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SEMITRAILER MOUNTED OXYGEN OR NITROGEN
GENERATING AND CHARGING PLANT

Part 1. Design Study

H. V. FARROW

AIR PRODUCTS, INCORPORATED

JANUARY 1954

WRIGHT AIR DEVELOPMENT CENTER

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SEATRAILER MOUNTED OXYGEN OR NITROGEN GENERATING AND CHARGING PLANT

Part 1. Design Study

H. W. Farrow

Air Products, Incorporated

January 1954

Equipment Laboratory
Contract No. AF 33(600)-19833
RDO No. 660-128

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio
FOREWORD

This report was prepared by Air Products, Incorporated, Allentown, Pennsylvania, on contract No. AF 33(600)-1955, dated 9 June 1952; Supplement Agreement No. 1, dated 2 March 1953; and Revision 1, dated 15 May 1953. Work was administered under the direction of C. H. Anderson, Vice-President-in-Charge-of-Engineering and H. W. Farrow acted as project engineer. The contract was initiated under Research and Development Order No. 660-122, "Improvement and Development of Oxygen Generating Plants and Auxiliary Equipment," by the Equipment Laboratory, Directorate of Laboratories, Wright Air Development Center, with A. M. Paulson serving as project engineer.

This is one of a series of three reports to be issued on this project. The second report will be issued upon completion of the operating tests on the mobile, liquid oxygen generator, while the third report will be issued upon completion of the entire program.

Included among those who cooperated in the study were C. J. Schilling, L. L. Volland, P. G. Foust, J. V. Fetterman of Air Products, Incorporated.
ABSTRACT

Design of a mobile generator capable of producing two tons per day of high-purity liquid oxygen or liquid nitrogen and capable of compressing the entire production capacity to 4000 PSIG as described. Flows of the operating cycle are pictured and discussed. Material and heat balances are calculated on the basis of theory and past experience gained from the fabrication of more than 500 oxygen generators, both mobile and stationary, of high- and low-purity type. Tentative specifications for the equipment components are listed.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

FOR THE COMMANDER:

[Signature]

RICHARD SMOLIK
Colonel, USAF
Chief, Equipment Laboratory

WADC TR 54-19 PT 1

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SUMMARY

To obtain the desired production of two tons per day of 99.5% pure liquid oxygen, or two tons per day of 99.0% pure liquid nitrogen, an air feed of approximately 1000 standard cubic feet per minute shall be used. This shall indicate a liquid oxygen recovery by weight of 4.2% or a liquid nitrogen recovery by weight of 3.7%. To operate the unit three diesel engines shall supply approximately 330 horsepower, which shall result in a ratio of approximately 1.1 pounds of liquid oxygen produced per pound of diesel fuel burned. A temperature approach of approximately 80°F shall be expected at the air inlet end of the heat exchanger. The estimated heat infiltration from ambient surroundings into the air separator shall be 1.5 B.T.U. per pound of air feed. It is estimated that the loss of air from the heat exchanger during the reversals, which occur every 10 minutes, shall be 3% of the total input. The semitrailer shall be approximately 32'-0" long, 9'-6" wide and 12'-0" high. These dimensions, which are reduced to a minimum, shall be for the greater part, dictated by the availability of equipment components in the air source section.
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SECTION I

CYCLE OF AIR SEPARATION

General

The cycles of air separation for this generator are pictured on four Air Products, Incorporated Drawings numbered 42559, 42560, 42561, and 42562. Each will illustrate a phase of operation and will herein be referred to as Figures 1, 2, 3 and 4. The liquid product is produced by the distillation of liquid air into pure oxygen or nitrogen dependent on requirements. Atmospheric air which forms the raw material is filtered, compressed, freed of water vapor and carbon dioxide in reversing heat exchangers, and then liquefied by a combination of cooling and expansion. The pure product which results from the distillation of the liquid air is drawn off as a liquid at column operating pressure or, is fed as a liquid into special pumps which compress the product to any pressure up to 4000 PSIA. The cold high-pressure liquid product leaving the pump is warmed in a heat exchanger, and flows as a gas into cylinders or into some other receiver. Since this product is the result of distillation of liquid air, it can be considered absolutely dry for all conditions of use.

It is necessary to remove the water vapor and carbon dioxide contents from the air inasmuch as these impurities, if not removed, would, in a relatively short period of time, "freeze out" at the sub-zero temperatures involved and thus plug lines and render the generator inoperative.

Detailed Description

Atmospheric air is drawn through mechanical filters to remove any foreign matter which may be injurious to the apparatus, and is then fed to an oil-free air compressor where its pressure is elevated to 100 PSIG. The air compressor is a three-stage unit, each stage consisting of a rotary blower which is direct-driven by a diesel engine through a suitable transmission. Some moisture, and also the heat of compression, are removed from the air in air-cooled inter- and aftercoolers.

The "high-pressure" air is then fed to the heat exchanger through a switch valve. This valve switches or reverses, at preset ten minute intervals, the heat exchanger passes for the incoming, high-pressure air and the effluent, low-pressure, waste air such that, the passes which were high-pressure air passes for the previous ten minutes then become effluent, waste air passes for the next ten minutes, and vice-versa. The remaining moisture, and also the carbon dioxide, in the high-pressure air are deposited in the heat exchanger at the different temperature levels which are in equilibrium with the vapor pressures and concentrations of the moisture and carbon dioxide. These deposits are made in the two passes alternately. While a deposit is being made in one pass, the deposit in the other pass is being "cleaned up" through the absorptive capacity of the dry, low-pressure, effluent, waste air.
After leaving the heat exchanger, the high-pressure air, which is then a saturated vapor, enters the air liquefier. The liquefier is an extension of the heat exchanger surface, and in it, liquefaction of a portion of the incoming air is effected. This portion is the amount of liquefaction necessary to keep the cycle operating, and it is equivalent to, (1) the amount of liquid withdrawn as the final product plus, (2) the amount of liquid which is vaporized as a result of the influx of heat into the generator from the ambient surroundings plus, (3) the amount of liquid which is lost as a result of the expansion from high-pressure-air pressure to column operating pressure, the pressure at which the liquid product is withdrawn.

The partially liquefied, high-pressure air then enters the phase separator, where its liquid and vapor phases are divided and directed into different streams.

The liquid stream is expanded to approximately 6 PSIG after which it is passed through a silica gel type hydrocarbon adsorber. In the adsorber, removal of the hydrocarbon content is accomplished to prevent their accumulation to dangerous concentrations in the distillation column. After every 150 or more hours of operation, the adsorber is reactivated by means of an electrically heated stream of hot dry air which absorbs the hydrocarbons and carries them off to atmosphere. This air is tapped from the air supply to the turbo expander.

After the adsorber the liquid stream is fed to the sub-cooling jackets of the liquid product pumps to prevent vaporization of the pure liquid product when the pump is operating, and thus keep the pump efficiency high. The stream is then directed to the low pressure section of either the nitrogen or oxygen column depending on the final product required.

The vapor phase is further divided into two streams. One of these, representing 75% of the total air feed, passes through the cold section of the heat exchanger from the cold end to the warmer end, and then feeds the turbo expander. The exhaust from the expander joins the effluent waste air stream which leaves the column and enters the air liquefier.

In the case of producing oxygen the other vapor stream from the phase separator is expanded through a valve from high-pressure-air pressure to high-pressure-column pressure, which is approximately 89 PSIA. This vapor enters the high-pressure column and is fed directly into the condenser where all of it is condensed by the product liquid oxygen which surrounds the tubes on the low-pressure-column side of the condenser. The resulting liquid is expanded to low-pressure-column pressure and introduced into the low-pressure column at the top as reflux. In order to prevent rare, inert gases such as neon, etc., which are found in the air, and which are not capable of being condensed by the liquid oxygen, from blanketing the condenser tube surfaces and thus impair their efficiencies, a stream is drawn off from the dome of the condenser and expanded into the effluent waste air stream which leaves the column. This non-condensable offtake, although very effective in accomplishing its purpose, is so very small in magnitude that it does not enter into the calculations for the material and heat balances.

The low-pressure column contains a number of bubble-cap pans of conventional design, which are fed at the proper points by the expanded liquid from the
incoming high-pressure air, and the expanded liquid from the high-pressure column. The liquid descending on these pans comes into intimate contact with the ascending vapor resulting from the column feeds as well as the vapor from the boiling oxygen which surrounds the tubes of the condenser. This intimate contact of vapor and liquid on each pan results in a gradual vaporization of the more-volatile constituent, nitrogen, and a condensation of the less-volatile constituent, oxygen. Sufficient pans are included in the low-pressure column to ensure that the liquid withdrawn from the bottom is 99.5% pure oxygen. Because the boiling point of argon is closer to the boiling point of oxygen than it is to the boiling point of nitrogen, it appears in the column in the vicinity of the oxygen, and shows up as the 0.5% impurity in the product oxygen.

Since there is only one product, oxygen, withdrawn from the column, the remaining oxygen and argon and all of the nitrogen leave the column at the top as a saturated vapor. This vapor passes through the oxygen subcooler where it subcools the product oxygen to prevent or reduce "flash" losses resulting from later expansion. After passing through the subcooler, it combines with the turbo expander exhaust and enters the air liquefier where it liquefies a portion of the incoming high-pressure air. From the air liquefier it passes through the heat exchanger where it both cools the incoming air to saturation temperature, and absorbs the moisture and carbon dioxide which were deposited by the incoming air during the preceding ten-minute switch period. It finally exhausts to atmosphere through the switch valve.

The product liquid oxygen is withdrawn from the bottom of the low-pressure column. It passes through the subcooler where it is subcooled by the effluent waste air to prevent or reduce "flash" losses resulting from expansion into the reciprocating oxygen pump, or into an external receiver. In the pump its pressure is elevated to 4000 PSI and it is discharged through a heat exchanger or vaporizer in the discharge line of the third-stage blower where it is warmed to ambient temperature.

In the case of producing nitrogen the other vapor stream from the phase separator is expanded through a valve from high-pressure-air pressure to high-pressure column pressure, which is approximately 52.2 PSI. The vapor enters the high-pressure nitrogen column which contains a number of bubble-cap pans of conventional design. The ascending vapor comes into intimate contact with liquid descending on the pans. This intimate contact of vapor and liquid on each pan results in a gradual vaporization of the more volatile constituent, nitrogen and a condensation of the less volatile constituent, oxygen, which is expanded into the low pressure column. The ascending vapor enters the condenser where it is condensed to a liquid nitrogen product by the crude oxygen product which surrounds the tubes on the low pressure column side of the condenser. As in the case of oxygen production a small noncondensible stream is removed from the dome of the condenser to prevent blanketing of the condenser surface.

The low pressure column consists essentially of a condenser and shell. The expanded crude oxygen from the high pressure column and the expanded liquid stream
from the product pump rockets are introduced into the low pressure column side of the condenser. These streams are vaporized by the condensing nitrogen in the high pressure column and the resulting vapor passes through several entrainment trays above the condenser in the low pressure column.

The waste vapor from the low pressure column passes through the subcooler. After passing through the subcooler, it combines with the turbo expander exhaust and enters the air liquefier where it liquefies a portion of the incoming high-pressure air. From the air liquefier it passes through the heat exchanger where it both cools the incoming air to saturation temperature, and absorbs the moisture and carbon dioxide which were deposited by the incoming air during the preceding ten-minute switch period. It finally exhausts to atmosphere through the switch valve.

The product liquid nitrogen is withdrawn from the bottom of the condenser. It passes through the subcooler into the reciprocating nitrogen pump, or into an external receiver. In the pump its pressure is elevated to 4000 PSIA and it is discharged through a heat exchanger or vaporizer in the discharge line of the third-stage blower where it is warmed to ambient temperature.

Pressure gauges, liquid-level gauges and temperature indicators are located throughout the system as necessary to serve as operating aids. In addition, all circuits in the cycle are protected against excess pressure by means of pop safety valves.

After 150 or more hours of operation, accumulation of moisture and carbon dioxide deposits may require that the generator be defrosted or derimed. To accomplish this, numerous outlets are provided at desired locations to vent the defrost air to atmosphere.

Should ambient air penetrate the air separator insulation jacket, its moisture content would be deposited upon the cold surfaces of the components and also upon the cold fiberglass insulation. To prevent this, the insulation jacket is put under a slight, positive pressure by means of a small stream of dry, nitrogen-rich air which is tapped from the turbo expander supply line and warmed in a coil inside the condensate trap.
SECTION II
ELECTRIC POWER AND CONTROL

The electric power and control circuits of this generator are pictured in Figure 5, Air Products, Incorporated Drawing No. 42-63, Single Line Wiring Diagram.

