
28	0,03853	0,001004	36,73	0,02723	28,0	609,5	581,5
30	0,04325	0,001004	32,93	0,03037	30,0	610,4	580,4
32	0,04847	0,001005	29,57	0,03382	32,0	611,3	579,3
34	0,05423	0,001006	26,60	0,03759	34,0	612,2	578,2
36	0,06057	0,001006	23,97	0,04172	36,0	613,0	577,0
38	0,06755	0,001007	21,63	0,04623	38,0	613,9	575,9
40	0,07520	0,001008	19,55	0,05115	40,0	614,7	574,7
42	0,08360	0,001009	17,69	0,05653	42,0	615,5	573,5
44	0,09279	0,001010	16,04	0,06234	44,0	616,4	572,4
46	0,10284	0,001010	14,56	0,06868	46,0	617,3	571,3
48	0,11382	0,001011	13,23	0,07559	48,0	618,1	570,1

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50	0,1258	0,001012	12,040	0,08306	50,0	619,0	569,0
55	0,1605	0,001015	9,578	0,1044	55,0	621,1	566,1
60	0,2031	0,001017	7,678	0,1302	60,0	623,2	563,2
65	0,2550	0,001020	6,201	0,1613	65,0	625,2	560,2
70	0,3178	0,001023	5,045	0,1982	70,0	627,3	557,3
75	0,3931	0,001026	4,133	0,2420	75,0	629,3	554,3
80	0,4829	0,001029	3,408	0,2934	80,0	631,3	551,3
85	0,5894	0,001032	2,828	0,3536	85,0	633,3	548,3
90	0,7149	0,001036	2,361	0,4235	90,0	635,2	545,2
95	0,8619	0,001010	1,982	0,5045	95,1	637,2	542,1
100	1,0332	0,001044	1,673	0,5977	100,1	639,1	539,0
105	1,2318	0,001047	1,419	0,7047	105,1	640,9	535,8
110	1,4609	0,001052	1,210	0,8264	110,2	642,8	532,6
115	1,7239	0,001056	1,036	0,9652	115,3	644,6	529,4
120	2,0245	0,001060	0,8917	1,121	120,3	646,4	526,1
125	2,3666	0,001065	0,7704	1,298	125,4	648,1	522,7
130	2,7544	0,001070	0,6683	1,496	130,5	649,8	519,3
135	3,192	0,001075	0,5820	1,718	135,6	651,4	515,8
140	3,685	0,001080	0,5087	1,966	140,7	653,0	512,3
145	4,237	0,001085	0,4461	2,242	145,8	654,5	508,7
150	4,854	0,001091	0,3926	2,547	151,0	656,0	505,0
155	5,540	0,001096	0,3466	2,885	156,2	657,5	501,3
160	6,302	0,001102	0,3068	3,258	161,3	658,7	497,4
165	7,146	0,001108	0,2725	3,670	166,5	660,0	493,5
170	8,076	0,001114	0,2426	4,122	171,8	661,3	489,5
175	9,101	0,001121	0,2166	4,617	177,0	662,4	485,4
180	10,225	0,001128	0,1939	5,157	182,3	663,6	481,3
185	11,456	0,001134	0,1739	5,750	187,6	664,6	477,0
190	12,800	0,001142	0,1564	6,394	192,9	665,5	472,6
195	14,265	0,001149	0,1409	7,097	198,2	666,3	468,1

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200	15,857	0,001157	0,1272	7,862	203,6	667,1	463,5
205	17,585	0,001161	0,1151	8,688	209,0	667,7	458,7
210	19,456	0,001173	0,1043	9,588	214,4	668,3	453,9
215	21,477	0,001181	0,09465	10,56	219,9	668,8	448,9
220	23,659	0,001190	0,08606	11,62	225,4	669,1	443,7
225	26,007	0,001199	0,07837	12,76	230,9	669,3	438,4
230	28,531	0,001209	0,07147	13,99	236,5	669,5	433,0
235	31,239	0,001219	0,06527	15,32	242,2	669,7	427,5
240	34,140	0,001229	0,05967	16,76	247,8	669,5	421,7
245	37,244	0,001240	0,05462	18,30	253,6	669,4	415,8
250	40,56	0,001251	0,05006	19,98	259,3	669,0	409,7
255	44,10	0,001263	0,04591	21,78	265,2	668,5	403,3
260	47,87	0,001276	0,04215	23,72	271,1	667,9	396,8
265	51,87	0,001289	0,03872	25,83	277,1	667,3	390,2
270	56,14	0,001302	0,03560	28,09	283,1	666,3	383,2
275	60,66	0,001317	0,03274	30,53	289,2	665,2	376,0
280	65,46	0,001332	0,03013	33,19	295,4	663,9	368,5
285	70,54	0,001348	0,02774	36,05	301,7	662,4	360,7
290	75,92	0,001366	0,02554	39,15	308,1	660,7	352,6
295	81,60	0,001384	0,02351	42,53	314,6	658,8	344,2
300	87,61	0,001404	0,02164	46,21	321,2	656,6	335,4
305	93,95	0,001425	0,01992	50,20	328,0	654,2	326,2
310	100,64	0,001447	0,01832	54,58	334,9	651,4	316,5
315	107,69	0,001472	0,01683	59,42	342,0	648,3	306,3
320	115,12	0,001499	0,01545	64,72	349,2	644,9	295,7
325	122,95	0,001529	0,01417	70,57	356,7	641,0	284,3
330	131,18	0,001562	0,01297	77,10	364,5	636,7	272,2
335	139,85	0,001599	0,01184	84,46	372,5	631,8	259,3
340	148,96	0,001639	0,01078	92,76	380,9	626,2	245,3
345	158,54	0,001686	0,00977	102,34	389,8	619,9	230,1
350	168,63	0,001741	0,00881	113,6	399,2	612,5	213,3
355	179,24	0,001807	0,00787	127,1	409,4	603,6	194,2
360	190,42	0,001894	0,00694	144,0	420,7	592,6	171,9
365	202,21	0,002020	0,00599	166,8	434,1	578,2	144,1
370	214,68	0,002220	0,00493	203,0	452,0	556,7	104,7
374	225,22	0,002800	0,00347	288,0	485,3	512,7	27,4

Key: (1). Temperature t cf °C. (2). Saturation pressure p atm(abs.). (3). Specific volume of water at saturation pressure v. m³/kg. (4). Specific volume of vapor v m³/kg. (5). Specific gravity/weight cf vapor r kg/m³. (6). Entnalpy (enthalpy). (7). liquid q kcal/kg. (8). vapor i kcal/kg. (9). Heat of vaporization r kcal/kg.

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Table 2. Saturated by water vapor (on the pressures).

(1) Давление насыщения p ата	(2) Температура °C	(3) Удельный объем воды при давлении насыщения v_0 м³/кг	(4) Удельный объем пара v м³/кг	(5) Удельный вес пара γ кг/м³	(6) Энтальпия (теплосодержание) (7) жидкости q ккал/кг	(8) пара i ккал/кг	(9) Теплота испарения r ккал/кг
0 01	6,7	0.001000	131,60	0,00760	6,7	600.2	593,5
0.015	12,7	0,001001	89.63	0.01116	12.8	602.9	590 1
0.02	17,2	0,001001	68,25	0.01465	17,3	604.9	587,6
0.025	20,8	0,001002	55,27	0,01809	20,8	606,4	585,6
0,03	23,8	0,001003	46,52	0,02150	23,8	607,8	584,0
0,04	28,6	0.001004	35,46	0,02820	28,7	609,8	581,1
0,05	32,6	0,001005	28,72	0,03482	32,6	611,5	578,9
0.06	35,8	0.001006	24,19	0,04134	35,8	612,9	577,1
0 08	41,2	0.001008	18,45	0,05420	41,2	615,2	574,0
0,10	45,5	0,001010	14,95	0,06689	45,5	617,0	571,6
0,12	49,1	0,001012	12,59	0,07943	49,1	618,6	569,5
0,15	53,6	0,001014	10,20	0,09804	53,6	620,5	566,9
0,20	59,7	0,001017	7,789	0,1284	59,7	623,1	563,4
0,25	64,6	0,001020	6,318	0,1583	64,5	625,0	560,5
0,30	68,7	0,001022	5,324	0,1878	68,7	626,8	558,1
0,35	72,3	0,001024	4,613	0,2170	72,2	628,2	556,0
0.40	75.4	0,001026	4.066	0,2459	75,4	629.5	554,1
0,45	78 3	0,001028	3,641	0,2746	78,3	630,6	552,3
0,50	80,9	0,001030	3,299	0,3031	80,9	631,6	550,7
0,60	85,5	0,001033	2,782	0,3595	85,5	633,5	548,0
0,70	89,5	0,001036	2,408	0,4153	89,5	635,1	545,6
0,80	93,0	0,001038	2,125	0,4706	93,1	636,4	543,3
0,90	96,2	0,001041	1,903	0,5255	96,3	637,6	541,3
1,0	99,1	0,001043	1,725	0,5797	99,2	638,8	539,6
1,1	101,8	0,001045	1,578	0,6337	101,9	639,8	537,9
1,2	104,3	0,001047	1,455	0,6873	104,4	640,7	536,3
1,3	106,6	0,001049	1,350	0,7407	106,7	641,6	534,9
1,4	108,7	0,001051	1,259	0,7943	108,9	642,3	533,4
1,5	110,8	0,001052	1,181	0,8467	111,0	643,1	532,1
1,6	112,7	0,001054	1,111	0,9001	113,0	643,8	530,8
1.8	116.3	0.001057	0,9954	1,0046	116,6	645,1	528,5
2,0	119,6	0,001060	0.9018	1,109	119,9	646,3	526,4
2,2	122,7	0,001063	0,8248	1,212	123,0	647,3	524,3
2,4	125,5	0,001065	0,7603	1,315	125,9	648,3	522,4