The electric power required by the product names, the hydrocarbon adsorber reactivation heater, switch valve timing control, and lighting is furnished by a 18.7 Kva, 120/208 volt, 3 phase, 4 wire, 60 cycle synchronous generator with direct connected exciter and automatic voltage regulator as an integral part of its frame. This alternating current generator is driven at 1800 RPM through a V-belt drive by one of the diesel engines in the air compressing section.

Power is distributed throughout the trailer from a control center which contains a three-phase main service circuit breaker for the circuit from the a-c generator; a combination three-phase starter for the pump motors; a three-phase circuit breaker and control for the hydrocarbon adsorber reactivation heater; and branch circuit breakers for the 120 volt single phase timing control, lighting, and power receptacle circuits.

Emergency lighting, alarm circuits for diesel engine cooling water and oil pressure indication, and emergency engine shut-down control are energized from the 24-volt d-c storage battery bank furnished for starting the diesel engines. This bank can be charged by one of the generators on either of two of the engines.
SECTION III
THERMODYNAMIC CALCULATIONS

The sources of thermodynamic data for this report were: Miller & Sullivan, U. S. Bureau of Mines, Mollier Charts of 1928; and V. C. Williams, Northwestern University.

The material balance of this cycle is based upon the following composition of atmospheric air: 21% oxygen, 78% nitrogen, and 1% argon.

The term "standard cubic feet per minute", abbreviated SCFM, as used in this report means one cubic foot of gas at the standard conditions of 70°F and 14.7 PSIA.

![Diagram of liquid nitrogen generator heat balance]

Ref: The refrigeration available results from the expansion of approximately 75% of the incoming air from 112 PSIA to 21 PSIA. For the expander to have an adiabatic efficiency of 72%, the assumed inlet temperature is $-240^\circ F$.

$H_i = \text{Enthalpy At Inlet Conditions 112 PSIA, } -240^\circ F$

$= 104.50 \text{ Btu/Lb}$

$H_0 = \text{Enthalpy at Expander Exhaust for 100% Expander Efficiency}$

$= 85.58 \text{ Btu/Lb}$
\( H_0 \text{ act} = \text{Enthalpy At Actual Exhaust Conditions} \)

\[ = 90.93 \text{ Btu/Lb} \]

\( \text{Efficiency} = \frac{H_1 - H_0 \text{ act}}{H_1 - H_0 \text{ isentropic}} \times 100 \)

\[ = \frac{104.5 - 90.93}{124.5 - 85.58} \times 100 = 71.72\% \]

This checks the anticipated value

\[ R = H_1 - H_0 \text{ act} \]

\[ = 104.5 - 90.93 \]

\[ = 13.57 \text{ Btu/Lb} \]

Since only 75\% of the incoming air is to be expanded

\[ R = 0.75 \times 13.57 \]

\[ = 10.18 \text{ Btu/Lb} \]

For 100 lbs.

\[ R = 1018 \text{ Btu} \]

Enthalpy of Incoming Air, \( H_A \)

At the conditions of 100 PSIG & 80°F, the heat content of 100 lbs. of entering air will be

\[ H_A = 18,430 \text{ Btu} \]

Enthalpy of Liquid Nitrogen, \( H_N \)

At the conditions of 14.7 PSI and -298°F, the enthalpy of liquid nitrogen is (Equivalent of 3.55 ATM SAT.)

\[ H_N = 12.02 \text{ Btu/Lb} \]

For x lbs., the heat content will be

\[ H_N = 12.02 \times x \]

Heat Leak, H.L.

The anticipated heat leak is taken as

\[ \text{H.L.} = 1.5 \text{ Btu/ib} \text{ or } 150 \text{ Btu for 100 lbs.} \]

NADC TR 54-29 PT 1
Enthalpy of the Effluent Waste Air, $H_W$

At the conditions of 1 FSIG & 72°F the enthalpy of the waste air is equal to the sum of the enthalpies of the constituents.

The enthalpy of nitrogen at these conditions is

$$H_N = 183.5 \text{ Btu/Lb}.$$  

Since 78-x pounds of $N_2$ are exhausted as waste in this case

$$H_N = 183.50 (78-x)$$

$$H_N = 14,313 - 183.5x \text{ Btu}$$

The enthalpy of the oxygen under these conditions is

$$H_O = 181.20 \text{ Btu/Lb}. $$

Since all the oxygen is waste

$$H_O = 22 \times 181.20$$

$$H_O = 3,986 \text{ Btu}$$

$$H_W = H_N + H_O$$

$$= 14313 - 183.5x + 3986$$

$$H_W = 18299 - 183.5x$$

Total Heat Balance

The total heat balance will be

$$H_A + H_L = H_W + E + H_W$$

$$18430 + 150 = 18299 - 183.5x + 12.02x + 1018$$

$$x = 4.30 \text{ pounds } N_2 \text{ produced per 100 pounds Air}$$

Since it is impossible to get sufficient subcooling 14.0% of the liquid nitrogen produced will flash.

The air required for 2 tons per day liquid production is

$$Q = 2 \left( \frac{\text{Tons}}{\text{Day}} \right) \times 2000 \left( \frac{\text{Lbs}}{\text{Ton}} \right) \times \frac{1}{24} \left( \frac{\text{Days}}{\text{Hr}} \right) \times \frac{1}{60} \left( \frac{\text{Min}}{\text{Hr}} \right) \times \frac{1}{0.075} \left( \frac{\text{Cu Ft}}{\text{Min}} \right) \times \frac{1}{0.0436} \left( \frac{\text{Lbs}}{\text{Cu Ft}} \right) \times \frac{1}{0.85} \left( \frac{\text{Hr}}{\text{Min}} \right)$$

$$Q = 1032 \text{ Assumimg a 3% reversal loss}$$

$$Q = 1032 \text{ BPM} = 1035 \text{ SCFM}$$

NAG TR 54-19 FT 1
Generator Material Balance

Point 1-N Standard Intake Conditions for Air Compressor

Pressure 14.7 PSIA
Temperature 70°F
Fluid State Superheated Vapor
Fluid Flow Rate

\[ W_1 = 1035 \times 0.075 \times 60 \times \frac{1}{28.9} \]

\[ = 161.16 \text{ Lb - Mols/hr} \]

Composition

\[ W_{O_2} = 0.21 \times 161.16 \]

\[ = 33.84 \text{ Mols/hr} \]

\[ W_{N_2} = 0.78 \times 161.16 \]

\[ = 125.72 \text{ Mols/hr} \]

\[ W_A = 0.01 \times 161.16 \]

\[ = 1.61 \text{ Mols/hr} \]

Enthalpy

At 14.7 PSIA and 70°F

\[ H_1 = 162.74 \text{ Btu/Lb} \]

Point 2-N Discharge for Air Compressor

Pressure 14.7 PSIA
Temperature 80°F
Fluid State Superheated Vapor
Fluid Flow Rate

The 3% friction loss is eliminated for the purpose of calculating a heat balance.

\[ W_2 = 156.02 \text{ Mols/hr} \]
Composition

\[ W_{O2} = 32.76 \text{ Mols/HR} \]
\[ W_{N2} = 121.70 \text{ Mols/HR} \]
\[ W_{A} = 1.56 \text{ Mols/HR} \]

Enthalpy

At 114.7 PSIA and 80°F

\[ H_2 = 184.30 \text{ Btu/Lb} \]

**Point 3-N High Pressure Air Leaving Heat Exchanger**

**Pressure**

114.7 PSIA

**Temperature**

-272°F

The air leaving the exchanger will be a saturated vapor at 114.7 PSIA.

**Fluid State** Saturated Vapor

**Fluid Flow Rate**

\[ W_3 = 156.02 \text{ Mols/HR} \]

Composition

\[ W_{O2} = 32.76 \text{ Mols/HR} \]
\[ W_{N2} = 121.70 \text{ Mols/HR} \]
\[ W_{A} = 1.56 \text{ Mols/HR} \]

Enthalpy

At 114.7 PSIA and -272°F

\[ H_3 = 95.79 \text{ Btu/Lb} \]

**Point 4-N High Pressure Air Leaving Air Liquifier**

**Pressure** 114.7 PSIA

**Temperature** -272°F

**Fluid State**

The liquid requirement of the air entering the liquifier is the sum of the liquid equivalent of the product takeoff, the liquid...
equivalent of the heat loss, and the liquid equivalent of the expansion loss.

Product Liquid Equivalent

The latent heat of nitrogen at 52.2 PSIA is \( H = 78.00 \) Btu/Lb

On the basis of 4.3\% recovery
\[ H = 3.35 \text{ Btu/Lb} \]

Heat Loss Liquid Equivalent
\[ H_{HL} = 1.5 \text{ Btu/Lb} \]

Expansion Loss Liquid Equivalent

The enthalpy drop at saturated vapor conditions resulting from the expansion of incoming air from 114.7 PSIA to 21 PSIA is

\[ H_{Exp} = 95.79 - 90.93 \]
\[ = 4.86 \text{ Btu/Lb} \]

Since only 25\% of the incoming air is to be expanded
\[ H_{Exp} = 0.25 \times 4.86 \]
\[ H_{Exp} = 1.22 \text{ Btu/Lb} \]

The total liquid requirement enthalpy drop is
\[ H = H_{T.D.} + H_{HL} + H_{Exp} \]
\[ = 3.35 + 1.50 + 1.22 \]
\[ = 6.07 \text{ Btu/Lb} \]

The latent heat of vaporization of air at 114.7 PSIA
\[ L.H. = 95.79 - 22.61 \]
\[ = 73.18 \text{ Btu/Lb} \]

Liquid Requirement = \( \frac{H}{L.H.} \times 100 \)

Liquid Requirement = \( \frac{6.07}{73.18} \times 100 \)
\[ = 8.29\% \]

Hence the fluid state will be 8.29\% liquid and 91.71\% vapor.
Composition

\[ W_{O_2} = 32.76 \text{ Mols/HR} \]
\[ W_{N_2} = 121.70 \text{ Mols/HR} \]
\[ W_A = 1.56 \text{ Mols/HR} \]

Enthalpy

At 114.7 PSIA and -272°F

\[ H_A = 89.72 \text{ Btu/Lb} \]

Point 5-6 High Pressure Air Leaving the Phase Separator and Entering the Expansion Valve

Entering the 7.8 atmosphere equilibrium curve for oxygen and nitrogen at -272°F or 104.59K for 21 mol percent oxygen

Total Mols = Mols Liquid + Mols Vapor

0.21 = 0.0829 (0.366) + 0.9171 (0.196)

0.21 = 0.0303 + 0.1798

0.21 + 0.2101

Mols Oxygen Vapor = 0.1798 x 156.02

\[ W_{O_2} = 28.04 \text{ Mols/HR} \]

Mols Oxygen Liquid = 0.0303 x 156.02

\[ W_{O_2} = 4.72 \text{ Mols/HR} \]

The amount of air entering the phase separator which is expanded into the high pressure column through the Al expansion valves is

100 - 75 - 8.29 = 16.71%

Pressure

114.7 PSIA

Temperature

-272°F

Fluid State

Saturated Vapor

Fluid Flow Rate

\[ W_5 = 0.1671 \times 156.02 \]

= 26.07 Mols/HR
Composition

\[ W_{O_2} = 26.07 \times 0.196 \]
\[ = 5.11 \text{ Mols/Hr} \]
\[ W_A = \frac{1}{21} \times 5.11 \]
\[ = 0.24 \]
\[ W_{N_2} = 26.07 - 5.11 - 0.24 \]
\[ = 20.72 \text{ Mols/Hr} \]

Enthalpy

At 114.7 PSIA and -272°F

\[ H_5 = 95.79 \text{ Btu/Lb} \]

Point 6-N High Pressure Air Entering High Pressure Nitrogen Column

Pressure

52.2 PSIA

Temperature

-282.5°F

Fluid State

Superheated Vapor

Fluid Flow Rate

Same as Point 5

\[ W_6 = 26.07 \text{ Mols/Hr} \]

Composition

Same as Point 5

\[ W_{O_2} = 5.11 \text{ Mols/Hr} \]
\[ W_{N_2} = 20.72 \text{ Mols/Hr} \]
\[ W_A = 0.24 \text{ Mols/Hr} \]

Enthalpy

At 52.2 PSIA and -282.5°F

\[ H_6 = 95.79 \text{ Btu/Lb} \]

Point 7-N High Pressure Air Leaving Phase Separator and Entering Cold Heat Exchanger

The pressure and temperature are the same as Point 5 with the flow and composition proportional to the division of the total vapor phase leaving the phase separator.
Pressure
Temperature
Fluid State
Fluid Flow Rate
Composition

W_{7} = 0.75 \times 156.02
= 117.02 \text{ Mols/Hr}

W_{O_{2}} = \text{Total O}_{2} \text{ Vapor leaving separator - Oxygen to Column}
= 28.04 - 5.11
= 22.93 \text{ Mols/Hr}

W_{A} = 1/21 \times 22.93
= 1.09 \text{ Mols/Hr}

W_{N_{2}} = 117.02 - 1.09 - 22.93
= 93.00 \text{ Mols/Hr}

Enthalpy
At 114.7 \text{ PSIA} and -272^\circ \text{F}

H_{7} = 95.79 \text{ Btu/Lb}

Point 6-N High Pressure Air Entering Turbo Expander

Stream 7 in passing through the heat exchanger will undergo a slight pressure drop and rise in temperature. This warm-up will increase the expander efficiency.

Pressure
Temperature
Fluid State
Fluid Flow Rate
Composition

W_{8} = 117.02 \text{ Mols/Hr}

Same as Point 7

Same as Point 7
\[ W_{O2} = 22.93 \text{ Mols/HR} \]
\[ W_{N2} = 93.00 \text{ Mols/HR} \]
\[ W_A = 1.09 \text{ Mols/HR} \]

 enfalpy 
At 112 PSIA and -240°F 
\[ H_8 = 104.50 \text{ Btu/Lb} \]

Point 9-N Low Pressure Air Leaving the Expander and Feeding the Low Pressure Column

No flow is demanded through Point 9 since the only purpose of such a flow is to give advantage to the low pressure column in so far as oxygen production is concerned.

Point 10-N Expander Exhaust Stream into Air Liquifier

Pressure 21 PSIA
Temperature -306°F
Fluid State Saturated Vapor
Fluid Flow Rate Same as Point 8
\[ W_{10} = 117.02 \text{ Mols/HR} \]

Composition Same as Point 8

Point 11-N Air Stream Feeding Air Liquifier

Pressure 21 PSIA
Temperature -306°F
Fluid State Saturated Vapor
Fluid Flow Rate

The flow will be stream 4 minus the product take-off
\[ W_{11} = 156.02 - 2 \times 2000 \times 0.86 \times 28 \times 24 \]
\[ W_{11} = 149.10 \text{ Mols/HR} \]
Composition

Referring to compositions at Point 14, Point 6 and Point 10.

\[ W_{O_2} = 5.11 \times 4.72 = 22.93 = 0.04 \]

\[ = 32.72 \text{ Mols/Hr} \]

\[ W_{N_2} = 20.72 \times 7.99 = 93.00 = 6.84 \]

\[ = 114.87 \text{ Mols/Hr} \]

\[ W_A = 0.24 \times 0.22 = 1.09 = 0.04 \]

\[ = 1.51 \text{ Mols/Hr} \]

Enthalpy

Combination of Points 19 and 10

\[ = 95.93 \times 617.02 \div 121.10 \times 12.08 = 90.97 \text{ Btu/Lb} \]

Point 12-N Air Leaving Air Liquifier and Entering Cold Heat Exchanger

Pressure

\[ 19 \text{ PSIA} \]

Temperature

All of the latent heat of the liquified air is taken by this stream.

\[ (95.79 - 89.72) = 6.07 \div 149.10 = 6.34 \]

\[ 6.34 \times 90.97 = 97.31 \text{ Btu/Lb} \]

\[ T_{12} = -283.60^\circ F \]

Fluid State

Superheated Vapor

Fluid Flow Rate

Same as Point 11

\[ W_{12} = 149.10 \text{ Mols/Hr} \]

Composition

Same as Point 11

\[ W_{O_2} = 32.72 \text{ Mols/Hr} \]

\[ W_{N_2} = 114.87 \text{ Mols/Hr} \]

\[ W_A = 1.51 \text{ Mols/Hr} \]
Enthalpy

At 19 PSIA and -283.6°F the enthalpy is

\[ H_{12} = 97.31 \text{ Btu/Lb} \]

**Point 13-N** Waste Air Leaving Warm Heat Exchanger

<table>
<thead>
<tr>
<th>Pressure</th>
<th>14.7 PSIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>72°F</td>
</tr>
<tr>
<td>Fluid State</td>
<td>Superheated Vapor</td>
</tr>
<tr>
<td>Fluid Flow Rate</td>
<td>Same as Point 12</td>
</tr>
</tbody>
</table>

\[ W_{13} = 149.10 \text{ Mols/HR} \]

**Composition**

\[ W_{O2} = 32.72 \text{ Mols/HR} \]
\[ W_{SP} = 114.87 \text{ Mols/HR} \]
\[ W_{A} = 1.51 \text{ Mols/HR} \]

Enthalpy

At 14.7 PSIA and 72°F,

\[ H_{13} = 182.97 \text{ Btu/Lb} \]

**Point 14-N** High Pressure Liquid Leaving Phase Separator

<table>
<thead>
<tr>
<th>Pressure</th>
<th>144.7 PSIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>-275.6°F</td>
</tr>
<tr>
<td>Fluid State</td>
<td>Saturated Liquid</td>
</tr>
<tr>
<td>Fluid Flow Rate</td>
<td>Same as Point 12</td>
</tr>
</tbody>
</table>

\[ W_{14} = 0.0629 \times 156.02 \]
\[ = 12.93 \text{ Mols/HR} \]

**Composition**

\[ W_{O2} = 4.72 \text{ Mols/HR} \]
\[ W_{A} = 4.72 \times 1/21 \]

WADC TR 54-19 PT 1
\[ W_1 = 0.72 \text{ Mols/HR} \]
\[ W_{N_2} = 12.93 - 0.22 - 4.72 \]
\[ W_{N_2} = 7.99 \text{ Mols/HR} \]

**Enthalpy**

At 114.7 PSIA and -275.6°F

\[ H_{14} = 22.55 \text{ Btu/Lb} \]

**Point 14-N** Low Pressure Air Leaving Expansion Valve and Entering Low Pressure Column

The liquid air is expanded to the pressure at the top of the low pressure column at constant enthalpy.

**Pressure**

21 PSIA

**Temperature**

-304.3°F

**Fluid State**

The expansion of saturated liquid from 114.7 PSIA to 21 PSIA results in

79.05% Liquid

20.95% Vapor

**Fluid Flow Rate**

Same as Point 14

\[ W_{15} = 12.93 \text{ Mols/HR} \]

**Composition**

\[ W_{O_2} = 4.72 \text{ Mols/HR} \]
\[ W_{N_2} = 7.99 \text{ Mols/HR} \]
\[ W_A = 0.22 \]

**Enthalpy**

At 21 PSIA and -304.3°F

\[ H_{15} = 22.55 \text{ Btu/Lb} \]
Point 16  Liquid Air Leaving High Pressure Column

This is the result of liquification of Stream 6 minus the product take-off.

Pressure 52.2 PSIA
Temperature -291.9°F
Fluid State Saturated Liquid
Fluid Flow Rate
\[ W_{16} = 26.07 - 6.92 = 19.15 \text{ Mols/Hr} \]
Composition
\[ W_{O2} = 5.11 - 0.005 \times \frac{2000 \times 2}{24 \times 28 \times 0.86} = 5.07 \text{ Mols/Hr} \]
\[ W_{N2} = 20.72 - 6.84 = 13.88 \]
\[ W_{A} = 0.24 - 0.04 = 0.20 \]
Enthalpy
At 52.7 PSIA and -291.9°F
\[ H_{16} = 12.77 \text{ Btu/Lb} \]

Point 17  Liquid Air Entering Low Pressure Column

Pressure 21 PSIA
Temperature -304.3°F
Fluid State Liquid and Vapor

The expansion of 52.2 PSIA saturated liquid to 21 PSIA results in 90.40% liquid and 9.60% vapor.

Fluid Flow Rate Same as Point 16
\[ W_{17} = 19.15 \text{ Mols/Hr} \]
Composition Same as Point 16
\[ W_{O2} = 5.07 \text{ Mols/Hr} \]
\[ W_{N2} = 13.88 \text{ Mols/Hr} \]
\[ W_{A} = 0.20 \text{ Mols/Hr} \]
Enthalpy

At 21 PSIA and \(-304.3^\circ F\)

\(H_{17} = 12.77 \text{ Btu/Lb}\)

**Point 18** Waste Air Leaving Low Pressure Column

The waste air leaving the low pressure column will be saturated vapor at the pressure at the top of the column.

**Pressure** 21.5 PSIA

**Temperature** \(-304.3^\circ F\)

**Fluid State** Saturated Vapor

**Fluid Flow Rate**

Stream 18 equals stream 19 which equals stream 4 minus stream 10 minus the product take-off

\[ W_{18} = 156.02 - 117.02 - \frac{2 \times 2000 \times 1}{24 \times 28} \times 0.84 \text{ (Due to product flash)} \]

\[ W_{18} = 32.08 \text{ Mols/Hr} \]

**Composition**

Stream 15 / stream 17

\[ W_{O2} = 5.07 + 4.72 = 9.79 \text{ Mols/Hr} \]

\[ W_{N2} = 7.99 + 13.88 = 21.87 \text{ Mols/Hr} \]

\[ W_{A} = 0.22 + 0.20 = 0.42 \text{ Mols/Hr} \]

Enthalpy

At 21 PSIA and \(-304.3^\circ F\)

\(H_{18} = 91.10 \text{ Btu/Lb}\)

**Point 19** Waste Air Leaving Subcooler (Same as Point 18)

**Pressure** 21 PSIA

**Temperature** \(-304.3^\circ F\)
Fluid State
Saturated Vapor

Fluid Flow Rate
Same as Point 18

Fluid Flow Rate

\[ \dot{W}_{19} = 32.08 \text{ Mols/Hr} \]

Composition
Same as Point 18

\[ \begin{align*}
\dot{W}_0 &= 9.79 \text{ Mols/Hr} \\
\dot{W}_{N_2} &= 21.87 \text{ Mols/Hr} \\
\dot{W}_A &= 0.42 \text{ Mols/Hr}
\end{align*} \]

Enthalpy
As shown

\[ H_{19} = 91.10 \text{ Btu/Lb} \]

Point 20 Liquid Nitrogen Entering Subcooler

Pressure
52.2 PSIA

Temperature
-298°F

Fluid State
Saturated Liquid

Fluid Flow Rate

\[ \dot{W} = \frac{2 \times 2000}{24 \times 0.86 \times 28} \]

\[ \dot{W}_{20} = 6.92 \text{ Mols/Hr} \]

Composition

\[ \begin{align*}
\dot{W}_{N_2} &= 6.92 \times 0.99 = 6.84 \text{ Mols/Hr} \\
\dot{W}_0 &= 0.04 \text{ Mols/Hr} \\
\dot{W}_A &= 0.04 \text{ Mols/Hr}
\end{align*} \]

It is assumed that the impurity is equally divided between oxygen and argon.

Enthalpy

At 52.2 PSIA and -298°F

\[ H_{20} = 12.02 \text{ Btu/Lb} \]
Point 21-N Liquid Nitrogen Take-Off

Pressure

Temperature

Fluid State

Fluid Flow Rates

\[ W_{21-N} = 6.92 \text{ mol/s/hr} \]

Composition

\[ W_{N2} = 6.84 \text{ mol/s/hr} \]
\[ W_{O2} = 0.04 \text{ mol/s/hr} \]
\[ W_A = 0.04 \text{ mol/s/hr} \]

Vapor

\[ W = 0.97 \text{ mol/s/hr} \]

Liquid

\[ W = 5.95 \text{ mol/s/hr} \]

Enthalpy

At 14.7 PSIA and -298°F

\[ H = 12.02 \text{ Btu/lb} \]
### Summary

The conditions calculated for the various points in the flow diagram are summarized below.