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2,6	128,1	0,001068	0,7055	1,417	128,5	649,2	520,7
2,8	130,6	0,001070	0,6581	1,520	131,1	650,0	518,9
3,0	132,9	0,001073	0,6169	1,621	133,4	650,7	517,3
3,2	135,1	0,001075	0,5807	1,722	135,7	651,4	515,7
3,4	137,2	0,001077	0,5486	1,823	137,8	652,1	514,3
3,6	139,2	0,001079	0,5199	1,923	139,9	652,8	512,9
3,8	141,1	0,001081	0,4942	2,024	141,8	653,3	511,5
4,0	142,9	0,001083	0,4709	2,124	143,7	653,9	510,2
4,5	147,2	0,001088	0,4215	2,373	148,1	655,2	507,1
5,0	151,1	0,001092	0,3817	2,620	152,1	656,3	504,2
5,5	154,7	0,001096	0,3491	2,871	155,9	657,3	501,5
6,0	158,1	0,001100	0,3214	3,111	159,3	658,3	498,9
6,5	161,2	0,001104	0,2981	3,356	162,6	659,2	496,5
7,0	164,2	0,001107	0,2778	3,600	165,7	659,9	494,2
7,5	167,0	0,001111	0,2603	3,843	168,6	660,6	492,0
8,0	169,6	0,001114	0,2418	4,085	171,4	661,2	489,8
8,5	172,1	0,001117	0,2312	4,327	174,0	661,8	487,9
9,0	174,5	0,001120	0,2189	4,568	176,5	662,3	485,8
9,5	176,8	0,001123	0,2079	4,811	179,0	662,8	483,9
10	179,0	0,001126	0,1980	5,051	181,3	663,3	482,1
11	183,2	0,001132	0,1808	5,531	185,7	664,1	478,4
12	187,1	0,001137	0,1663	6,013	189,8	664,9	475,1
13	190,7	0,001143	0,1540	6,494	193,6	665,6	472,0
14	194,1	0,001148	0,1434	6,974	197,3	666,2	468,9
15	197,4	0,001153	0,1342	7,452	200,7	666,7	465,9
16	200,4	0,001157	0,1261	7,930	204,0	667,1	463,1
17	203,4	0,001162	0,1189	8,410	207,2	667,5	460,3
18	206,1	0,001166	0,1125	8,889	210,2	767,8	457,6
19	208,8	0,001171	0,1067	9,372	213,1	668,2	455,1
20	211,4	0,001175	0,1015	9,852	215,9	668,5	452,6
21	213,9	0,001180	0,09676	10,34	218,6	668,7	450,1
22	216,2	0,001183	0,09245	10,82	221,2	668,9	447,7
23	218,5	0,001187	0,08849	11,30	223,8	669,0	445,2
24	220,8	0,001191	0,08486	11,78	226,2	669,2	443,0
25	222,9	0,001195	0,08150	12,27	228,6	669,3	440,7

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26	225,0	0,001199	0,07838	12,76	230,9	669,4	438,5
27	227,0	0,001203	0,07551	13,24	233,2	669,4	436,2
28	229,0	0,001207	0,07282	13,73	235,4	669,5	434,1
29	230,9	0,001211	0,07032	14,22	237,5	669,5	432,0
30	232,8	0,001214	0,06797	14,93	239,6	669,6	430,0
32	236,4	0,001222	0,06370	15,70	243,7	669,6	425,9
34	239,8	0,001229	0,05995	16,68	247,6	669,5	421,9
36	243,0	0,001236	0,05654	17,69	251,3	669,4	418,1
38	246,2	0,001243	0,05352	18,68	254,9	669,2	414,3
40	249,2	0,001249	0,05077	19,70	258,4	669,0	410,6
42	252,1	0,001256	0,04829	20,71	261,8	668,8	407,0
44	254,9	0,001263	0,04601	21,73	265,0	668,5	403,5
46	257,6	0,001269	0,01394	22,76	268,2	668,2	400,0
48	260,2	0,001276	0,04203	23,79	271,3	667,9	396,6
50	262,7	0,001283	0,04026	24,84	274,3	667,5	393,2
55	268,7	0,001299	0,03639	27,48	281,5	666,6	385,1
60	274,3	0,001315	0,03313	30,18	288,3	665,4	377,1
65	279,5	0,001331	0,03036	32,94	294,8	664,0	369,2
70	284,5	0,001347	0,02798	35,74	301,0	662,6	361,6
75	289,2	0,001363	0,02589	38,63	307,0	661,0	354,0
80	293,6	0,001379	0,02405	41,58	312,8	659,3	346,5
85	297,9	0,001395	0,02243	44,58	318,4	657,6	339,2
90	301,9	0,001412	0,02096	47,71	323,8	655,7	331,9
95	305,8	0,001428	0,01965	50,89	329,1	653,8	324,7
100	309,5	0,001445	0,01846	54,17	334,2	651,7	317,5
110	316,6	0,001480	0,01638	61,05	344,2	647,2	303,0
120	323,2	0,001517	0,01463	68,35	353,9	642,5	288,6
130	329,3	0,001557	0,01313	76,16	363,4	637,2	273,8
140	335,1	0,001600	0,01182	84,60	372,7	631,7	259,0
150	340,6	0,001644	0,01066	93,81	381,9	625,6	243,7
160	345,7	0,001693	0,00963	103,9	391,1	618,9	227,8
170	350,7	0,001748	0,00868	115,2	400,4	611,5	211,1
180	355,4	0,001812	0,00780	128,2	410,1	602,8	192,7
190	359,8	0,001890	0,00697	143,5	420,4	593,0	172,6
200	364,1	0,001987	0,00618	161,9	431,3	581,4	150,1
210	368,2	0,002130	0,00535	186,9	444,5	565,9	121,4
220	372,1	0,002380	0,00436	229,0	463,0	542,3	79,9

Key: (1). Saturation pressure p atm(abs.). (2). Temperature t °C. (3). Specific volume of water at saturation pressure v, m³/kg. (4). Specific volume of vapor v kg/m³. (5). Specific gravity/weight of vapor γ kg/m³. (6). Enthalpy (entnalpy). (7). liquid q kcal/kg. (8). vapor i kcal/kg. (9). Heat of vaporization r kcal/kg.

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Table 3. Overheated water vapor.

t, °C \ p, atm		0,05	0,06	0,08	0,10	0,12	0,16	0,20	0,30	0,40
60	v	31,31	26,08	19,56	15,64	13,02	9,76	7,797		
	i	623,9	623,9	623,8	623,7	623,6	623,4	623,2		
80	v	33,19	27,65	20,74	16,58	13,81	10,36	8,277	5,507	4,123
	i	633,0	632,9	632,9	632,8	632,8	632,6	632,5	632,1	631,7
100	v	35,08	29,23	21,92	17,53	14,60	10,95	8,752	5,826	4,365
	i	642,1	642,1	642,1	642,0	641,9	641,8	641,7	641,4	641,1
120	v	36,96	30,80	23,10	18,47	15,39	11,54	9,226	6,143	4,604
	i	651,1	651,1	651,1	651,0	651,0	650,9	650,8	650,6	650,3
140	v	38,85	32,37	24,28	19,42	16,18	12,13	9,699	6,459	4,842
	i	660,2	660,2	660,1	660,1	660,1	660,0	659,9	659,8	659,5
160	v	40,73	33,94	25,46	20,36	16,96	12,72	10,17	6,776	5,079
	i	669,4	669,4	669,3	669,3	669,3	669,2	669,1	669,0	668,8
180	v	42,62	35,51	26,64	21,30	17,75	13,31	10,65	7,092	5,317
	i	678,6	678,5	678,5	678,5	678,5	678,4	678,3	678,2	678,0
200	v	44,50	37,08	27,82	22,24	18,54	13,90	11,12	7,407	5,553
	i	687,8	687,8	687,8	687,7	687,7	687,7	687,6	687,5	687,4
220	v	46,39	38,65	28,99	23,19	19,32	14,49	11,59	7,722	5,790
	i	697,0	697,0	697,0	697,0	697,0	696,9	696,9	696,8	696,7
240	v	48,27	40,22	30,17	24,13	20,11	15,08	12,06	8,038	6,026
	i	706,4	706,4	706,3	706,3	706,3	706,2	706,2	706,1	706,1
260	v	50,15	41,79	31,35	25,07	20,89	15,66	12,54	8,352	6,263
	i	715,8	715,8	715,7	715,7	715,7	715,7	715,6	715,5	715,5
280	v	52,04	43,36	32,52	26,02	21,68	16,25	13,01	8,667	6,500
	i	725,2	725,2	725,2	725,2	725,2	725,2	725,2	725,1	725,1
300	v	53,92	44,93	33,70	26,96	22,46	16,84	13,48	8,983	6,736
	i	734,8	734,8	734,8	734,8	734,8	734,8	734,8	734,7	734,7
320	v	55,80	46,50	34,88	27,90	23,25	17,43	13,95	9,298	6,971
	i	744,4	744,4	744,4	744,4	744,4	744,4	744,4	744,3	744,3
340	v	57,69	48,07	36,05	28,84	24,03	18,02	14,42	9,612	7,207
	i	754,0	754,0	754,0	754,0	754,0	754,0	754,0	754,0	753,9
360	v	59,57	49,64	37,23	29,78	24,82	18,61	14,89	9,926	7,443
	i	763,8	763,8	763,8	763,8	763,8	763,8	763,8	763,8	763,7
380	v	61,46	51,20	38,41	30,72	25,60	19,20	15,36	10,24	7,679
	i	773,6	773,6	773,6	773,6	773,6	773,6	773,6	773,6	773,5
400	v	63,33	52,78	39,59	31,67	26,39	19,79	15,83	10,55	7,916
	i	783,4	783,4	783,4	783,4	783,4	783,4	783,4	783,4	783,3
420	v	65,21	54,35	40,76	32,61	27,17	20,37	16,30	10,87	8,151
	i	793,3	793,3	793,3	793,3	793,3	793,3	793,3	793,3	793,2
440	v	67,09	55,92	41,94	33,55	27,95	20,96	16,77	11,18	8,387
	i	803,3	803,3	803,3	803,3	803,3	803,3	803,3	803,3	803,2
460	v	68,98	57,48	43,12	34,49	28,74	21,54	17,23	11,50	8,623
	i	813,3	813,3	813,3	813,3	813,3	813,3	813,3	813,3	813,2
480	v	70,86	59,05	44,30	35,43	29,52	22,13	17,70	11,81	8,858
	i	823,4	823,4	823,4	823,4	823,4	823,4	823,4	823,4	823,4
500	v	72,74	60,62	45,47	36,38	30,31	22,72	18,17	12,12	9,093
	i	833,6	833,6	833,6	833,6	833,6	833,6	833,6	833,6	833,6
550	v	77,45	64,55	48,41	38,73	32,27	24,20	19,35	12,91	9,682
	i	859,3	859,3	859,3	859,3	859,3	859,3	859,3	859,3	859,3

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t, °C \ p, atm		0,50	0,60	0,70	0,80	0,90	1,0	1,2	1,4	1,6
100	v	3,487	2,902	2,484	2,169	1,925	1,730			
	i	640,8	640,4	640,2	639,9	639,5	639,2			
120	v	3,679	3,063	2,623	2,292	2,035	1,830	1,521	1,300	1,135
	i	650,1	649,9	649,7	749,4	649,2	649,0	648,5	648,0	647,5
140	v	3,870	3,223	2,760	2,413	2,143	1,926	1,602	1,371	1,197
	i	659,3	659,2	659,0	658,8	658,6	658,4	658,0	657,7	657,3
160	v	4,060	3,382	2,896	2,532	2,249	2,023	1,683	1,440	1,258
	i	668,6	668,5	668,3	668,2	668,0	667,8	667,5	667,2	666,9
180	v	4,250	3,540	3,033	2,652	2,356	2,119	1,763	1,509	1,319
	i	677,9	677,7	677,5	677,5	677,3	677,2	676,9	676,7	676,4
200	v	4,440	3,700	3,169	2,771	2,462	2,214	1,843	1,578	1,379
	i	687,2	687,1	687,0	686,9	686,7	686,6	686,4	686,1	685,9
220	v	4,629	3,858	3,304	2,890	2,568	2,310	1,923	1,647	1,439
	i	696,6	696,5	696,4	696,3	696,1	696,0	695,8	695,6	695,4
240	v	4,819	4,016	3,440	3,009	2,673	2,405	2,002	1,715	1,499
	i	705,9	705,9	705,8	705,7	705,6	705,5	705,3	705,1	704,9
260	v	5,008	4,174	3,576	3,127	2,779	2,500	2,082	1,783	1,559
	i	715,4	715,3	715,3	715,2	715,1	715,1	714,9	714,7	714,5
280	v	5,197	4,331	3,711	3,246	2,884	2,595	2,161	1,851	1,619
	i	725,0	724,9	724,9	724,8	724,7	724,7	724,5	724,3	724,2
300	v	5,387	4,489	3,847	3,364	2,989	2,690	2,240	1,919	1,678
	i	734,6	734,5	734,5	734,4	734,3	734,3	734,2	734,0	733,9
320	v	5,577	4,646	3,982	3,482	3,095	2,784	2,320	1,987	1,738
	i	744,2	744,1	744,1	744,0	743,9	743,9	743,8	743,6	743,5
340	v	5,767	4,804	4,117	3,601	3,200	2,880	2,399	2,056	1,798
	i	753,9	753,8	753,8	753,7	753,6	753,6	753,5	753,4	753,3
360	v	5,955	4,961	4,252	3,720	3,305	2,975	2,478	2,123	1,857
	i	763,7	763,6	763,6	763,5	763,4	763,4	763,3	763,2	763,1
380	v	6,144	5,118	4,388	3,838	3,410	3,068	2,556	2,190	1,916
	i	773,5	773,4	773,4	773,3	773,2	773,2	773,1	773,0	773,0
400	v	6,333	5,277	4,522	3,956	3,515	3,163	2,635	2,258	1,975
	i	783,3	783,3	783,2	783,2	783,1	783,1	783,0	783,0	782,9
420	v	6,521	5,434	4,657	4,074	3,620	3,257	2,713	2,325	2,034
	i	793,2	793,2	793,1	793,1	793,1	793,1	793,0	793,0	792,9
440	v	6,710	5,591	4,792	4,191	3,725	3,352	2,792	2,393	2,093
	i	803,2	803,2	803,1	803,1	803,1	803,1	803,0	803,0	802,9
460	v	6,898	5,750	4,927	4,309	3,830	3,446	2,871	2,460	2,152
	i	813,2	813,2	813,1	813,1	813,1	813,1	813,0	813,0	812,9
480	v	7,087	5,906	5,061	4,427	3,936	3,540	2,950	2,528	2,211
	i	823,3	823,3	823,3	823,3	823,2	823,2	823,2	823,1	823,1
500	v	7,275	6,063	5,196	4,545	4,040	3,635	3,028	2,595	2,270
	i	833,5	833,5	833,5	833,5	833,4	833,4	833,4	833,3	833,3
550	v	7,746	6,454	5,532	4,840	4,302	3,871	3,225	2,765	2,418
	i	859,3	859,2	859,2	859,2	859,2	859,2	859,1	859,1	859,0

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Continuation Table 3.

t, °C \ p, atm		1,8	2,0	2,5	3,0	4,0	5,0	6,0	7,0	8,0
120	v	1,006	0,903							
	i	647,0	646,5							
140	v	1,062	0,955	0,760	0,630					
	i	656,9	656,5	655,6	654,5					
160	v	1,117	1,004	0,800	0,664	0,494	0,392	0,323		
	i	666,6	666,4	665,5	664,7	663,1	661,3	659,4		
180	v	1,171	1,053	0,840	0,698	0,520	0,413	0,342	0,291	0,252
	i	676,1	675,9	675,2	674,5	673,2	671,7	670,1	668,8	667,3
200	v	1,225	1,102	0,879	0,730	0,545	0,433	0,359	0,306	0,266
	i	685,7	685,4	684,8	684,2	683,0	681,7	680,6	679,5	678,2
220	v	1,278	1,150	0,918	0,763	0,570	0,454	0,376	0,321	0,280
	i	695,2	695,0	694,4	693,9	692,9	691,7	690,7	689,7	688,7
240	v	1,332	1,198	0,957	0,796	0,594	0,474	0,393	0,336	0,293
	i	704,8	704,6	704,0	703,6	702,7	701,7	700,9	699,9	699,0
260	v	1,385	1,246	0,995	0,828	0,619	0,494	0,410	0,350	0,305
	i	714,4	714,2	713,7	713,4	712,6	711,7	710,9	710,1	709,3
280	v	1,438	1,294	1,034	0,860	0,643	0,513	0,426	0,364	0,318
	i	724,0	723,9	723,5	723,2	722,5	721,8	721,1	720,3	719,6
300	v	1,491	1,342	1,072	0,892	0,668	0,533	0,443	0,379	0,331
	i	733,8	733,7	733,3	733,0	732,4	731,8	731,2	730,5	729,9
320	v	1,545	1,390	1,111	0,924	0,692	0,552	0,459	0,393	0,343
	i	743,4	743,3	743,1	742,8	742,3	741,7	741,2	740,5	740,0
340	v	1,598	1,437	1,149	0,956	0,716	0,572	0,475	0,407	0,355
	i	753,2	753,1	752,9	752,6	752,2	751,6	751,1	750,6	750,2
360	v	1,650	1,485	1,187	0,988	0,740	0,591	0,492	0,421	0,367
	i	763,0	762,9	762,7	762,5	762,1	761,6	761,1	760,7	760,3
380	v	1,702	1,532	1,225	1,020	0,764	0,610	0,508	0,435	0,380
	i	772,9	772,8	772,6	772,4	772,0	771,6	771,1	770,8	770,4
400	v	1,755	1,579	1,263	1,052	0,788	0,629	0,524	0,448	0,392
	i	782,8	782,7	782,5	782,4	782,0	781,6	781,2	780,9	780,5
420	v	1,807	1,627	1,301	1,084	0,811	0,649	0,540	0,462	0,404
	i	792,8	792,7	792,5	792,4	792,0	791,6	791,3	791,0	790,7
440	v	1,860	1,674	1,339	1,115	0,835	0,668	0,556	0,476	0,416
	i	802,9	802,7	802,5	802,4	802,1	801,8	801,5	801,2	800,9
460	v	1,913	1,721	1,377	1,147	0,859	0,687	0,572	0,490	0,428
	i	812,8	812,8	812,7	812,5	812,3	812,0	811,7	811,4	811,1
480	v	1,965	1,768	1,415	1,178	0,883	0,706	0,588	0,503	0,440
	i	823,0	823,0	822,9	822,7	822,5	822,2	821,9	821,6	821,3
500	v	2,018	1,815	1,453	1,210	0,907	0,725	0,604	0,517	0,452
	i	833,2	833,2	833,1	832,9	832,7	832,4	832,2	831,9	831,7
520	v	2,071	1,864	1,490	1,242	0,930	0,744	0,619	0,531	0,464
	i	843,4	843,4	843,3	843,1	842,9	842,7	842,5	842,3	842,1
550	v	2,150	1,935	1,547	1,289	0,966	0,772	0,643	0,551	0,482
	i	859,0	858,9	858,8	858,7	858,5	858,3	858,1	857,9	857,7

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Continuation Table 3.

t, °C \ p, atm		9,0	10	12	14	16	18	20	25	30
180	v	0,223	0,199							
	i	665,5	663,8							
200	v	0,235	0,210	0,173	0,146					
	i	676,8	675,4	672,9	670,0					
220	v	0,247	0,221	0,183	0,155	0,134	0,118	0,104		
	i	687,5	686,5	684,5	682,3	679,8	677,0	674,4		
240	v	0,259	0,232	0,192	0,163	0,141	0,124	0,111	0,086	0,070
	i	698,1	697,2	695,4	693,5	691,4	689,3	687,2	681,4	675,0
260	v	0,270	0,243	0,201	0,171	0,148	0,131	0,117	0,092	0,075
	i	708,5	707,7	706,0	704,4	702,6	700,8	699,0	694,2	688,9
280	v	0,282	0,253	0,209	0,178	0,155	0,137	0,122	0,096	0,079
	i	718,9	718,2	716,7	715,2	713,7	712,1	710,6	706,5	702,1
300	v	0,293	0,263	0,218	0,186	0,162	0,143	0,128	0,101	0,083
	i	729,3	728,6	727,3	725,9	724,7	723,3	722,0	718,5	714,9
320	v	0,304	0,273	0,227	0,193	0,168	0,149	0,133	0,106	0,087
	i	739,5	738,9	737,7	736,5	735,4	734,2	733,1	730,1	727,0
340	v	0,315	0,283	0,235	0,201	0,175	0,155	0,139	0,110	0,0[illegible]1
	i	749,7	749,1	748,1	747,0	746,0	744,9	743,9	741,2	738,4
360	v	0,326	0,293	0,243	0,208	0,181	0,161	0,144	0,114	0,094
	i	759,8	759,3	758,3	757,4	756,5	755,5	754,6	752,2	749,6
380	v	0,337	0,303	0,252	0,215	0,188	0,166	0,149	0,118	0,098
	i	769,9	769,5	768,6	767,8	767,0	766,1	765,2	763,1	760,9
400	v	0,348	0,313	0,260	0,222	0,194	0,172	0,154	0,123	0,101
	i	780,1	779,7	778,9	778,2	777,4	776,6	775,8	773,9	771,9
420	v	0,359	0,322	0,268	0,229	0,200	0,177	0,159	0,127	0,105
	i	790,3	789,9	789,1	788,5	787,8	787,1	786,3	784,7	782,9
440	v	0,369	0,332	0,276	0,236	0,206	0,183	0,164	0,131	0,108
	i	800,5	800,1	799,5	798,9	798,2	797,6	796,9	795,4	793,7
460	v	0,380	0,342	0,284	0,243	0,213	0,188	0,169	0,135	0,112
	i	810,8	810,4	809,9	809,3	808,7	808,1	807,5	806,1	804,5
480	v	0,391	0,352	0,293	0,250	0,219	0,194	0,174	0,139	0,115
	i	821,1	820,8	820,3	819,7	819,1	818,6	818,1	816,8	815,3
500	v	0,401	0,361	0,301	0,257	0,225	0,199	0,179	0,143	0,119
	i	831,5	831,2	830,7	830,2	829,7	829,2	828,7	827,4	826,1
520	v	0,412	0,371	0,309	0,264	0,231	0,205	0,184	0,147	0,122
	i	841,9	841,6	841,1	840,6	840,1	839,7	839,3	838,1	836,9
540	v	0,423	0,380	0,317	0,271	0,237	0,210	0,189	0,151	0,125
	i	852,3	852,0	851,6	851,2	850,7	850,3	849,9	848,8	847,7
550	v	0,428	0,385	0,321	0,275	0,240	0,213	0,192	0,153	0,127
	i	857,5	857,3	856,9	856,5	855,0	856,6	855,2	854,2	853,1