<table>
<thead>
<tr>
<th>Pt No</th>
<th>Pressure (PSIA)</th>
<th>Temp (F°)</th>
<th>O2</th>
<th>N2</th>
<th>A</th>
<th>Total</th>
<th>Phase</th>
<th>Enthalpy Etu/lb</th>
<th>Total Etu/ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-N</td>
<td>14.7</td>
<td>70</td>
<td>33.84</td>
<td>125.71</td>
<td>1.61</td>
<td>161.16</td>
<td>Vapor</td>
<td>182.74</td>
<td>851,116</td>
</tr>
<tr>
<td>2-N</td>
<td>114.7</td>
<td>80</td>
<td>32.76</td>
<td>121.70</td>
<td>1.56</td>
<td>156.02</td>
<td>Vapor</td>
<td>184.30</td>
<td>831,005</td>
</tr>
<tr>
<td>3-N</td>
<td>114.7</td>
<td>-272</td>
<td>32.76</td>
<td>121.70</td>
<td>1.56</td>
<td>156.02</td>
<td>Vapor</td>
<td>95.79</td>
<td>431,915</td>
</tr>
<tr>
<td>4-N</td>
<td>114.7</td>
<td>-272</td>
<td>32.76</td>
<td>121.70</td>
<td>1.56</td>
<td>156.02</td>
<td>Liq &amp; Vap</td>
<td>89.72</td>
<td>404,546</td>
</tr>
<tr>
<td>5-N</td>
<td>114.7</td>
<td>-272</td>
<td>5.11</td>
<td>20.72</td>
<td>0.24</td>
<td>26.07</td>
<td>Vapor</td>
<td>95.79</td>
<td>72,170</td>
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<td>-282.5</td>
<td>5.11</td>
<td>20.72</td>
<td>0.24</td>
<td>26.07</td>
<td>Vapor</td>
<td>95.79</td>
<td>72,170</td>
</tr>
<tr>
<td>7-N</td>
<td>114.7</td>
<td>-272</td>
<td>22.93</td>
<td>93.00</td>
<td>1.09</td>
<td>117.02</td>
<td>Vapor</td>
<td>95.79</td>
<td>323,950</td>
</tr>
<tr>
<td>8-N</td>
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<td>-240</td>
<td>22.93</td>
<td>93.00</td>
<td>1.09</td>
<td>117.02</td>
<td>Vapor</td>
<td>104.50</td>
<td>353,406</td>
</tr>
<tr>
<td>9-N</td>
<td>21.0</td>
<td>-306</td>
<td>22.93</td>
<td>93.00</td>
<td>1.09</td>
<td>117.02</td>
<td>Vapor</td>
<td>90.93</td>
<td>307,514</td>
</tr>
<tr>
<td>10-N</td>
<td>21.0</td>
<td>-306</td>
<td>32.72</td>
<td>114.87</td>
<td>1.51</td>
<td>149.10</td>
<td>Vapor</td>
<td>90.97</td>
<td>392,545</td>
</tr>
<tr>
<td>11-N</td>
<td>21.0</td>
<td>-306</td>
<td>32.72</td>
<td>114.87</td>
<td>1.51</td>
<td>149.10</td>
<td>Vapor</td>
<td>97.31</td>
<td>419,914</td>
</tr>
<tr>
<td>12-N</td>
<td>21.0</td>
<td>-306</td>
<td>32.72</td>
<td>114.87</td>
<td>1.51</td>
<td>149.10</td>
<td>Vapor</td>
<td>182.97</td>
<td>789,548</td>
</tr>
<tr>
<td>13-N</td>
<td>114.7</td>
<td>-275.6</td>
<td>4.72</td>
<td>7.99</td>
<td>0.22</td>
<td>12.93</td>
<td>Liquid</td>
<td>22.55</td>
<td>8,826</td>
</tr>
<tr>
<td>14-N</td>
<td>114.7</td>
<td>-275.6</td>
<td>4.72</td>
<td>7.99</td>
<td>0.22</td>
<td>12.93</td>
<td>Liquid</td>
<td>22.55</td>
<td>8,826</td>
</tr>
<tr>
<td>15-N</td>
<td>21.5</td>
<td>-304.3</td>
<td>4.72</td>
<td>7.99</td>
<td>0.22</td>
<td>12.93</td>
<td>Liquid</td>
<td>22.55</td>
<td>8,826</td>
</tr>
<tr>
<td>16-N</td>
<td>21.5</td>
<td>-304.3</td>
<td>4.72</td>
<td>7.99</td>
<td>0.22</td>
<td>12.93</td>
<td>Liquid</td>
<td>12.77</td>
<td>7,067</td>
</tr>
<tr>
<td>17-N</td>
<td>21.5</td>
<td>-304.3</td>
<td>5.07</td>
<td>13.88</td>
<td>0.20</td>
<td>19.15</td>
<td>Liquid</td>
<td>12.77</td>
<td>7,067</td>
</tr>
<tr>
<td>18-N</td>
<td>21.5</td>
<td>-304.3</td>
<td>5.07</td>
<td>13.88</td>
<td>0.20</td>
<td>19.15</td>
<td>Liquid</td>
<td>12.77</td>
<td>7,067</td>
</tr>
<tr>
<td>19-N</td>
<td>21.0</td>
<td>-304.3</td>
<td>9.79</td>
<td>21.87</td>
<td>0.42</td>
<td>32.08</td>
<td>Vapor</td>
<td>91.10</td>
<td>85,031</td>
</tr>
<tr>
<td>20-N</td>
<td>21.0</td>
<td>-304.3</td>
<td>9.79</td>
<td>21.87</td>
<td>0.42</td>
<td>32.08</td>
<td>Vapor</td>
<td>91.10</td>
<td>85,031</td>
</tr>
<tr>
<td>21-N</td>
<td>14.7</td>
<td>-298</td>
<td>0.04</td>
<td>6.84</td>
<td>0.04</td>
<td>6.92</td>
<td>Liquid</td>
<td>12.02</td>
<td>2,329</td>
</tr>
<tr>
<td>22-N</td>
<td>14.7</td>
<td>-298</td>
<td>0.04</td>
<td>6.84</td>
<td>0.04</td>
<td>6.92</td>
<td>Liquid</td>
<td>12.02</td>
<td>2,329</td>
</tr>
</tbody>
</table>
Heat Balance

For any heat balance \( Q_{in} = Q_{out} \) where \( Q = W(Lbs/\text{Hr}) \times H(\text{Btu/Lb}) \)

Heat Exchanger Balance

\( Q_{in} = Q_2 + Q_7 + Q_{12} \)
where \( Q_2 \) is corrected to allow for the loss due to reversal

\[
= 831,005 + 323,950 + 419,914 \\
= 1,574,869
\]

\( Q_{out} = Q_3 + Q_8 + Q_{13} \)

\[
= 1,574,869
\]

Air Liquifier Balance

\( Q_{in} = Q_3 + Q_{11} \)

\[
= 131,915 + 392,546 \\
= 524,460
\]

\( Q_{out} = Q_4 + Q_{12} \)

\[
= 404,546 + 417,924 \\
= 822,460
\]

Phase Separator Heat Balance

\( Q_{in} = Q_4 \)

\[
= 404,546
\]

\( Q_{out} = Q_5 + Q_7 + Q_{14} \)

\[
= 72,170 + 323,950 + 8,426 \\
= 404,546
\]
Turbo Expander Heat Balance

\[ Q_{in} = Q_g \]
\[ = 353,406 \]

\[ Q_{out} = Q_10 + Q_{work} \]
\[ = 307,514 + Q_w \]

\[ Q_{work} = 353,406 - 307,514 \]
\[ = 45,892 \]
\[ or \]
\[ = 18.04 \text{ H.P.} \]

Distillation Column Heat Balance

\[ Q_{in} = Q_6 + Q_{15} + Q_{Heat \, Leak} \]
\[ = 72,170 + 8,426 + (156.02 \times 1.5 \times 28.9) \]
\[ = 87,360 \]

\[ Q_{out} = Q_{18} + Q_{20} \]
\[ = 85,931 + 2,329 \]
\[ = 87,360 \]
Overall Heat Balance

Liquid Oxygen Production

Incoming Air
100 lbs at
100 PSIG, 80°F
Hₐ = Enthalpy
(Ref. Page 12)

Air
Separator

Waste Air
79 Lbs N₂ & Argon, (21-x) Lbs O₂
1 PSIG, 72°F
H₊ = Enthalpy

Refrigeration = R
(Ref. Page 12)

Heat Leak = H.L.
(Ref. Page 12)

Liquid O₂ Drain
x Lbs at 14.7 PSIA
-298°F
Hₒ = Enthalpy

Figure 8 Liquid Oxygen Generator Heat Balance

Enthalpy of the Liquid O₂ Drained, Hₒ

At the conditions of 14.7 PSIA and -298°F the enthalpy of the liquid O₂ is

\[ Hₒ = 8.89 \text{ Btu/Lb} \]

For x lbs. drained

\[ Hₒ = 8.89x \text{ Btu} \]

Enthalpy of the Effluent Waste Air, H₊

At the conditions of 1 PSIG and 72°F the enthalpy of the waste air is equal to the sum of the enthalpies of the constituents.

The enthalpy of nitrogen at these conditions is

\[ H_{N₂} = 183.5 \text{ Btu/Lb} \]

All of the nitrogen contained in the intake air will be waste thus

\[ H_{N₂} = 183.5 \times 79 = 14,497 \text{ Btu} \]

The enthalpy of oxygen at these conditions is

\[ H_{O₂} = 181.2 \text{ Btu/Lb} \]
The oxygen contained in the waste air will be

\[(21 - x) \text{ lbs/100 lbs of Air Feed}\]

\[H_{ow} = 181.2 \times (21 - x)\]

\[= 3805 - 181.2x \text{ Btu}\]

\[H_{w} = H_{ow} + H_{w} = 14,497 + 3,805 - 181.2x\]

\[H_{w} = 18,302 - 181.2x \text{ Btu}\]

**Total Heat Balance**

The total heat balance will be

\[H_{f} + H_{L} = H_{w} + R + H(0)\]

\[18,430 + 150 = 18,302 - 181.2x + 1,018 + 0.89x\]

\[740 = 172.31x\]

\[x = 4.29 \text{ lbs O}_2/100 \text{ lbs Air Feed}\]

This indicates a 4.29% recovery by weight. For two tons per day the required air intake will be

\[Q = \frac{2 \text{ Tons} \times 2000 \text{ lbs} \times \frac{1 \text{ Day}}{\text{ Days}} \times \frac{1 \text{ day}}{24 \text{ Hrs}} \times \frac{1 \text{ Hr}}{60 \text{ Min}} \times \frac{1 \text{ cu ft}}{0.075 \text{ lb}} \times \frac{1}{0.0429}}\]

\[Q = 863 \text{ SCFM}\]

Assuming a 3% loss during reversal

\[0.03 \times 863 = 25.9\]

\[Q = 863 - 25.9 = 837 \text{ say 890 SCFM}\]

Since the expander requires 750 SCFM and the compressors are capable of 1000 SCFM

\[Q = 1000\]

\[1000 \times 24 \times 60 \times 0.075 \times 0.0429\]

\[2000\]

Production = 2.33 T/D

0 including Reversal Loss = 1030 SCFM
Summary: Liquid Oxygen Production

As in the liquid nitrogen cycle the following points are the result of the thermodynamic analysis:

<table>
<thead>
<tr>
<th>Pt. No.</th>
<th>Pressure (PSIA)</th>
<th>Temp. (°F)</th>
<th>O₂ _</th>
<th>N₂</th>
<th>A</th>
<th>Composition (lb Mols/Hr)</th>
<th>Phase</th>
<th>Enthalpy (Btu/lb)</th>
<th>Total Heat (Btu/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-0</td>
<td>14.7</td>
<td>70</td>
<td>32.7</td>
<td>121.45</td>
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</table>

**NOTE:** 2% Reversal Loss not included in Point 1 Tabulation
Overall Heat Balance

Gaseous Nitrogen Production

Incoming Air
100 Lbs at 100 PSIG, 800°F

$H_A = \text{Enthalpy}$
(Ref. Page 12)

Waste Air
(78-x) Lbs $N_2$, 22 Lbs $O_2$ & Argon
1 PSIG 720°F

$H_W = \text{Enthalpy}$

Air Separator

Pump Input = $H_p$

Refrigeration = $R$
(Ref. Page 12)

Heat Leak = $H.L.$
(Ref. Page 12)

Nitrogen Product
$x$ Lbs at 4014.7 PSIA

$H_N = \text{Enthalpy}$

Figure 9 Gaseous Nitrogen Heat Balance

Enthalpy of the Liquid $N_2$ Pumped, $H_N$

At the condition of 4014.7 PSIA, the enthalpy of the pumped nitrogen is

$H_N = 12.02 \text{ Btu/lb}$

For $x$ Lbs pumped

$H_N = 12.02x \text{ Btu}$

Enthalpy of the Effluent Waste Air, $H_W$

At the conditions of 1 PSIG and 720°F the enthalpy of the waste air is equal to the sum of the enthalpies of the constituents.