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Continuation Table 3.

t, °C \ p, atm		35	40	45	50	60	70	80
260	v	0,0623	0,0530	0,0457				
	i	683,8	678,0	671,6				
280	v	0,0663	0,0568	0,0494	0,0433	0,0341		
	i	697,8	693,0	687,9	682,7	671,0		
300	v	0,0700	0,0602	0,0526	0,0465	0,0371	0,0303	0,0250
	i	711,1	706,9	702,5	698,4	689,0	678,7	667,0
320	v	0,0735	0,0634	0,0556	0,0493	0,0398	0,0329	0,0276
	i	723,6	720,2	716,3	712,9	705,2	697,1	688,1
340	v	0,0768	0,0664	0,0584	0,0519	0,0421	0,0351	0,0298
	i	735,6	732,6	729,5	726,5	720,1	713,3	706,1
360	v	0,0800	0,0694	0,0610	0,0544	0,0443	0,0371	0,0317
	i	747,1	744,5	742,0	739,4	733,9	728,0	721,9
380	v	0,0832	0,0722	0,0636	0,0568	0,0464	0,0391	0,0335
	i	758,5	756,2	753,9	751,7	746,9	741,8	736,5
400	v	0,0863	0,0750	0,0662	0,0591	0,0485	0,0409	0,0352
	i	769,8	767,8	765,7	763,6	759,3	754,8	750,3
420	v	0,0894	0,0777	0,0686	0,0614	0,0505	0,0426	0,0368
	i	781,0	779,1	777,4	775,4	771,5	767,4	763,4
440	v	0,0924	0,0804	0,0711	0,0636	0,0524	0,0443	0,0383
	i	792,0	790,3	788,7	786,9	783,4	779,8	776,1
460	v	0,0954	0,0830	0,0734	0,0658	0,0542	0,0460	0,0398
	i	803,0	801,5	799,9	798,3	795,2	791,9	788,6
480	v	0,0983	0,0856	0,0758	0,0679	0,0561	0,0476	0,0412
	i	813,9	812,5	811,1	809,7	806,8	803,8	800,9
500	v	0,1012	0,0882	0,0781	0,0700	0,0579	0,0492	0,0427
	i	824,8	823,5	822,2	820,9	818,3	815,6	812,9
520	v	0,1041	0,0908	0,0804	0,0721	0,0597	0,0508	0,0441
	i	835,7	834,5	833,3	832,1	829,7	827,3	824,7
540	v	0,1070	0,0933	0,0827	0,0742	0,0614	0,0523	0,0454
	i	846,6	845,5	844,4	843,3	841,1	838,8	836,4
550	v	0,1084	0,0946	0,0838	0,0752	0,0623	0,0531	0,0461
	i	852,0	851,0	849,9	848,8	846,7	844,5	842,2
600	v	0,1155	0,1008	0,0894	0,0803	0,0666	0,0568	0,0494
	i	879,3	878,4	877,5	876,6	874,7	873,0	871,1
650	v	0,1225	0,1070	0,0950	0,0853	0,0708	0,0605	0,0527
	i	906,7	905,9	905,2	904,4	902,9	901,4	899,8
700	v	0,1295	0,1131	0,1004	0,0902	0,0750	0,0641	0,0559
	i	934,3	933,7	933,1	932,4	931,2	929,8	928,4

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Continuation Table 3.

t, °C \ p, atm		90	100	120	140	160	180	200	220
320	v	0,0234	0,0199						
	i	677,7	666,0						
340	v	0,0255	0,0221	0,0168	0,0125				
	i	698,2	689,4	669,1	642,8				
360	v	0,0274	0,0240	0,0187	0,0147	0,0115	0,0086		
	i	715,4	708,6	692,8	674,5	651,8	620,3		
380	v	0,0291	0,0256	0,0203	0,0161	0,0133	0,0108	0,0087	0,0066
	i	731,0	725,3	712,7	698,7	682,4	663,6	640,3	607,0
400	v	0,0307	0,0271	0,0217	0,0178	0,0147	0,0123	0,0103	0,0086
	i	745,5	740,6	730,1	718,7	706,0	691,8	675,8	657,0
420	v	0,0322	0,0285	0,0230	0,0190	0,0159	0,0135	0,0116	0,0099
	i	759,1	754,9	745,9	736,3	725,9	714,7	702,2	688,8
440	v	0,0336	0,0298	0,0242	0,0201	0,0170	0,0146	0,0126	0,0110
	i	772,4	768,6	760,7	752,4	743,6	734,2	724,1	713,5
460	v	0,0350	0,0311	0,0253	0,0211	0,0180	0,0155	0,0135	0,0119
	i	785,3	781,9	774,8	767,4	759,7	751,6	743,2	734,2
480	v	0,0363	0,0323	0,0264	0,0221	0,0189	0,0164	0,0141	0,0127
	i	797,8	794,8	788,4	781,7	774,9	767,8	760,6	752,8
500	v	0,0376	0,0335	0,0274	0,0231	0,0198	0,0172	0,0151	0,0135
	i	810,1	807,3	801,5	795,6	789,5	783,2	776,7	769,9
550	v	0,0407	0,0364	0,0299	0,0253	0,0218	0,0191	0,0169	0,0151
	i	840,0	837,7	833,2	828,4	823,6	818,7	813,7	808,5
600	v	0,0437	0,0392	0,0323	0,0274	0,0237	0,0208	0,0185	0,0167
	i	869,3	867,4	863,6	859,8	855,9	851,9	847,8	843,7
650	v	0,0467	0,0418	0,0346	0,0294	0,0255	0,0225	0,0201	0,0181
	i	898,2	896,7	893,5	890,3	887,0	883,8	880,4	876,9
700	v	0,0495	0,0444	0,0368	0,0313	0,0272	0,0240	0,0215	0,0194
	i	927,1	925,8	923,1	920,3	917,6	914,8	911,9	909,0

The designations:

v - specific volume of vapor, m^3/kg; i - enthalpy (heat content) of vapor, kcal/kg; p - pressure, atm(abs.); t - temperature, °C.

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Table 4. Physical parameters of water vapor on the line of saturation.

(1) Температура t °C	(2) Давление p *атм*	(3) Удельный вес γ *кг/м³*	(4) Удельная теплоемкость c_p *ккал/кг °C*	(5) Коэффициент теплопроводности $10^6 \lambda$ *ккал/м·час °C*	(6) Коэффициент температуропроводности $10^6 a$ *м²/час*	(7) Динамическая вязкость $10^6 \mu$ *кг · сек/м²*	(8) Кинематическая вязкость $10^6 \nu$ *м²/сек*
100	1,03	0,598	0,48	2,08	72,5	1,23	20,15
110	1,46	0,827	0,49	2,23	55,1	1,30	15,43
120	2,02	1,121	0,50	2,37	42,7	1,36	11,88
130	2,75	1,496	0,52	2,40	30,9	1,40	9,17
140	3,69	1,966	0,55	2,45	22,6	1,44	7,18
150	4,85	2,547	0,57	2,59	17,4	1,51	5,80
160	6,30	3,258	0,60	2,64	13,50	1,55	4,67
170	8,08	4,122	0,62	2,75	10,75	1,60	3,80
180	10,23	5,157	0,65	2,86	8,55	1,64	3,12
190	12,80	6,394	0,69	2,98	6,75	1,67	2,59
200	15,86	7,862	0,72	3,10	5,48	1,73	2,16
210	19,46	9,588	0,77	3,22	4,37	1,78	1,82
220	23,66	11,62	0,82	3,33	3,50	1,83	1,54
230	28,53	13,99	0,87	3,44	2,83	1,88	1,32
240	34,14	16,76	0,95	3,66	2,30	1,93	1,13
250	40,56	19,98	1,01	3,88	1,92	1,98	0,974
260	47,87	23,72	1,08	4,10	1,60	2,04	0,843
270	56,14	28,09	1,19	4,31	1,29	2,10	0,732
280	65,46	33,19	1,30	4,55	1,05	2,16	0,637
290	75,92	39,15	1,51	4,88	0,81	2,22	0,557
300	87,61	46,21	1,65	5,40	0,71	2,29	0,487
310	100,64	54,58	1,88	5,80	0,56	2,37	0,425
320	115,12	64,72	2,20	6,33	0,44	2,45	0,372
330	131,18	77,10	2,56	7,00	0,35	2,55	0,325
340	148,96	92,76	2,80	8,00	0,308	2,67	0,282
350	168,63	113,6	4,00	9,20	0,203	2,82	0,243
360	190,42	144,0	5,00	10,60	0,148	3,03	0,207
370	214,68	203,0	7,00	13,20	0,093	3,45	0,169

Key: (1). Temperature of t°C. (2). Pressure p atm(abs.). (3). Specific gravity/weight γ kg/m³. (4). Specific heat c_p kcal/kg °C. (5). Coefficient of thermal conductivity $10^2 \lambda$ kcal/m-hour °C. (6). Coefficient of thermal diffusivity $10^3 a$ m²/h. (7). Dynamic viscosity $10^6 \mu$ kg•s/m². (8). Kinematic viscosity. (9). m³/s.

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Physical parameters of overheated water vapor.

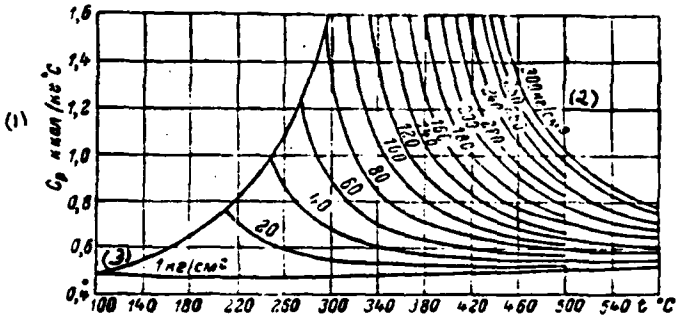

Fig. 1. Heat capacity of superheated water vapor.

Key: (1). kcal/kg °C. (2). kg/cm³. (3). kg/cm².

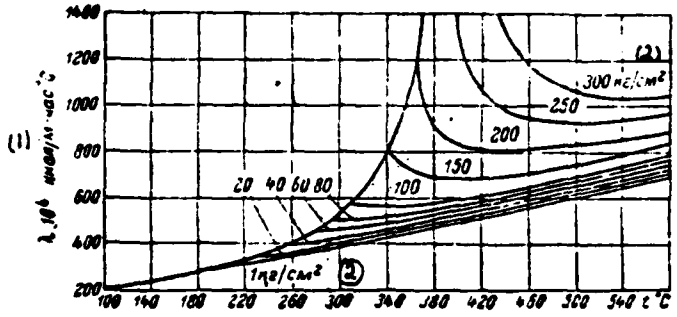

Fig. 2. Coefficient of thermal conductivity of overheated water vapor.

Key: (1). kcal/m-hour °C. (2). kg/cm².

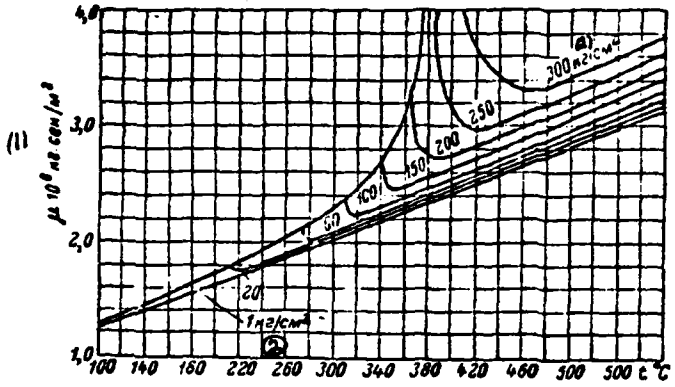

Fig. 3. Coefficient of dynamic viscosity of overheated water vapor.

Key: (1). kg•s/m³. (2). kg/cm².

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Table 5. Physical parameters for the dry air at p=1 atm(abs.).

(1) Температура t °C	(2) Удельный вес γ кг/м³	(3) Удельная теплоемкость c_p ккал/кг °C	(4) Коэффициент теплопроводности $10^3 \lambda$ ккал/м·час °C	(5) Коэффициент температуропроводности $10^3 a$ м²/час	(6) Динамическая вязкость $10^9 \mu$ кг·сек/м²	(7) Кинематическая вязкость $10^6 \nu$ (%) м²/сек
—180	3,685	0,250	0,65	0,705	0,66	1,76
—150	2,817	0,248	1,00	1,45	0,89	3,10
—100	1,984	0,244	1,39	2,88	1,20	5,94
—50	1,534	0,242	1,75	4,73	1,49	9,54
—20	1,365	0,241	1,94	5,94	1,66	11,93
0	1,252	0,241	2,04	6,75	1,75	13,70
10	1,206	0,241	2,11	7,24	1,81	14,70
20	1,164	0,242	2,17	7,66	1,86	15,70
30	1,127	0,242	2,22	8,14	1,91	16,61
40	1,092	0,242	2,28	8,65	1,96	17,60
50	1,056	0,243	2,35	9,14	2,00	18,60
60	1,025	0,243	2,41	9,65	2,05	19,60
70	0,996	0,243	2,46	10,18	2,08	20,45
80	0,968	0,244	2,52	10,65	2,14	21,70
90	0,942	0,244	2,58	11,25	2,20	22,90
100	0,916	0,244	2,64	11,80	2,22	23,78
120	0,870	0,245	2,75	12,90	2,32	26,20
140	0,827	0,245	2,86	14,10	2,40	28,45
160	0,789	0,246	2,96	15,25	2,46	30,60
180	0,755	0,247	3,07	16,50	2,55	33,17
200	0,723	0,247	3,18	17,80	2,64	35,82
250	0,653	0,249	3,42	21,2	2,85	42,8
300	0,596	0,250	3,69	24,8	3,03	49,9
350	0,549	0,252	3,93	28,4	3,21	57,5
400	0,508	0,253	4,17	32,4	3,36	64,9
500	0,450	0,256	4,64	40,0	3,69	80,4
600	0,400	0,260	5,00	49,1	4,00	98,1
800	0,325	0,266	5,75	68,0	4,54	137,0
1000	0,268	0,272	6,55	89,9	5,05	185,0
1200	0,238	0,278	7,27	113,0	5,50	232,5
1400	0,204	0,284	8,00	138,0	5,89	282,5
1600	0,182	0,291	8,70	165,0	6,28	338,0
1800	0,165	0,297	9,40	192,0	6,68	397,0

Key: (1). Temperature t °C. (2). Specific gravity/weight γ kg/m³. (3). Specific heat c_p kcal/kg °C. (4). Coefficient of thermal conductivity $10^2 \lambda$ kcal/m-hour °C. (5). Coefficient of thermal diffusivity $10^2 \alpha$ m²/h. (6). Dynamic viscosity $10^6 \mu$ kg-s•m². (7). Kinematic viscosity. (8). m²/s.

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Table 6. Physical parameters cr water on the line of saturation.

(1) Температура t °C	(2) Давление p ата	(3) Удельный вес γ кг/м³	(4) Удельная теплоемкость c_p ккал/кг °C	(5) Коэффициент теплопроводности λ ккал/м·час °C	(6) Коэффициент температуропроводности $10^6 a$ м²/час °C	(7) Динамическая вязкость $10^6 \mu$ кг·сек/м²	(8) Кинематическая вязкость $10^6 \nu$ м²/сек	(9) Коэффициент $10^4 \beta$ 1/°C
1	1	999,8	1,012	0,474	4,7	182,5	1,790	−0,63
10	1	999,6	1,006	0,494	4,9	133,0	1,300	+0,88
20	1	998,2	1,004	0,515	5,1	102,0	1,000	2,07
30	1	995,6	1,003	0,531	5,3	87,7	0,805	3,04
40	1	992,2	1,003	0,545	5,5	66,6	0,659	3,90
50	1	988,0	1,003	0,557	5,6	56,0	0,556	4,6
60	1	983,2	1,004	0,567	5,8	48,0	0,479	5,3
70	1	977,7	1,006	0,574	5,8	41,4	0,415	5,8
80	1	971,8	1,007	0,580	5,9	36,3	0,366	6,3
90	1	965,3	1,009	0,585	6,0	32,1	0,326	7,0
100	1,03	958,3	1,010	0,587	6,1	28,8	0,295	7,5
110	1,46	951,8	1,012	0,589	6,1	26,0	0,268	8,0
120	2,02	943,1	1,015	0,590	6,2	23,5	0,244	8,6
130	2,75	934,8	1,020	0,590	6,2	21,6	0,226	9,2
140	3,69	926,1	1,025	0,589	6,2	20,0	0,212	9,7
150	4,85	916,9	1,032	0,588	6,2	18,9	0,202	10,3
160	6,30	907,4	1,040	0,587	6,2	17,7	0,191	10,8
170	8,08	897,3	1,048	0,584	6,2	16,6	0,181	11,5
180	10,22	886,9	1,057	0,583	6,2	15,6	0,173	12,2
190	12,80	876,0	1,066	0,576	6,2	14,8	0,166	12,9
200	15,86	864,7	1,078	0,570	6,1	14,1	0,160	13,6
210	19,46	852,8	1,10	0,563	6,0	13,4	0,154	14,6
220	23,66	840,3	1,11	0,555	6,0	12,8	0,149	15,6
230	28,53	827,3	1,12	0,548	6,0	12,2	0,145	16,7
240	34,14	813,6	1,13	0,540	5,9	11,7	0,141	17,9
250	40,56	799,2	1,16	0,531	5,7	11,2	0,137	19,4
260	47,87	784,0	1,18	0,520	5,6	10,8	0,135	21,2
270	56,14	767,9	1,20	0,507	5,5	10,4	0,133	22,3
280	65,46	750,7	1,25	0,494	5,3	10,0	0,131	24,0
290	75,92	732,3	1,30	0,480	5,0	9,6	0,129	25,7
300	87,61	712,5	1,38	0,464	4,7	9,3	0,128	31,4
310	100,64	690,6	1,47	0,446	4,4	9,0	0,128	36
320	115,12	667,1	1,57	0,425	4,1	8,7	0,128	40
330	131,18	640,2	1,72	0,402	3,7	8,3	0,127	45
340	148,96	609,4	1,95	0,376	3,2	7,9	0,127	61
350	168,63	572,0	2,2	0,344	2,7	7,4	0,127	69
360	190,42	524,0	2,43	0,306	2,4	6,8	0,127	112
370	214,68	448,0	2,68	0,252	2,1	5,8	0,127	314

Key: (1). Temperature t °C. (2). Pressure p atm(abs.). (3). Specific gravity/weight γ kg/m³. (4). Specific heat c_p kcal/kg °C. (5). Coefficient of thermal conductivity λ kcal/m-hour °C. (6). Coefficient of thermal conductivity 10^4 a m²/h °C. (7). Dynamic viscosity 10^6 μ kg-s/m². (8). Kinematic viscosity 10^6 ν m²/s. (9). Coefficient of 10^4 β 1 °C.

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Table 7. Physical parameters of turbine oil UT.