$H_{NW} = 183.5 \text{ Btu/lb}$

The nitrogen contained in the waste air will be $(78 - x)$ Lbs/100 Lbs of Air Feed thus

$H_{NW} = (78 - x) 183.5$

$= 14,313 - 183.5x$

The enthalpy of oxygen at these conditions is

$H_{OW} = 181.3 \text{ Btu/lb}$
All of the oxygen contained in the intake air will be waste hence

\[ H_{OW} = 181.2 \times 22 \]
\[ = 3,986 \text{ Btu} \]

\[ H_W = H_{NW} + H_{OW} = 14,313 - 183.5x + 3,986 \]
\[ = 18,299 - 183.5x \]

Pump Input

It is estimated that the pump input to the circuit is 2 H.P., or

\[ 2 \left( \frac{\text{HP}}{\text{HP-Hr}} \right) \times 2,544 \left( \frac{\text{Btu}}{\text{hr}} \right) \times \frac{1}{1} \left( \frac{\text{Hrs}}{\text{Hr}} \right) = 30.53 \text{ Btu/Lb N}_2 \]

Since there are to be \( x \) Lbs of nitrogen pumped per 100 Lbs of air feed

\[ H_p = 30.53x \text{ Btu} \]

Total Heat Balance

The total heat balance will be

\[ H_A + H.L. + H_p = H_w + R + H_n \]
\[ 18,430 + 150 + 30.53x = 18,299 - 183.5x + 1,018 + 12.02x \]
\[ 18,580 + 30.53x = 19,317 - 171.48x \]
\[ 202.0x = 737 \]
\[ x = 3.65 \text{ Lbs N}_2/100 \text{ Lbs Air Feed} \]

This indicates a 3.65\% recovery by weight. For two tons per day the required air intake will be

\[ Q = 2 \text{ Tons} \times \frac{2,000 \text{ Lbs}}{1 \text{ Day}} \times \frac{1}{24 \text{ Hrs}} \times \frac{1}{60 \text{ Min}} \times \frac{1}{0.075 \text{ Lb}} \times \frac{1}{0.0365} \]
\[ Q = 1045 \text{ S.C.F.M} \]

Since 3\% is assumed to be Reversal Loss

\[ 0.03 \times 71.5 = 30 \]

Total Air Required = 1045 S.C.F.M.
Summary: Gaseous Nitrogen Production

As in the liquid nitrogen cycle the following points are the result of the thermodynamic analysis:

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<tr>
<th>Pt. No</th>
<th>Pressure (PSTa)</th>
<th>Temp. (°F)</th>
<th>O₂ (Lb Mols/hr)</th>
<th>N₂ (Lb Mols/hr)</th>
<th>A (Lb Mols/hr)</th>
<th>Total (Lb Mols/hr)</th>
<th>Phase</th>
<th>Enthalpy (Btu/Lb)</th>
<th>Total Heat (Btu/hr)</th>
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</table>

NOTE: 3% Reversal Loss not included in Point 1 Tabulation
Overall Heat Balance

Gaseous Oxygen Production

Air Intake
100 Lbs at 100 PSIG, 80°F
HA = Enthalpy
(Ref. Page 12)

Pump Input = Hp
(Ref. Page 36)

Heat Leak = H.L.
(Ref. Page 12)

Waste Air
79 Lbs N₂, (21-x) Lbs O₂
1 PSIG, 72°F
Hₚ = Enthalpy

Air Generator

Refrigeration = R
(Ref. Page 12)

Oxygen Product
x Lbs at 4014.7 PSIA
Hₒ = Enthalpy

Figure 10 Gaseous Oxygen Heat Balance

Enthalpy of the Liquid O₂ Pumped, Hₒ

At the condition of 4014.7 PSIA the enthalpy of the pumped liquid is

Hₒ = 8.9 Btu/Lb

For x Lbs. pumped

Hₒ = 8.99x Btu

Enthalpy of the Effluent Waste Air, Hₚ

At the conditions of 72°F and 1 PSIG the enthalpy of the effluent waste air equals the sum of the enthalpies of the constituents.

The enthalpy of nitrogen under these conditions is

HₚN = 183.5 Btu/Lb

All of the nitrogen contained in the intake air will be waste thus

HₚN = 183.5 x 79 = 14,497 Btu

The enthalpy of oxygen under these conditions is

Hₒ = 181.2 Btu/Lb
The oxygen contained in the waste air will be:

\[(21 - x) \text{ Lbs/100 Lbs of Air Feed}\]

\[H_{NW} = 181.2 (21 - x)\]

\[= 3,805 - 181.2x\]

\[H_{W} = H_{NW} + H_{O} = 14,477 + 3,805 - 181.2x\]

\[H_{W} = 18,302 - 181.2x \text{ Btu}\]

**Total Heat Balance**

The total heat balance will be:

\[H_{A} + H_{I} + H_{p} = H_{W} + R + H_{O}\]

\[18,430 + 150 + 30.53x = 18,302 - 181.2x + 1,018 + 8.89x\]

\[740 = 203.74x\]

\[x = 3.63 \text{ Lbs O}_2/100 \text{ Lbs Air Feed or 3.63\% by weight recovery}\]

The required air intake for two tons per day will be:

\[Q = \frac{2 \times 2000 \text{ Lbs} \times \frac{1}{24} \text{ Days} \times \frac{1}{60} \text{ Hrs} \times \frac{1}{0.075} \text{ Cu Ft} \times \frac{1}{0.0363}}{\text{Day} \times \text{Ton} \times \text{24 Hr} \times \text{60 Min}}\]

\[Q = 1020 \text{ SCFM}\]

Assuming 3\% Loss upon Reversal

\[Q = 1050 \text{ SCFM}\]
Summary: Gaseous Oxygen Production

As in the liquid nitrogen cycle the following points are the result of the thermodynamic analysis:

<table>
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<th>Pt. No</th>
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<th>Composition (Lb Mole/HR)</th>
<th>Total</th>
<th>Phase</th>
<th>Enthalpy (Btu/HR)</th>
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<td>433,426</td>
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<td>13-PO</td>
<td>14.7</td>
<td>72</td>
<td>28.17</td>
<td>123.88 1.56</td>
<td>153.61</td>
<td>Vapor</td>
<td>182.97</td>
<td>809,694</td>
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<tr>
<td>14-PO</td>
<td>114.7</td>
<td>-275.6</td>
<td>6.03</td>
<td>10.34 0.29</td>
<td>16.66</td>
<td>Liquid</td>
<td>22.55</td>
<td>10,887</td>
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<tr>
<td>15-PO</td>
<td>21</td>
<td>-304.3</td>
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<td>10.34 0.29</td>
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<td>Liquid</td>
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</tr>
<tr>
<td>19-PO</td>
<td>114.7</td>
<td>-275.6</td>
<td>5.28</td>
<td>28.74 0.47</td>
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<td>5.21</td>
<td>Vapor</td>
<td>8.89</td>
<td>1,482</td>
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</table>

NOTE: 3% Reversal Loss not included in Point 1 Tabulation
SECTION IV
EQUIPMENT SPECIFICATIONS

General

The equipment specifications listed below are considered to meet the requirements of the liquid oxygen, nitrogen generator from the viewpoints of performance, size, and weight. However, they shall be subject to possible changes resulting from final design considerations as well as availability of materials. The layout of the equipment components within a semitrailer is illustrated in Figure 12.

SEMITRAILER

Description

Semitrailer - The semitrailer shall be a Fruehauf semitrailer. It shall be constructed so that it is adaptable for towing by a standard Army truck tractor, and shall withstand the strains of service encountered when towed across the country with full equipment. The unit shall not exceed the following dimensions:

- Height: 12 ft. 0 in.
- Width: 9 ft. 6 in.
- Length: 32 ft. 0 in.

The total weight of the semitrailer and equipment shall be approximately 45,756 pounds, of which approximately 16,450 pounds shall represent the weight of the semitrailer. The semitrailer shall permit a clear sweep of 70 inches behind the king pin for full turning. A standard SAE king pin shall be provided and shall be located approximately 27 inches back of the trailer front edge to permit the swinging of the trailer corner through a clear space of 62 inches. The trailer fifth wheel plate shall be of sufficient size to fit a 36-inch diameter fifth wheel on the truck tractor and shall be 53 inches from a level ground surface when the trailer floor is level.

Running Gear

Wheels - The wheels, studs, and cap nuts shall conform to applicable Government specifications.

Wheel Hubs - The wheel hubs shall be fitted with tapered roller bearings of adequate size for the required speeds and loads. Bearings shall conform to SAE standards.

Tires - Tires shall be of the heavy duty, truck-and-bus, balloon type, with nondirectional mid-and-snow type tread.

Tubes - Tubes shall be of the heavy duty type.
Brakes

Service Brakes - Service brakes, controllable from the driver's seat of the towing vehicle, shall be provided. The drums shall have flanges or ribbing to prevent objectionable distortion when the brakes are applied. The brakes shall be of the internal expanding, two shoe, heavy-duty type, having constant lift cams and rigid brake-shoe anchors, and shall be operated through fully enclosed worm-gear type slack adjusters. Brakes, anchors, and cams shall have suitable lubrication fittings.

Service Brake Controls (Air) - All detail parts and assemblies of the brake control system shall be equal to and interchangeable with the equipment manufactured by The Bendix Westinghouse Automotive Air Brake Company, Elyria, Ohio, and shall be installed in accordance with the manufacturer's latest recommendations. The controls shall be provided with standard emergency break-away features. The break-away arrangement shall conform to requirements of the Interstate Commerce Commission. The controls shall be sealed in a manner that will ensure satisfactory operation in all kinds of weather. All chambers shall be provided with drains on the non-pressure side. Air hose connections and fittings shall be of the replaceable type with spring protectors. Air line filters shall be provided in both emergency and service lines. A relay emergency exhaust check valve and heavy-duty clamping studs shall be furnished. The standard air-brake couplings shall be provided for connecting the brake lines to the towing vehicle. A dummy coupling shall be attached with a chain to each of the air hose couplings. Two detachable air hose lines of proper length and equipped with standard air hose couplings, shall be supplied for connecting the brake system to the towing vehicle. When detached, the hose lines, with electrical connecting cable, shall be carried on the generating plant.

Parking Brakes - In addition to the air-brake mechanism, a ratchet-and-pawl type mechanism, or equivalent, shall be provided for operating and setting the brakes by hand. This brake shall be capable of skidding the wheels under full load on a dry, level, concrete pavement. The parking brakes shall be operated by a crank or lever placed in a suitable, protected position on the right hand side or rear of the vehicle. No part of the brake mechanism shall be a factor limiting the travel clearance.

Landing Gear - The landing gear shall be of rugged construction, shall be manually operated, and shall be so designed that the wheels may be independently operated to serve as leveling jacks. The landing gear shall be provided with a locking mechanism to lock the landing gear in any position. Two, built-in, screw-type leveling jacks shall be provided at the rear of the trailer. The jacks shall be dirt-proof and self-aligning. Suitable jack planks shall be furnished, conveniently mounted under the trailer.

Body - The body shall be of van-type with door and/or window openings designed to afford the most efficient operating conditions. The roof shall be crowned for drainage purposes, and shall be made in removable sections or provided with removable hatches to permit removal and replacement of equipment components within the van. The roofing material shall have sufficient strength to support a 200 pound man walking thereon. Suitable heavy-duty drip moulding shall be provided around the entire roof.
Floor - The semitrailer floor shall be adequate for the equipment loads and operating conditions. When an all metal floor is provided, it shall be coated with a suitable non-skid, plastic material. When a wood floor is provided, the wood for the floor shall be either maple or birch, second grade, in accordance with the National Maple Flooring Manufacturer's Association Grading Rules, or oak, select grade, in accordance with the National Oak Flooring Manufacturer's Association Grading Rules. Wood flooring shall be not less than \( \frac{3}{8} \) inches thick and shall be surfaced two sides and tongue-and-grooved. Floors shall be chemically treated to repel insects. Flooring shall run lengthwise of the trailer and shall be securely fastened to each cross member by means of galvanized wood screws with heads countersunk to be flush with the floor. The floor shall be sealed at all joints with pitch or other suitable sealing compound.

Doors and/or Windows - Doors, removable panels or hatches shall be provided on the semitrailer as required for convenience of operation, accessibility of plant components, and to facilitate removal of equipment for repair and maintenance. Windows shall be installed in the van-type body of the semitrailer as required. Windows shall be glazed with shatterproof glass.

Steps - Demountable-type steps shall be provided for use at the doors. Steps shall be provided with suitable grab handles and non-slip tread plates, and shall be easily attached and detached at the sill. Provision shall be made for stowing steps inside the semitrailer when not in use.

Wiring - The vehicle shall be wired for an electrical supply of 24 volts direct current. Cable used for wiring shall be enclosed in flexible non-metallic tubing. Terminal lugs shall be soldered to the wire ends. Junction blocks shall have bases made of thermosetting, laminated, phenol formaldehyde plastic, or other equally suitable material, and shall be equipped with suitable studs, washers and nuts for the attachment of terminal lugs. The circuits shall be color or number traced. Suitable grommets, or clamps, to prevent chafing of cable, shall be furnished where wire passes through structural members. A receptacle with hinged cover, to allow the running lights of the semitrailer to be controlled from the driver's seat of the towing vehicle, shall be recessed in the frame. A cable to connect the trailer to the towing vehicle shall be provided.