(1) Температура t °C	(2) Удельный вес γ кг/м³	(3) Удельная теплоемкость c_p ккал/кг °C	(4) Коэффициент теплопроводности λ ккал/м·час °C	(5) Коэффициент температуропроводности 10^4 a м²/час	(6) Вязкость		
					(6a) динамическая 10^6 μ кг · сек/м²	(6b) кинематическая 10^6 ν м²/сек	(6c) в градусах Энглера °E
0	912	0,422	0,1119	2,91	72 500	780	105
5	909	0,426	0,1116	3,05	46 200	500	68
10	905	0,43	0,1113	3,19	31 300	340	46
15	902	0,434	0,1110	3,32	20 950	228	32
20	899	0,438	0,1107	3,45	14 800	162	22
25	896	0,442	0,1104	3,605	10 500	115	15,5
30	893	0,447	0,1101	3,73	7 550	83	11,5
35	889	0,451	0,1098	3,87	5 660	62,5	8,5
40	886	0,455	0,1095	4,0	4 420	49	6,8
45	883	0,459	0,1092	4,12	3 440	38,2	5,4
50	880	0,4635	0,1089	4,24	2 780	31	4,25
55	877	0,468	0,1086	4,37	2 235	25	3,62
60	873	0,472	0,1083	4,51	1 825	20,5	3,05
65	870	0,476	0,1080	4,64	1 515	17,1	2,62
70	867	0,4805	0,1077	4,74	1 290	14,6	2,35
75	864	0,485	0,1074	4,86	1 110	12,6	2,12
80	861	0,489	0,1071	4,98	939	10,7	1
85	857	0,493	0,1068	5,11	—	—	—
90	854	0,4975	0,1065	5,24	—	—	—
95	851	0,5015	0,1062	5,36	—	—	—
100	848	0,506	0,1059	5,48	—	—	—

Key: (1). Temperature t °C. (2). Specific gravity/weight γ kg/m³. (3). Specific heat c_p kcal/kg °C. (4). Coefficient of thermal conductivity λ kcal/m-hour °C. (5). Coefficient of thermal diffusivity 10^4 a m²/ hour. (6). Viscosity. (6a). dynamic 10^6 μ kg·s/m². (6b). kinematic 10^6 ν m³/s. (6c). in the Engler degrees °E.

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Table 8.

Physical parameters of turbine oil T.

(1) Температура t °C	(2) Удельный вес γ кг/м³	(3) Удельная теплоемкость c_p ккал/кг °C	(4) Коэффициент теплопроводности λ ккал/м·час °C	(5) Коэффициент температуропроводности 10^6 a м²/час	(6) Вязкость		
					(6a) динамическая 10^6 μ кг · сек/м²	(6b) кинематическая 10^6 ν м²/s	(6c) в градусах Энглера °E
0	908	0,426	0,1125	2,89	152 800	1650	225
5	904,5	0,43	0,1122	3,03	92 000	1000	135
10	901	0,434	0,1119	3,17	59 700	650	83
15	898	0,438	0,1116	3,3	38 000	415	58
20	895	0,4425	0,1113	3,43	25 550	280	37,5
25	892	0,4465	0,1109	3,59	17 700	195	26,5
30	888	0,451	0,1106	3,72	12 680	140	19,2
35	885	0,455	0,1103	3,85	8 920	99	13,9
40	882	0,459	0,1100	3,97	6 740	75	10,2
45	879	0,463	0,1097	4,1	5 110	57	7,8
50	876	0,467	0,1094	4,22	4 020	45	6,3
55	872,5	0,472	0,1091	4,37	3 110	35	5
60	869,5	0,476	0,1088	4,49	2 510	28,4	4,05
65	866	0,48	0,1085	4,62	2 070	23,5	3,22
70	863	0,484	0,1082	4,74	1 715	19,5	2,9
75	860	0,4885	0,1079	4,85	1 445	16,5	2,6
80	856,5	0,493	0,1076	4,97	1 220	14	2,3
85	853,5	0,497	0,1073	5,09	1 040	12	2,06
90	850	0,5015	0,1070	5,24	—	—	—
95	847	0,506	0,1067	5,35	—	—	—
100	844	0,51	0,1064	5,46	—	—	—

Key: (1). Temperature T °C. (2). Specific gravity/weight γ kg/m³. (3). Specific heat c_p kcal/kg °C. (4). Coefficient of thermal conductivity λ kcal/m-hour °C. (5). Coefficient of thermal diffusivity 10^4 α m³/h. (6). Viscosity. (6a). dynamic 10^6 μ kg•s/m². (6b). kinematic 10^6. (6c). in the Engler degrees °E.

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Table 9. Physical parameters cr diesel oil.

(1) Температура t °C	(2) Удельный вес γ кг/м³	(3) Удельная теплоемкость c_p ккал/кг °C	(4) Коэффициент теплопроводности λ ккал/м·час °C	(5) Коэффициент температуропроводности $10^4 a$ м²/час	(6) Вязкость		
					(6a) динамическая $10^5 \mu$ кг · сек/м²	(6b) кинематическая $10^6 \nu$ м²/сек	(6c) в градусах Энглера °E
0	922	0,4225	0,1107	2,87	—	—	—
5	918	0,4265	0,1104	3,02	243 000	2600	280
10	915	0,431	0,1101	3,14	141 600	1520	200
15	912	0,435	0,1098	3,28	89 200	960	126
20	908,4	0,439	0,1095	3,41	57 400	620	84
25	905,5	0,443	0,1092	3,56	37 400	405	55
30	902	0,4475	0,1089	3,69	25 700	280	37
35	899	0,452	0,1086	3,81	17 400	190	26
40	895,5	0,456	0,1083	3,94	12 300	135	18,4
45	892	0,46	0,1080	4,07	9 100	100	14
50	889	0,464	0,1077	4,2	6 870	76	10,5
55	886	0,4685	0,1074	4,34	5 140	57	7,8
60	882,4	0,473	0,1071	4,45	4 040	45	6,3
65	879	0,477	0,1068	4,56	3 220	36	5,1
70	876	0,481	0,1065	4,71	2 590	29	4,1
75	873	0,4855	0,1062	4,81	2 180	24,5	3,27
80	870	0,490	0,1059	4,92	1 770	20	3
85	866,5	0,494	0,1056	5,05	1 480	16,8	2,6
90	863,1	0,498	0,1053	5,19	1 250	14,2	2,3
95	860	0,502	0,1050	5,3	—	—	—
100	857	0,5065	0,1047	5,41	—	—	—

Key: (1). Temperature t °C. (2). Specific gravity/weight γ kg/m³. (3). Specific heat c_p kcal/kg °C. (4). Coefficient of thermal conductivity λ kcal/m-hour °C. (5). Coefficient of thermal conductivity 10^4 α m²/h. (6). Viscosity. (6a). dynamic 10^6 μ kg•s/m². (6b). kinematic 10^6 ν m²/s. (6c). in the Engler degrees °E.

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Table 10. Physical parameters of the admiralty fuel oil M12.

(1) Температура t °C	(2) Удельный вес γ кг/м³	(3) Удельная теплоемкость c_p ккал/кг °C	(4) Коэффициент теплопроводности λ ккал/м·час °C	(5) Коэффициент температуропроводности $10^6 a$ м²/час	(6) Вязкость		
					(6a) динамическая $10^6 \mu$ кг · сек/м²	(6b) кинематическая $10^6 \nu$ м²/сек	(6c) в градусах Энглера °E
0	940,9	0,418	0,1083	2,84	—	—	—
5	937,9	0,422	0,1080	2,98	—	—	—
10	934,9	0,426	0,1077	3,12	181 000	1900	240
15	932,1	0,43	0,1074	3,24	108 000	1140	150
20	928,8	0,434	0,1071	3,45	64 200	730	100
25	925,5	0,438	0,1068	3,53	43 400	460	63
30	922,7	0,442	0,1065	3,65	30 100	320	43
35	919,7	0,446	0,1062	3,78	20 400	218	29,5
40	916,7	0,451	0,1060	3,89	14 720	158	21,5
45	913,6	0,455	0,1057	4,01	10 700	115	15,6
50	910,6	0,459	0,1054	4,14	8 110	87	12
55	907,6	0,463	0,1051	4,28	6 180	67	9,1
60	904,5	0,467	0,1048	4,4	4 780	52	7,2
65	901,5	0,471	0,1045	4,51	3 760	41	5,7
70	898,5	0,475	0,1042	4,64	2 940	32,2	4,7
75	895,2	0,48	0,1039	4,75	2 490	27,3	3,9
80	892,4	0,484	0,1036	4,86	2 235	24,6	3,3
85	889,3	0,488	0,1033	4,97	1 710	18,9	2,8
90	886,3	0,493	0,1030	5,11	1 425	15,8	2,5
95	883,3	0,497	0,1027	5,21	1 205	13,4	2,2
100	880,2	0,501	0,1024	5,34	1 060	11,8	2,05

Key: (1). Temperature t °C. (2). Specific gravity/weight γ kg/m³. (3). Specific heat c_p kcal/kg °C. (4). Coefficient of thermal conductivity λ kcal/m-hour °C. (5). Coefficient of thermal diffusivity 10^4 α m²/h. (6). Viscosity. (6a). dynamic 10^6 μ kg•s/m². (6b). kinematic 10^6 ν m²/s. (6c). in Engler degrees °E.

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Table 11. Physical parameters of the admiralty fuel oil M20.

(1) Температура t °C	(2) Удельный вес γ кг/м³	(3) Удельная теплоемкость c_p ккал/кг °C	(4) Коэффициент теплопроводности λ ккал/м·час °C	(5) Коэффициент температуропроводности $10^4 a$ м²/час	(6) Вязкость		
					(6a) динамическая $10^7 \mu$ кг · сек/м²	(6b) кинематическая $10^6 \nu$ м²/сек	(6c) в градусах Энглера E
0	953,6	0,416	0,1069	2,82	—	—	—
5	950,7	0,419	0,1066	2,95	—	—	—
10	947,8	0,423	0,1063	3,09	—	—	—
15	944,9	0,427	0,1060	3,22	269 000	2800	300
20	942	0,431	0,1057	3,35	158 000	1650	215
25	939,1	0,436	0,1054	3,5	95 600	1000	135
30	936,2	0,44	0,1051	3,62	58 200	610	83
35	933,3	0,444	0,1049	3,74	37 050	390	54
40	930,4	0,449	0,1046	3,86	25 600	270	36
45	927,5	0,452	0,1043	3,97	17 950	190	25,5
50	924,6	0,457	0,1040	4,09	12 800	136	19
55	921,7	0,461	0,1037	4,23	9 200	98	13,5
60	918,8	0,465	0,1034	4,36	6 920	74	10,2
65	915,9	0,469	0,1031	4,47	5 320	57	7,8
70	913	0,474	0,1028	4,58	4 180	45	6,1
75	910,1	0,477	0,1025	4,69	3 340	36	5,1
80	907,2	0,482	0,1023	4,8	2 630	28,5	4,1
85	904,3	0,486	0,1020	4,91	2 190	23,8	3,5
90	901,4	0,490	0,1017	4,98	1 760	19,2	2,9
95	898,5	0,494	0,1014	5,16	1 470	16,1	2,54
100	895,5	0,498	0,1011	5,27	1 275	14	2,3

Key: (1). Temperature t °C. (2). Specific gravity/weight γ kg/m³. (3). Specific heat c_p kcal/kg °C. (4). Coefficient of thermal conductivity λ kcal/m-hour °C. (5). Coefficient of thermal conductivity 10^4 α m²/h. (6). Viscosity. (6a). dynamic 10^6 μ kg•s/m². (6b). kinematic 10^6 ν m²/s. (6c). in the Engler degrees °E.