Lamps and Reflector Assemblies - All lamps shall be readily accessible for the changing of bulbs and lenses, and for making repairs. The stop and tail lamps shall be recessed approximately \( \frac{1}{2} \) inch from the surface of the frame member. The following lamps and reflectors shall be provided on the vehicle, located to conform to Interstate Commerce Commission Motor Carrier Safety Regulations:

- Reflect Reflector (Red and Amber)
- Receptacle and Hinged Cover Assembly
- R.H. Tail Lamp Assembly, 24 Volt
- L.H. Tail Lamp Assembly, 24 Volt
- Clearance Lamp Assembly, 24 Volt

Semitrailer Insulation - The semitrailer operating space shall be insulated with suitable insulating material such as mineral fiber bonded together with a thermosetting plastic resin to form a resilient, semi-rigid, dimensionally stable insulation, sealed in place against moisture infiltration.
Electrical Equipment - A suitable number of dome lights with necessary wiring and switches, and with bulbs of sufficient candlepower shall be installed to provide adequate light for operating the equipment at night. A sufficient number of convenience outlets shall be provided for emergency droplight cords. An emergency auxiliary lighting system supplied by power from the 24 volt diesel engine starting battery bank shall be provided.

Construction Design Methods - All construction design methods and materials for all parts of the unit shall be selected for the lightest possible and item without sacrifice of dependability and strength.

Lubrication - All moving parts shall be provided with suitable means of lubrication.

Lubricants - All moving parts shall be designed to operate efficiently and satisfactorily when lubricated with standard Armed Forces lubricants.

Grease Fittings - Grease fittings shall be located in accessible, protected positions. A bright red circle shall be painted around each lubricating point.

Caution Plates - Where the use of high-pressure lubricating equipment, 1,000 PSI or higher, will damage grease seals or other parts, a suitable warning shall be affixed to the equipment in a conspicuous location.

Fungus Control - The semitrailer shall be treated to resist the growth of fungus.

Lifting Attachments - The semitrailer shall be provided with suitable lifting attachments to enable the trailer, with all equipment installed in it, to be lifted in its normal position. The lifting attachment shall have a minimum safety factor of five based on the ultimate strength of the material. The eye of each lifting attachment shall be not less than three inches in diameter.

Manufacturer's Identification - The semitrailer shall bear the manufacturer's name and/or trademark on a name plate securely affixed in a conspicuous place. In lieu of the name plate, the manufacturer's identification may be cast integral with, stamped, or otherwise permanently marked upon the components of the equipment.

Instruction Plates - The semitrailer, when applicable, shall be equipped with instruction plates, suitably located, describing any special or important procedures to be followed in operating and servicing the equipment.

Treatment, Painting, and Stenciling - All parts of the semitrailer body and running gear shall be treated and painted to resist the effects of sand, dust, humidity and moist salt air.

Stenciling - The gross weight of the semitrailer with all equipment installed in it shall be stenciled on each side of the semitrailer in such manner as to be readily discernible to military personnel. The prescribed tire pressure shall be stenciled on the frame or body of the unit in a position near the wheels, using block- or stencil-type letters not more than one inch high.
AIR FILTER

Description

The air filter element shall be a Dollinger Corporation staynew Model WE-4, dry panel type air filter, complete with cell frame and insert. The filtering medium shall be bonded glass. Two elements shall be required. They shall be mounted in a lightweight steel duct.

Specifications

<table>
<thead>
<tr>
<th>Nominal Filter Element Size, Ins.</th>
<th>Height</th>
<th>Width</th>
<th>Thickness</th>
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<table>
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<tr>
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<td>Air Velocity, FPM</td>
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<table>
<thead>
<tr>
<th>Maximum Capacity</th>
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<table>
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<tr>
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<td>At 1000 CFM Air Volume, Ins. of Water</td>
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<table>
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<th>Width, Ins.</th>
<th>Length, Ins.</th>
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<td>14</td>
<td>42</td>
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<table>
<thead>
<tr>
<th>Approximate Total Weight, Lbs.</th>
<th>125</th>
</tr>
</thead>
</table>

AIR COMPRESSOR

Description

The air compressor shall consist of three Read Standard Corporation "Standardeire" blowers. Each blower shall be a three lobe, rotary, positive displacement, axial flow, horizontal, heavy duty blower having helical rotors. By compounding one Model 8E14, one Model 7E10 and one Model 5E10 blower, 1000 standard cubic feet per minute of air shall be compressed from intake conditions of 14.7 PSIA and 70°F and discharged as oil-free air at 114.7 PSIA. Each blower shall be equipped with a shaft extension to provide a drive for an intercooler or aftercooler fan. This extension shall be capable of transmitting a load of 10 horsepower to the cooling fan by either a direct drive or through the use of a V-belt drive.
Each stage shall be tested individually in accordance with the American Society of Mechanical Engineers Power Test Code (PTC 9-39). Each stage shall be guaranteed to be within the permissible limit of 3% of the specifications listed below.

Specifications

<table>
<thead>
<tr>
<th></th>
<th>1st Stage</th>
<th>2nd Stage</th>
<th>3rd Stage</th>
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<tbody>
<tr>
<td>Blower Model</td>
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<td>7B10</td>
<td>5B10</td>
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<tr>
<td>Speed, RPM</td>
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<td>2390</td>
<td>3220</td>
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<tr>
<td>Intake Pressure, PSIA</td>
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<tr>
<td>Discharge Pressure, PSIA</td>
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<td>60.9</td>
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<td>Absolute Pressure Ratio</td>
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<td>2.0:1</td>
<td>1.93:1</td>
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<td>Intake Volume, CFM</td>
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<tr>
<td>Intake Temperature, °Rankine</td>
<td>730</td>
<td>560</td>
<td>560</td>
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<tr>
<td>Discharge Temperature, °F</td>
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<td>302</td>
<td>287</td>
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<tr>
<td>Adiabatic Horsepower</td>
<td>60</td>
<td>56.5</td>
<td>52.3</td>
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<tr>
<td>Brake Horsepower</td>
<td>102</td>
<td>103</td>
<td>99</td>
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<td>Overall Adiabatic Efficiency, %</td>
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<td>53</td>
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Approximate Size

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<td>41</td>
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<tr>
<td>Height, In.</td>
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<td>Approximate Weight, Lbs.</td>
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<td>950</td>
<td>710</td>
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INTERCOOLERS AND AFTERCOOLER

Description

The intercoolers and aftercooler shall be Trane Company coolers. They shall be of all aluminum construction. The cooling air face shall measure 20-5/8 inches by 32 inches, and the cooling air flow length shall be 10 inches.

Specifications

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<thead>
<tr>
<th></th>
<th>1st Stage</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Duty, Btu/hr</td>
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<td>270,000</td>
<td>235,000</td>
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<tr>
<td>Hot Air Side</td>
<td></td>
<td></td>
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<tr>
<td>Flow, Lbs/hr</td>
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<td>4,500</td>
<td>4,500</td>
</tr>
<tr>
<td>Inlet Temperature, °F</td>
<td>264</td>
<td>302</td>
<td>287</td>
</tr>
<tr>
<td>Outlet Temperature, °F</td>
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<td>90</td>
<td>90</td>
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<tr>
<td>Inlet Pressure, PSI</td>
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<td>101.0</td>
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<td>Pressure Drop, PSI</td>
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<tr>
<td>H₁/₂, Btu/HR, sq.ft., °F</td>
<td>27.8</td>
<td>27.8</td>
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<tr>
<td>Number of Passages</td>
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<td>24</td>
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<tr>
<td>Flow Length, In.</td>
<td>12</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Fin Type</td>
<td>1/8 In. Serrated</td>
<td>1/8 In. Serrated</td>
<td>1/8 In. Serrated</td>
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<td>0.375 x 0.006</td>
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¹/ Sensible heat transfer coefficient corrected for fin efficiency.

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<td>Fin Spacing, Per In.</td>
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<td>541</td>
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<tr>
<td>Air Outlet Connection Size, In.</td>
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<tr>
<td>Air Blowdown Connection Size, In.</td>
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<td>1-1/2</td>
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</tr>
<tr>
<td>Cooling Air Side</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Flow, Lbs/Hr</td>
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<td>13,500</td>
<td>13,500</td>
</tr>
<tr>
<td>Inlet Temperature, OP</td>
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<td>80</td>
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<tr>
<td>Outlet Temperature, OP</td>
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<td>152.3</td>
</tr>
<tr>
<td>Pressure Drop, Ins. Water</td>
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<td>4.28</td>
<td>4.24</td>
</tr>
<tr>
<td>H, Btu/Hr., Sq. Ft., OP</td>
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<tr>
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<tr>
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<tr>
<td>Fin Type</td>
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<tr>
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<td>0.416 x 0.006</td>
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<tr>
<td>Fin Spacing, Per In.</td>
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<td>17</td>
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<tr>
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<td>850</td>
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<tr>
<td>Approximate Total Weight, Lbs.</td>
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<td>120</td>
<td>120</td>
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</tbody>
</table>

INTER- AND AFTERCOOLER FANS

Description

The inter- and aftercooler fans shall be Trans Company centrifugal fans with the blades inclined backward to the direction of rotation. They shall be of single width and shall have single inlets. They shall be of lockseam-type construction, with convertible discharge orientation, and with standard steel shafts.

Specifications

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<th>1st Stage</th>
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</tr>
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<td>16 BI SW5I</td>
<td>13 BI SW5I</td>
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<tr>
<td>Fan Size</td>
<td>16</td>
<td>16</td>
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</tr>
<tr>
<td>Fan Arrangement</td>
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<td>2</td>
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<tr>
<td>Fan Class</td>
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<td>II</td>
</tr>
<tr>
<td>Wheel Width, %</td>
<td>83</td>
<td>83</td>
<td>95</td>
</tr>
<tr>
<td>Fan Speed, RPM</td>
<td>2330</td>
<td>2390</td>
<td>3220</td>
</tr>
<tr>
<td>Direction of Rotation Viewing Driveshaft End</td>
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<td>Clockwise</td>
<td>Clockwise</td>
</tr>
<tr>
<td>Delivery, CFM</td>
<td>3465</td>
<td>3825</td>
<td>3465</td>
</tr>
<tr>
<td>Static Pressure, Ins. of Water</td>
<td>4.24</td>
<td>4.28</td>
<td>4.24</td>
</tr>
<tr>
<td>Brake Horsepower</td>
<td>3.28</td>
<td>3.42</td>
<td>3.69</td>
</tr>
<tr>
<td>Orientation of Discharge</td>
<td>Up Blast</td>
<td>Up Blast</td>
<td>Up Blast</td>
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<td>Approximate Weight, Lbs.</td>
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<td>86</td>
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</table>

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DIESEL ENGINE

Diesel Engine Horsepower Requirements

In this generator, the blowers and inter- and aftercooler fans of each stage are direct-driven in tandem by separate diesel engines through suitable transmissions. In addition, a 18.7 kva, 120/208 volt, 3 phase, 60 cycle electrical generator is belt driven by the third-stage diesel engine. The following table is a compilation of the anticipated brake horsepower loads on the individual diesel engines required to drive these components:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Blower</th>
<th>Transmission Loss - 2 to 4%</th>
<th>Intercooler Fan</th>
<th>Electric Generator</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Stage</td>
<td>102</td>
<td>3.57</td>
<td></td>
<td>3.28</td>
<td>108.85</td>
</tr>
<tr>
<td>2nd Stage</td>
<td>103</td>
<td>3.60</td>
<td></td>
<td>3.42</td>
<td>110.02</td>
</tr>
<tr>
<td>3rd Stage</td>
<td>99</td>
<td>3.46</td>
<td></td>
<td>3.69</td>
<td>117.15</td>
</tr>
</tbody>
</table>

Description

The three diesel engines shall be General Motors Corporation two cycle, six cylinder, radiator-cooled, short base, open diesel engines, Series 6-71, Model 6030C.

Specifications

- Engine Model Number: 6030C
- Engine Model Number: 6-71 PC55
- 1000 RPM
- Continuous Rating at 1800 RPM
- Maximum Torque, 1000 RPM (60 Cu. In. Injector), Lb Ft
- Piston Speed at 1800 RPM, RPM
- Piston Speed at 1600 RPM, RPM
- Compression Ratio
- Lubrication: Forced Feed
- Flywheel Housing Size
- Maximum Fuel Pump Lift to Fuel Pump Level, In.
- Heat Absorbed by Cooling Water (Per HP at Ambient Temperature of 110°F) Btu/HP/hour
- Air Required for Scavenging and Combustion at 1800 RPM, CFM
- Exhaust Back Pressure (Maximum at Manifold Flange at 1800 RPM), In. Hg.
- Lubricating Oil Refill Capacity, Including Filter(s), Qt.
- Cooling Water System Capacity, Gal.
Approximate Size
Length, In. 62-13/16
Width, In. 22
Height, In. 49-1/2
Approximate Weight, Dry, Lbs. 2600

Standard Equipment
Rotation - Counterclockwise, viewing flywheel end.
Cooling System - Heavy duty radiator, lubricating oil cooler, water outlet manifold, thermostat for temperature control, engine water circulating pump, suction type fan.
Fuel System - Primary and secondary fuel filters, 60 cu. mm. injectors, fuel circulating pump.
Lubrication System - Lubricating oil pressure pump, oil filter assembly.
Instruments - Instrument Panel Assembly includes: Starter switch, ammeter, lube oil pressure gauge, water temperature gauge, throttle control knob, remote control lever and space for accessory air heater controls and tachometer.
Miscellaneous - Fabricated steel base, hydraulic type governor with control on instrument panel, exhaust manifold and companion flange, tools for ordinary maintenance, manual for minor maintenance and operating instructions.

Optional Equipment
Electrical - Battery charging generator and voltage regulator assembly (24 volt, 600 watt insulated) starting motor (24 volt, insulated).
Miscellaneous - Air inlet housing for remotely mounted extra capacity air cleaner, Donaldson extra heavy duty oil bath type air cleaner.

Accessories
Automatic Bell Alarm for high water temperature and low oil pressure, air heater and pump for cold weather starting, 18-inch flexible exhaust connection with pipe thread ends, unmounted muffler for moderate silencing.

DIESEL ENGINE TRANSMISSION

Description
The diesel engine transmission shall be a Cotta Transmission Company Model FAAU-R Transmission equipped with an SAE No. 1 bell housing and Rockford single plate, 12", over-center clutch. It shall be complete with pilot bearings and oil circulating pump. The transmission shall be so designed and constructed that it is capable of attachment and connection to a General Motors Model 60300 Series 6-71 RC55 Diesel Engine without modification. The transmission bell
housing shall be fabricated with a clutch operating shaft extending through and to the outside on both right and left hand sides of the bell housing to provide for optional location of a clutch operating lever.

Specifications

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Unit No. 1</th>
<th>Unit No. 2</th>
<th>Unit No. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horsepower to be Transmitted, Minimum</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Input Speed, RPM (Approximate)</td>
<td>1580</td>
<td>1620</td>
<td>1600</td>
</tr>
<tr>
<td>Output Speed, RPM (Approximate)</td>
<td>2330</td>
<td>2390</td>
<td>3220</td>
</tr>
<tr>
<td>Overaccel Ratio</td>
<td>1,476:1</td>
<td>1,476:1</td>
<td>2,012</td>
</tr>
<tr>
<td>Transmission Efficiency, Per Cent</td>
<td>96 to 98</td>
<td>96 to 98</td>
<td>96 to 98</td>
</tr>
<tr>
<td>Type of Duty</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td>Direction of Rotation, Viewing</td>
<td>Counter-Clockwise</td>
<td>Counter-Clockwise</td>
<td>Counter-Clockwise</td>
</tr>
<tr>
<td>Approximate Size</td>
<td>34</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>Length, In.</td>
<td>34</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>Width, In.</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Height, In.</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Approximate Weight, Lbs.</td>
<td>630</td>
<td>630</td>
<td>630</td>
</tr>
</tbody>
</table>

DIESEL ENGINE STARTING BATTERY

Description

The diesel engine starting battery shall be a Delco Products Division of General Motors Corporation Heavy Duty, Model 25A1, Six-Volt Storage Battery. The battery shall have three lead and acid type cells enclosed in a composition rubber case. Four of these batteries shall be connected in series to generate the 24 volts necessary to start the diesel engines.

Specifications

Capacity
200 Ampere Hours at 20 Hour Rating
150 Ampere Hours at 4 Hour Rating

Delivery Rates
50 Amperes for 175 Minutes at 80°F
300 Amperes for 11 Minutes at 0°F
820 Amperes for 1.5 Minutes at 0°F
1060 Amperes for 1.5 Minutes at 30°F

At the above rates the battery shall be depleted to an average of one volt per cell.

Approximate Size
Length, In. 16-1/2
Width, In. 7-1/2
Height, In. 10

Approximate Weight, Lbs. 80
DIESEL ENGINE FUEL OIL SUPPLY TANK

Calculation of Size

In accordance with the contract, the fuel supply tank shall have a minimum capacity for 12 hours of continuous operation for the generator at full load.

Specific Fuel Consumptions

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>Horsepower</th>
<th>RPM</th>
<th>OPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>First-Stage Engine</td>
<td>108.85</td>
<td>1600</td>
<td>7.14</td>
</tr>
<tr>
<td>Second-Stage Engine</td>
<td>110.02</td>
<td>1600</td>
<td>7.23</td>
</tr>
<tr>
<td>Third-Stage Engine</td>
<td>117.15</td>
<td>1600</td>
<td>7.68</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>22.05</td>
</tr>
</tbody>
</table>

Capacity Required

\[ V_{req'd} = \frac{22.05 \text{ (Gal)}}{12 \text{ (Hrs)}} \]

\[ = 265 \text{ Gals.} \]

Use \[ V_{tank} = 275 \text{ Gals.} \]

For the trailer which is 9 feet 6 inches wide, a steel, cylindrical fuel tank 8 feet 10 inches long shall be strapped beneath the floor of the air source section.

\[ V_{cyl} = \frac{\pi D_i^2}{4} \text{ (cross sectional area) x L (length)} \]

Also

\[ V_{cyl} = 275 \text{ (Gals)} \times 231 \text{ (Cu In)} \]

\[ D_i^2 = 275 \times 231 \times 4 \]

\[ D_i = 27.68 \text{ Ins. Use 27.75 Ins.} \]

Specifications

| Inside Diameter, In. | 27.75 |
| Length, In.          | 106.0 |
| Thickness, In.       | 1/8   |
| Capacity, Gals.      | 275   |
| Weight, Dry, Lbs.    | 360   |
| Weight, Wet, Lbs.    | 2310  |
AIR COMPRESSOR CONDENSATE TRAP

Description

The air compressor condensate trap shall be fabricated by Air Products, Incorporated. It shall have a tangential side inlet and a bottom outlet. It shall have a condensate drain connection at the lowest point in the bottom head.

Specifications

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell Length, Ins.</td>
<td>30</td>
</tr>
<tr>
<td>Shell Diameter, Ins.</td>
<td>10</td>
</tr>
<tr>
<td>Shell Thickness, Ins.</td>
<td>1/8</td>
</tr>
<tr>
<td>Head Diameter, Ins.</td>
<td>10</td>
</tr>
<tr>
<td>Head Thickness, Ins.</td>
<td>1/8</td>
</tr>
<tr>
<td>Head Height, Ins.</td>
<td>4</td>
</tr>
<tr>
<td>Inlet Connection Size, Ins.</td>
<td>4</td>
</tr>
<tr>
<td>Outlet Connection Size, Ins.</td>
<td>4</td>
</tr>
<tr>
<td>Condensate Drain Connection Size, Ins.</td>
<td>1</td>
</tr>
<tr>
<td>Maximum Working Pressure, PSIG</td>
<td>100</td>
</tr>
<tr>
<td>Approximate Weight, Lbs.</td>
<td>50</td>
</tr>
</tbody>
</table>

SWITCH VALVE

Description

The switch valve shall be manufactured by Air Products, Incorporated. It shall be a double poppet-type valve having a carbon steel body and stainless steel stem. It shall have two 4-inch high pressure air inlet connections; one 5-inch waste air outlet connection; and two 5-inch connections common to both the high pressure air outlet and the waste air inlet. The switch valve shall be actuated by a Loganport Machine Company, Incorporated non-rotating, double-acting air cylinder, Model No. 2106C. The air cylinder shall have a 6-inch bore, 4-inch stroke and 1/2 inch iron pipe size air connections. The air cylinder, in turn, shall be controlled by a Bellows Company four-way solenoid air valve, Model No. SV-158 Electro-Air Valve, having a 115/8 volt transformer and 1/2 inch iron pipe size air inlet connection. The solenoid valve shall be air powered and shall be actuated in both directions by low-voltage, momentary-energized solenoid coils. It shall have an operating pressure of 50 PSIG, and shall have adjustments provided to limit the speed of the control cylinder in both directions.

WARM HEAT EXCHANGER

Description

The warm heat exchanger shall be a Trane Company brazed aluminum core type heat exchanger.
Specifications

Core Size
17 in. passage width over channels
20-7/8 in. no flow (passage stack height)
88-1/2 in. core length over face channels

Core Passages
50 passages per core shall be headered into 2 streams of 25 passages each
16-1/2 in. width inside channels
0.375 in. nominal passage height

Fins
Trane 1/8 in. serrated
0.375 in. nominal height
15 fins per inch
0.003 in. thickness
61 in. effective heat transfer length

Distribution
Provision shall be made for gas distribution at each end of each passage.

Headers
The headers shall be fabricated from standard 5 inch 38F aluminum pipe.

Shell
External parting sheets and 1/4 inch protective pads shall be provided on each core, one on each side of 20-7/8 inch no flow (passage stack height).

Supports
Support boxes and angles shall be provided at each end of the core.

Material Thickness, Inches
Outside Core Sheets = 0.064
Parting Sheets = 0.032
Side Channels = 0.040
Top Header Channels = 0.064
Side Protection Fin = 0.008
Packing Fin = 0.008
Distributor Fin = 0.024 Perforated

Tests
The core shall be subjected to hydrostatic and air pressure tests to check for interpassage and external leakage. The core shall be guaranteed to be satisfactory at a maximum working pressure of 100 PSI.
COLD HEAT EXCHANGER

Description

The cold heat exchanger shall be a Trane Company brazed aluminum core type heat exchanger.

Specifications

Core Size
17 in. passage width over channels
20-7/8 in. no flow (passage stack height)
80-1/2 in. core length over face channels

Core Passages
50 passages per core shall be headered into 3 streams of 20, 20, and 10 passages respectively.
16-1/2 in. width inside channels
0.375 in. nominal passage height

Fins
Trans 1/8 in. serrated
0.375 in. nominal height
15 fins per inch
0.008 in. thickness
73 in. effective heat transfer length

Distribution
Provision shall be made for gas distribution at each end of a passage.

Headers
The headers shall be fabricated from standard 5 inch 3SF aluminum pipe.

Shell
External parting sheets and 1/4 inch protective pads shall be provided on each core, one on each side of 20-7/8 inch no flow (passage stack height).

Supports
Support boxes and angles shall be provided at each end of the core.

Material Thickness, Inches
Outside Core Sheets - .064
Parting Sheets - .032
Side Channels - .040
Top Header Channels - .064
Side Protection Fin - .008
Packing Fin - .008
Distributor Fin - .024 Perforated

Tests
The core shall be subjected to hydrostatic and air pressure tests to check for interpassage and external leakage. The core shall be guaranteed to be satisfactory at a maximum working pressure of 100 PSIG.
AIR LIQUEFIER

Description
The air liquefier shall be a Trane Company brazed aluminum core type heat exchanger.

Specifications
Core Size
8-3/4 in. passage width over channels
12-3/4 in. no flow (passage stack height)
51-1/4 in. core length over face channels

Core Passages
30 passages per core to be headered into 2 streams of 20 and 10 passages.
16-1/2 in. width inside channels
0.375 in. nominal passage height

Fins
Trane 1/8 in. serrated
0.375 in. nominal passage height
15 fins per inch
0.008 in. thickness
43-3/4 in. effective heat transfer length

Distribution
Provision shall be made for gas distribution at each end of a passage.

Headers
The headers shall be fabricated from standard 3 and 5 inch 38F aluminum pipe.

Shells
External parting sheets and 1/4 inch protective pads shall be provided on each core, one on each side of 12-3/4 inch no flow (passage stack height).

Supports
Support boxes and angles shall be provided at each end of the core.

Material Thicknesses, Inches
Outside Core Sheets - .064
Parting Sheets - .032
Side Channels - .040
Top Header Channels - .064
Side Protection Fin - .008
Packing Fin - .008
Distributor Fin - .024 Perforated

Tests
The core shall be subjected to hydrostatic and air pressure tests to check for interpassage and external leakage. The core shall be guaranteed satisfactory at a maximum working pressure of 100 PSIG.

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CHECK VALVE

Description

The check valve shall be manufactured by Air Products, Incorporated. It shall be a double poppet-type valve of stainless steel construction. In one end it shall have one 4-inch high pressure air outlet connection; in the opposite end it shall have one 5-inch waste air inlet connection; and in the side it shall have one 5-inch connection common to both the incoming high pressure air and the effluent waste air. The check valve shall measure approximately 14 inches in length and shall weigh approximately 125 pounds.