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Table 12. Physical parameters of fuel mazut M40.

(1) Температура t °C	(2) Удельный вес γ кг/м³	(3) Удельная теплоемкость c_p ккал/кг °C	(4) Коэффициент теплопроводности λ ккал/м·час °C	(5) Коэффициент температуропроводности $10^6 a$ м²/час	(6) Вязкость		
					(6a) динамическая $10^6 \mu$ кг · сек/м²	(6b) кинематическая $10^6 \nu$ м²/сек	(6c) в градусах Энглера °E
0	970,3	0,412	0,1050	2,8	—	—	—
5	967,5	0,416	0,1047	2,93	—	—	—
10	964,7	0,420	0,1044	3,06	—	—	—
15	961,8	0,424	0,1041	3,19	—	—	—
20	959	0,428	0,1039	3,31	—	—	—
25	956,2	0,432	0,1036	3,46	243 600	2500	280
30	953,3	0,435	0,1033	3,59	145 800	1500	200
35	950,5	0,44	0,1030	3,71	92 000	950	129
40	947,7	0,445	0,1027	3,81	62 700	650	87
45	944,8	0,449	0,1024	3,94	42 300	440	61
50	942	0,453	0,1022	4,05	30 700	320	43
55	939,2	0,457	0,1019	4,19	21 200	222	31
60	936,3	0,462	0,1016	4,3	16 200	170	22,5
65	933,5	0,465	0,1013	4,42	11 600	122	17
70	930,7	0,469	0,1010	4,52	9 010	95	13,1
75	927,8	0,473	0,1007	4,64	7 170	76	10,5
80	925	0,477	0,1005	4,76	5 650	60	8,2
85	922,2	0,482	0,1002	4,85	4 510	48	6,8
90	919,3	0,486	0,0999	5,0	3 650	39	5,5
95	916,5	0,49	0,0996	5,1	2 940	31,5	4,5
100	913,6	0,494	0,0993	5,21	2 510	27	3,9

Key: (1). Temperature t °C. (2). Specific gravity/weight γ kg/m³. (3). Specific heat c_p kcal/kg °C. (4). Coefficient of thermal conductivity λ kcal/m-hour °C. (5). Coefficient of thermal diffusivity 10^4 α m²/h. (6). Viscosity. (6a). dynamic 10^6 μ kg•s/m². (6b). kinematic 10^6 ν m²/s. (6c) in Engler degrees °E.

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Table 13.

(1) Температура t °C	(2) Средняя теплоемкость при τ=1, c, ккал/кг °C	(3) Мазут Ф		(4) Масло					
				(5) турбинное М		(6) моторное Т		(7) солярное	
		τ	°E	τ	°E	τ	°E	τ	°E
0	0,403	0,927	110	0,913	110	0,927	110	0,906	12,6
5	0,407	0,924	87,5	0,910	90,0	0,924	110	0,903	10,2
10	0,411	0,921	43,0	0,906	53,0	0,921	110	0,900	6,7
15	0,415	0,918	29,0	0,903	36,0	0,918	103	0,896	4,9
20	0,419	0,915	20,4	0,900	24,8	0,915	74,2	0,893	3,8
25	0,423	0,911	14,5	0,897	17,5	0,911	47,4	0,890	3,2
30	0,427	0,909	8,30	0,893	12,7	0,909	32,2	0,887	2,6
35	0,431	0,905		0,890		0,905		0,883	
40	0,435	0,902	5,30	0,887	7,20	0,902	16,2	0,880	2,1
45	0,439	0,899		0,884		0,899		0,877	
50	0,443	0,896	3,20	0,880	4,63	0,896	9,50	0,874	1,71
55	0,447	0,893		0,877		0,893		0,870	
60	0,451	0,890	2,40	0,874	3,21	0,890	5,90	0,867	1,54
65	0,455	0,887		0,870		0,887		0,864	
70	0,459	0,884	2,00	0,868	2,60	0,884	4,00	0,861	1,41
75	0,463	0,881		0,864		0,881		0,857	
80	0,467	0,878	1,70	0,861	2,05	0,878	2,95	0,854	1,31
85	0,471	0,874		0,858		0,874		0,851	
90	0,475	0,871		0,855	1,73	0,871	2,40	0,848	1,24
95	0,479	0,868		0,851		0,867		0,844	
100	0,483	0,865	1,40	0,848	1,57	0,865	2,10	0,841	1,19

Key: (1). Temperature t °C. (2). Average/mean heat capacity with $\gamma=1$, c_1 [1] kcal/kg °C.

FOOTNOTE [1]. The average/mean heat capacity c, which corresponds to the specific gravity/weight of oil-products, is determined from the formula

$$c = \frac{c_1}{\sqrt{\gamma_{15}}} \text{ kcal/kg of } ^\circ\text{C},$$

where γ_{15} - specific gravity/weight with 15°C, kg/m³. ENDFOOTNOTE.

(3). Petroleum residue F. (4). Oil. (5). turbine. (6). motor. (7). solar.

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Table 14. Physical parameters of marine water.

(a) Наименование бассейна		(b) Удельный вес, т/м³	(c) Соленость, °Б (Брандта)
(1) Белое море	(2) в горле		3300
	(3) в средней части	1,019—1,021	2500—2600
	(4) в Двинском заливе		1000
(5) Балтийское море	(6) в Ботническом заливе		200—500
	(7) в Финском заливе	1,000—1,006	200—150
	(8) Гогланд и Аландские о-ва	1,010—1,016	600—670
	(9) в проливе Бельт	1,010—1,016	1000—2200
(10) Черное море	(11) северо-западная часть	1,015—1,018	1700
	(12) средняя и южная часть	1,015—1,018	1850
(13) Каспийское море	(14) в середине	—	1000—1500
	(15) вдоль берега	—	100—1000
(16) Мраморное море	(17) у Босфора	—	2000—2100
	(18) у Дарданелл	—	2400—2500
(19) Азовское море		—	930—1200
(20) Средиземное море		—	до 4100
(21) Красное море		—	до 4100
(22) Японское море		—	3400
(23) Немецкое море		—	3400
(24) Северный Ледовитый океан		1,024—1,025	3500
(25) Атлантический океан		1,025—1,027	3700—3790
(26) Тихий океан		1,025—1,032	3400—3690
(27) Индийский океан		1,025—1,032	3200—3750

(28) Теплоемкость морской воды в зависимости от солености

(29) Соленость, °Б	0,000	2000	3000	3500	4000
(30) Средняя теплоемкость, ккал/кг °С	1,0	0,951	0,939	0,932	0,926

(31) Единицы измерения солености

$$1°Б = 10\ (32)\ мг/л = 0{,}001\%$$

(33) Значение коэффициентов вязкости и теплопроводности морской воды в зависимости от солености и температуры

(34) Температура t, °С	(35) Коэффициент динамической вязкости $10^6\ \mu$ кг·сек/м²			(36) Коэффициент теплопроводности λ ккал/м·час °С			
	(37) соленость °Б						
	1000	2000	3000	1000	2000	3000	3500
0	184,0	185,0	186,0	0,465	0,457	0,454	0,453
5	156,0	157,5	158,5	0,471	0,464	0,461	0,460
10	134,7	136,0	137,5	0,477	00471	0,468	0,467
15	117,5	118,8	120,0	0,484	0,478	0,475	0,474
20	104,0	105,2	106,5	0,490	0,484	0,482	0,480
25	92,4	93,5	95,0	0,497	0,491	0,488	0,487
30	83,2	84,5	85,5	0,503	0,498	0,495	0,494
35	76,9	78,0	79,0	0,510	0,505	0,502	0,501

Key: (a). Designation of basin. (b). Specific gravity/weight, t/m^3. (c). Salinity °B (Brandt). (1). White Sea. (2). in throat. (3). in middle part. (4). in Dvina gulf. (5). Baltic sea. (6). in Gulf of Bothnia. (7). In Gulf of Finland. (8). Gogland and Aland Is. (9). in strait/spill Baelt. (10). Cherryy sea. (11). northwestern part. (12). middle and southern part. (13). Caspian Sea. (14). in middle. (15). along coast. (16). Marble sea. (17). in Bosporus. (18). in Dardanelles. (19). Azov sea. (20). Mediterranean. (21). Red sea. (22). Sea of Japan. (23). German sea. (24). Arctic Ocean. (25). Atlantic Ocean. (26). Pacific Ocean. (27). Indian Ocean. (28). Heat capacity of marine water in depending on salinity. (29). Salinity, °B. (30). Average/mean heat capacity, kcal/kg of °C. (31). Units salinity measurement. (32). mg/l. (33). Value of coefficients of viscosity and thermal conductivity of marine water in depending on salinity and temperature. (34). Temperature t, °C. (35). Coefficient of dynamic viscosity 10^6 μ $kg \cdot s/m^2$. (36). Coefficient of thermal conductivity λ kcal/m-hour °C. (37). salinity °B.

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Table 15. Conversion of the English units measurement into the metric ones.

(a) Наименование	(b) Единицы измерения	
	(c) английские	(d) метрические
(1) Длина	(2) 1 дюйм (")	25,4 *мм*
	(3) 1 фут (') = 12"	0,305 *м*
	(4) 1 ярд = 3'	0,9144 *м*
	(5) 1 миля = 1760 (6) ярдов	1,609 *км*
	(7) 1 морская миля	1,853 *км*
(8) Площадь	(9) 1 кв. дюйм	6,451 *см*²
	(10) 1 кв. фут	0,0929 *м*²
	(11) 1 кв. ярд	0,836 *м*²
(12) Объем	(13) 1 куб. дюйм	16,387 *см*³
	(14) 1 имперский галлон	4,546 *л* (19)
	(15) 1 США галлон	3,785 *л*
	(16) 1 нефт. баррель = 42 (17) США галлона	159 *л*
	(18) 1 куб. фут	28,3 *л*
(20) Вес	(21) 1 гран = 1/7000 (22) фунта	0,0648 *г* (22a)
	(23) 1 унция = 1/16 фунта (22)	28,35 *г*
	(24) 1 фунт	0,4536 *кг* (24a)
	(25) 1 шорт-тонна (короткая) = 2000 фунтов	0,907 *т* (27)
	(26) 1 лонг-тонна (длинная) = = 2240 фунтов	1,016 *т* (27)
(28) Давление	(29) 1 унция/кв. дюйм	(30) 44 *мм* вод. ст.
	(31) 1 фунт/кв. дюйм	0,0703 *кг/см*² (32)
	(31) 1 фунт/кв. дюйм	(33) 0,0680 физич. *ат*
	(34) 1 лонг-тонна/кв. дюйм	157,5 *кг/см*² (35)
	(31) 1 фунт/кв. дюйм	(36) 703 *мм* вод. ст.
	(31) 1 фунт/кв. дюйм	(36) 51,712 *мм* рт. ст.

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(a) Наименование	(b) Единицы измерения	
	(c) английские	(d) метрические
(37) Удельный вес и плотность	(38) 1 гран/куб. фут	2,29 (39) г/м³
	(40) 1 гран/имп. галлон	0,0143 (41) кг/м³
	(40) 1 гран/имп. галлон	14,3 г/м³ (53)
	(41) 1 унция/куб. фут	1,0 кг/м³ (41)
	(42) 1 фунт/куб. фут	16,0 кг/м³
	(43) 1 фунт/галлон	100 кг/м³
	(44) 1 куб. фут/фунт	(45) 62,5 л/кг
(46) Количество тепла	(47) 1 BTU = 1° F фунт = 778 футофунтов	(48) 107,53 кгм = 0,293 (49) ватт-час = = 0,252 ккал (50)
	(51) 1 BTU/фунт	0,555 ккал кг (52)
	(53) 1 BTU/куб. фут	8,9 (54) ккал/м³
	(55) 1 BTU/кв. фут	(56) 2,71 ккал/м²
(57) Коэффициент теплопередачи	(58) 1 BTU/кв. фут-час °F	(59) 4, 88 ккал/м²-час °C
(60) Удельная теплоемкость	(51) 1 BTU/фунт °F	(52) 1,0 ккал/кг °C
(61) Теплопроводность	1 BTU/(62) фут-час °F	1,488 (63) ккал/м-час °C
	1 BTU/(64) дюйм-час °F	17,88 (63) ккал/м-час °C
	1 BTU/(65) дюйм кв. фут-час °F	(63) 0,124 ккал/м-час °C
(66) Вязкость	(67) 1 фунт/фут сек	14,882 (68) г/см·сек
	1 (69) фунт сек./кв.фут	47,88 (70) кг/м·сек = 478,66
	(73) 1 кв. фут/сек.	478,65 (71) пуаз = 4,882 (72) кг·сек/м²
		0,929 м²/сек (74)
	(75) 1 стокс	929 стокс (75)
		(76) 1 см²/сек = 1·10⁻⁴ м²/сек (96) = = 0,36 м²/час (77)
(78) Температура	t °F	$32 + \frac{9}{5} t$ °C
(79) Разность температур	Δt °F	$\frac{\Delta t}{1,8}$ °C

Key: (a). Designation. (b). Units measurement. (c). English. (d). metric. (1). Length. (2). inch. (3). foot. (4). yard. (5). mile. (6). yards. (7). nautical mile. (8). Area. (9). sq. inch. (10). sq. foot. (11). sq. yard. (12).) Volume. (13). cu. inch. (14). imperial gallon. (15). USA gallon. (16). oil barrel. (17). USA gallon. (18). cu. foot. (19). l. (20). Weight. (21). grain. (22). pound. (22a). g. (23). ounce. (24). pound. (24a). kg. (25). 1 short-ton (short)=2000 pounds. (26). 1 long-ton (long)=2240 pounds. (27). t. (28). Pressure. (29). ounce/sq. inch. (30). mm H_2O. (31). pound/sq. inch. (32). kg/cm². (33). phys. atm(tech). (34). long-ton/sq. inch. (35). kg/cm³. (36). mm Hg. (37). Specific weight and density. (38). grain/cub. foot. (39). g/m³. (40). grain/imp. gallon. (41). kg/m³. (41a). ounce/cub. foot. (42). pound/cub. foot. (43). pound/gallon. (44). cu. feet/pound. (45). l/kg. (46). Quantity of heat. (47). pound=778 foot-pounds. (48). kg.-m. (49). watt-hour. (50). kcal. (51). pound. (52). kcal/kg. (53). cu. foot. (54). kcal/m³. (55). sq. foot. (56). kcal/m². (57). Coefficient of heat transfer. (58). sq. foot-hour °F. (59). kcal/m²h. (60). Specific heat. (61). Thermal conductivity. (62). foot- hour. (63). kcal/m-hour. (64). inch-hour. (65). inch sq. foot-hour. (66). Viscosity. (67). pound/foot s. (68). g/cm•s. (69). pound s/sq. foot. (70). kg/m•sek. (71). poise. (72). kg•s/m². (73). sq. feet/s. (74). m²/s. (75). stoke. (76). cm²/s. (77). m²/h. (78). Temperature. (79). Difference in temperatures.

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Table 16. Designations and dimensionality of basic values.

	(a) Наименование величин	(b) Обозначения	(c) Размерность
(1)	Длина	l	м, см, мм
(2)	Ширина	b	м, см, мм
(3)	Высота, глубина	h	м, см, мм
(4)	Диаметр	d	м, см, мм
(5)	Радиус	r	м, см, мм
(6)	Площадь	F	м², см²
(7)	Поверхность	S	м², см²
(8)	Объем	V	м³, см³
(9)	Вес	G	(10) т, кг
(11)	Удельный вес	γ	(12) т/м³, кг/м³
(13)	Удельный объем	v	(14) м³/кг
(15)	Плотность	ρ	(16) кг·сек²/м⁴
(17)	Соленость	S	(18) °Б. (Брандта)
(19)	Время	t	(20) час., сек.
(21)	Скорость	v, u	(22) м/сек
(23)	Ускорение силы тяжести	g	(24) м/сек²
(25)	Расход	G, Q	(26) кг/час, м³/час
(27)	Температура	t	°C
(28)	Абсолютная температура	T	°K
(29)	Разность температур	Δt	°C
(30)	Энтальпия (теплосодержание) пара	i	(31) ккал/кг
(32)	Энтальпия (теплосодержание) жидкости	q	(31) ккал/кг
(33)	Теплота парообразования	r	(31) ккал/кг
(34)	Теплоемкость	c	(31) ккал/кг °C
(35)	Теплопроводность	λ	(36) ккал/м-час °C
(37)	Коэффициент температуропроводности	a	(38) м²/час
(39)	Коэффициент линейного расширения	α	—
(40)	Газовая постоянная	R	(41) кгм/кг °K
(42)	Коэффициент теплоотдачи	α	ккал/м²-час °C (43)

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	ⓐ Наименование величин	ⓑ Обозначения	ⓒ Размерность
(43)	Количество тепла	Q	(44) ккал/час
(45)	Давление	p	(46) кг/м², кг/см²
(47)	Потери давления	Δp	(48) кг/м², кг/см²
(48)	Динамический коэффициент вязкости	μ	(49) кг·сек/м²
(50)	Кинематический коэффициент вязкости	ν	(51) м², сек
(52)	Критерий Рейнольдса	Re	—
(53)	Критерий Прандтля	Pr	—
(54)	Критерий Пекле	Pe	—
(55)	Критерий Грасгофа	Gr	—
(56)	Сосредоточенная сила	P	(57) кг
(58)	Равномерно распределенная нагрузка	q	(59) кг/см²
(60)	Момент инерции	I	см⁴
(61)	Момент сопротивления	W	см³
(62)	Модуль упругости	E	(59) кг/см²
(63)	Коэффициент Пуассона	μ	—
(64)	Предел прочности	σ_b	(59) кг/см²
(65)	Предел текучести	σ_s	(59) кг/см²
(66)	Предел ползучести	σ_n	(59) кг/см²
(67)	Допускаемое напряжение на растяжение	R_z	(59) кг/см²
(68)	Допускаемое напряжение на изгиб	R_b	(59) кг/см²
(69)	Допускаемое напряжение на сжатие	R_d	(59) кг/см²
(70)	Допускаемое напряжение на срез	$R_{ср}$	(59) кг/см²
(71)	Допускаемое напряжение на смятие	$R_{см}$	(59) кг/см²
(72)	Запас прочности	n	—
(73)	Толщина стенки	s	см, мм
(74)	Прибавка на коррозию, допуски, овальность и т. д.	C	см, мм
(75)	Коэффициент прочности шва	φ	—
(76)	Количество трубок, болтов	z	(77) шт.
(78)	Шаг трубок, болтов	t	мм

Key: (a). Name of values. (b). Designations. (c). Dimensionality. (1). Length. (2). Width. (3). Height/altitude, depth. (4). Diameter. (5). Radius. (6). Area. (7). Surface. (8). Volume. (9). Weight. (10). t, kg. (11). Specific gravity/weight. (12). t/m^3, kg/m^3. (13). Specific volume. (14). m^3/kg. (15). Density. (16). $kg \cdot s^2/m^4$. (17). Salinity. (18). °B (Brandt). (19). Time. (20). hour, s. (21). Speed. (22). m/s. (23). Acceleration of gravity. (24). m/s^2. (25). Expenditure. (26). kg/h, m^3/h. (27). Temperature. (28). Absolute temperature. (29). Difference in temperatures. (30). Enthalpy (enthalpy) of vapor. (31). kcal/kg. (32). Enthalpy (enthalpy) of liquid. (33). Heat of vaporization. (34). Heat capacity. (35). Thermal conductivity. (36). kcal/m-hour °C. (37). Coefficient of thermal conductivity. (38). m^2/h. (39). Coefficient of linear expansion. (40). Gas constant. (41). kg-m/kg. (42). Heat-transfer coefficient. (43). $kcal/m^2h$. (43a). Quantity of heat. (44). kcal/h. (45). Pressure. (46). kg/m^2, kg/cm^2. (47). Losses of pressure. (48). Coefficient of dynamic viscosity. (49). $kg \cdot s/m^2$. (50). Kinematic modulus of viscosity. (51). m^2/s. (52). Reynolds number. (53). Prandtl number. (54). Peclet's criterion. (55). Grashof's criterion. (56). Concentrated force. (57). kg. (58). Evenly distributed load. (59). kg/cm^2. (60). Moment of inertia. (61). Moment of resistance. (62). Modulus of elasticity. (63). Poisson ratio. (64). Ultimate strength. (65). Yield point. (66). Creep limit. (67). Permissible

tensile stress. (68). Allowable stress or curvature. (69). Permissible compression stress. (70). Permissible shear stress. (71). Permissible crumpling stress. (72). Safety factor. (73). Wall thickness. (74). Addition to corrosion, allowances, ovality, etc. (75). Modulus of resistance of joint. (76). Quantity of tubes, bolts. (77). pcs. (78). Space or tubes, bolts.

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