PHASE SEPARATOR

Description

The phase separator shall be manufactured by Air Products, Incorporated. It shall be provided with a tangential, side, air inlet connection, a top vapor outlet connection, and a bottom liquid outlet connection. In addition, the phase separator shall be provided with connections to accommodate a liquid level gage.

Specifications

<table>
<thead>
<tr>
<th>Model</th>
<th>41490D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Copper</td>
</tr>
<tr>
<td>Shell Length, Ins.</td>
<td>24</td>
</tr>
<tr>
<td>Shell Diameter, Ins.</td>
<td>8-1/8 O.D.</td>
</tr>
<tr>
<td>Shell Thickness, Ins.</td>
<td>0.170</td>
</tr>
<tr>
<td>Head Diameter, Ins.</td>
<td>8-1/8 I.D.</td>
</tr>
<tr>
<td>Head Thickness, Ins.</td>
<td>1/4</td>
</tr>
<tr>
<td>Air Inlet Connection Size, Ins.</td>
<td>3-1/8 O.D.</td>
</tr>
<tr>
<td>Vapor Outlet Connection Size, Ins.</td>
<td>3-1/8 O.D.</td>
</tr>
<tr>
<td>Liquid Outlet Connection Size, Ins.</td>
<td>5/8 O.D.</td>
</tr>
<tr>
<td>Upper Liquid Level Gage Connection Size, In.</td>
<td>5/8 O.D.</td>
</tr>
<tr>
<td>Maximum Working Pressure, PSIG</td>
<td>100</td>
</tr>
<tr>
<td>Approximate Overall Length, Ins.</td>
<td>32</td>
</tr>
<tr>
<td>Approximate Weight, Lbs.</td>
<td>53</td>
</tr>
</tbody>
</table>

TURBO EXPANDER

Description

The turbo expander shall be an Air Products, Incorporated high-speed, centrifugal, expander, equipped with an air loaded energy absorber complete with lubrication system.
Specifications

The turbo expander shall be designed, built, and guaranteed to operate satisfactorily under the following conditions:

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Rate, Lb/Min</td>
<td>54.6</td>
</tr>
<tr>
<td>Inlet Pressure, PSIA</td>
<td>112</td>
</tr>
<tr>
<td>Exhaust Pressure, PSIA</td>
<td>21</td>
</tr>
<tr>
<td>Inlet Temperature, OF</td>
<td>-240</td>
</tr>
<tr>
<td>Exhaust Temperature, OF</td>
<td>-206</td>
</tr>
<tr>
<td>Approximate Weight, Lbs.</td>
<td>160</td>
</tr>
</tbody>
</table>

EXPANDER LOADER

Description

The expander loading device consists of a centrifugal impeller keyed to the expander shaft. The impeller rotates at the same speed as the expander wheel and imparts the shaft energy to the fluid being pumped. The amount of power which is absorbed is proportional to the quantity and density of the pumped fluid. This is controlled by a valve which admits the fluid to the inlet of the loader.

HYDROCARBON ADSORBER

Description

The hydrocarbon adsorber shall be an Air Products, Incorporated, silica gel type adsorber, Model No. 41510D. It shall consist of a pressure vessel having top inlet and bottom outlet connects. The pressure vessel shall be charged with silica gel. It shall be provided with filters to keep foreign particles from entering and silica gel from leaving the adsorber.

Specifications

<table>
<thead>
<tr>
<th>Pressure Vessel</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td></td>
</tr>
<tr>
<td>Shell Length, Ins.</td>
<td>36</td>
</tr>
<tr>
<td>Shell Diameter, Ins.</td>
<td>8-1/8 O.D.</td>
</tr>
<tr>
<td>Shell Thickness, Ins.</td>
<td>0.170</td>
</tr>
<tr>
<td>Head Diameter, Ins.</td>
<td>8-1/8 I.D.</td>
</tr>
<tr>
<td>Head Thickness, Ins.</td>
<td>1/4</td>
</tr>
<tr>
<td>Inlet Connection Size, Ins.</td>
<td>5/8 O.D.</td>
</tr>
<tr>
<td>Outlet Connection Size, Ins.</td>
<td>5/8 O.D.</td>
</tr>
<tr>
<td>Maximum Working Pressure, PSIG</td>
<td>15</td>
</tr>
<tr>
<td>Approximate Overall Length, Ins.</td>
<td>45</td>
</tr>
<tr>
<td>Approximate Weight, Charged, Lbs.</td>
<td>123</td>
</tr>
</tbody>
</table>
Adsorbent
Material: Silica Gel
Size, Mesh: 3-8
Density, Lbs/Cu. Ft.: 38-40
Quantity Required, Lbs.: 42

Inlet Filter
Material: Porex Grade 1
Diameter, Ins.: 1-1/8 O.D.
Wall Thickness, Ins.: 1/8
Length, Ins.: 5-1/4

Primary Outlet Filter
Material: Alumina Tabular Balls
Ball Diameter, Ins.: 1/4
Quantity Required, Cu.Ft.: 1/2

Secondary Outlet Filter
Material: Porex Grade 1
Diameter, Ins.: 1-1/8
Wall Thickness, Ins.: 1/8
Length, Ins.: 5-1/4

OXYGEN DISTILLATION COLUMN

Description
The distillation column shall be an Air Products, Incorporated column. It shall consist of a tube-type condenser and a low pressure column having a number of bubble-cap pans of conventional design. The high pressure side of the condenser shall be designed and fabricated for a maximum working pressure of 100 PSIG. The low pressure column, which is also the low pressure side of the condenser, shall have a maximum working pressure of 15 PSIG. The column shall be provided with connections, properly sized and located, to accommodate all of the required column feeds and off-takes. Sufficient pans shall be included in the low pressure column to ensure that the product liquid oxygen, when withdrawn from the column at a rate of two tons per day, shall be 99.5% pure when the air available to the oxygen generator is approximately 1000 standard cubic feet per minute, and when the material balances are as calculated in Section III of this report. The column shall be approximately 12 1/8 inches in diameter and 8 feet 6 inches high and shall weigh approximately 600 pounds dry.

NITROGEN DISTILLATION COLUMN

Description
The distillation column shall be an Air Products, Incorporated column. It shall consist of a tube-type condenser and a high pressure column having a number of bubble-cap pans of conventional design. The high pressure column

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and high pressure side of the condenser shall be designed and fabricated for a maximum working pressure of 100 PSIG. The low pressure column and low pressure side of the condenser shall be designed and fabricated for a maximum working pressure of 15 PSIG. The column shall be provided with the necessary connections, properly sized and located to accommodate all of the required column feeds and off-takes. Sufficient pans shall be included in the high pressure column to insure that the product liquid nitrogen when withdrawn from the column at a rate of two tons per day shall be 99.0% pure, when the air available to the generator is approximately 1000 standard cubic feet per minute and when the material balances are as calculated in Section III of this report. The column shall be approximately 13 1/8 inches in diameter and 5 feet 6 inches high and shall weigh approximately 450 pounds dry.

**SUBCOOLER**

**Description**

The subcooler shall be an Air Products, Incorporated extended-surface type heat exchanger, Model No. 415060. In the subcooler, pure liquid shall flow through the tubes of the core while waste air gas shall flow around the tubes through the shell.

**Specifications**

<table>
<thead>
<tr>
<th>Core</th>
<th>Finned Copper Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube Size, IPS</td>
<td>3/4</td>
</tr>
<tr>
<td>Tube Length, Ins.</td>
<td>60</td>
</tr>
<tr>
<td>Fin Height, Ins.</td>
<td>1/2</td>
</tr>
<tr>
<td>Fin Orientation</td>
<td>Axial</td>
</tr>
<tr>
<td>No. of Fins per Circumference</td>
<td>18</td>
</tr>
<tr>
<td>No. of Tubes</td>
<td>7</td>
</tr>
<tr>
<td>Liquid Inlet Connection Size, Ins.</td>
<td>7/8 O.D.</td>
</tr>
<tr>
<td>Liquid Outlet Connection Size, Ins.</td>
<td>7/8 O.D.</td>
</tr>
<tr>
<td>Maximum Working Pressure, PSIG</td>
<td>15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shell</th>
<th>Cooper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length, Ins.</td>
<td>75</td>
</tr>
<tr>
<td>Diameter, Ins.</td>
<td>6-1/8 O.D.</td>
</tr>
<tr>
<td>Thickness, Ins.</td>
<td>0.140</td>
</tr>
<tr>
<td>Head Diameter, Ins.</td>
<td>6-1/8 I.D.</td>
</tr>
<tr>
<td>Head Thickness, Ins.</td>
<td>0.187</td>
</tr>
<tr>
<td>Waste Air Inlet Connection Size, Ins.</td>
<td>3-1/8 O.D.</td>
</tr>
<tr>
<td>Waste Air Outlet Connection Size, Ins.</td>
<td>3-1/8 O.D.</td>
</tr>
<tr>
<td>Maximum Working Pressure, PSIG</td>
<td>15</td>
</tr>
</tbody>
</table>

Approximate Overall Length, Ins. 91
Approximate Weight, Lbs. 154
LIQUID PRODUCT PUMPS AND DRIVE MOTORS

Description

The liquid product pumps shall be an Air Products, Incorporated horizontal, reciprocating-plunger type. The pumps shall be driven through a crank-and-connecting rod mechanism by electric motors through a gear reduction. The pumps shall be provided with thermal brakes which will allow the pump drive mechanisms to operate at atmospheric temperature while the pump cylinders are at the temperature of the liquid product being pumped. The pump capacities shall be controlled by variation of the pump stroke.

Specifications

**Pump**
- Delivery, CFH gas Equivalent: 2000
- Plunger Diameter, Ins.: 5/8
- Stroke, Ins.: Variable up to 3
- Speed, RPM: 100
- Intake Pressure, PSIG: 7
- Discharge Pressure, PSIG: 4000

**Motors**
- 3 Horsepower, 220/440 Volts, 3 Phase, 60 cycle, Squirrel-Cage Induction, Ball Bearing, Horizontal, Open, 40º Rise, Continuous Duty, Normal Torque, Low Starting Current, with 100 RPM American Gear Manufacturers' Association Class III, Helical Gears Hand Matched for Minimum Back Lash and Quiet Operation.

OXYGEN-NITROGEN VAPORIZER

Description

The oxygen-nitrogen vaporizer shall be manufactured by Air Products, Incorporated. It shall be a tube-type heat exchanger consisting of copper coils contained within a steel shell. The pure high pressure liquid product shall flow through the copper coils while high pressure air from the aftercooler of the air compressor shall flow across the tubes within the shell.

Specifications

**Shell**
- Material: Steel
- Length, Ins.: 48
- Diameter, Ins.: 12
- Thickness, Ins.: 0.120
- Head Diameter, Ins.: 12
- Head Thickness, Ins.: 1/8
- Maximum Working Pressure, PSIG: 100
ALTERNATING-CURRENT GENERATOR

Specifications

The alternating-current generator shall have the following characteristics: 10.7 Kva, 120/208 volts, 3 phase, 4 wire, 60 cycle, .8 power factor, 1800 RPM, synchronous, horizontal, ball-bearing, dripproof, self-excited by direct connected exciter, windings of generator and exciter shall be moisture and fungus proof.

The alternating-current generator shall have a shaft extension suitable for a V-belt drive and shall be complete with a solid adjustable base or slide rails.

HYDROCARBON ADSORBER REACTIVATION HEATER

Description

The hydrocarbon adsorber reactivation heater shall be an Air Products, Incorporated resistance heater, Model No. 311440. It shall consist of two heating elements, the resistance heating coils of which are imbedded in compacted magnesium oxide which is contained within a grounded, chrome-steel sheath. Each element shall be rated at 1 kilowatt at 230 volts alternating current single phase. The two elements shall be connected in open-delta for the three phase circuit. The maximum allowable sheath temperature shall be 1400 to 1500°F.

INTERCONNECTING PIPING

Description

The interconnecting piping shall be of as lightweight material as practical. It shall be adequately strong for the service intended and shall be sized to keep pressure losses within tolerable limits. Operating conditions such as temperature, pressure, location and application shall dictate the choice of material to be used. Every piping circuit of the liquid product generator shall be protected against excess pressure by means of pop safety valves.
AIR SEPARATOR INSTRUMENT PANEL

Description

The air separator instrument panel shall be fabricated by Air Products, Incorporated. It shall support pressure gages, liquid level gages and temperature indicators which shall serve as operating aids for the liquid oxygen generator. The instrument panel and its supports shall be fabricated of steel. Its measurements shall be approximately 30 inches long by 37 inches wide. The following instruments shall be flush mounted and readily accessible and demountable for service, if necessary.

- High Pressure Column Pressure Gages
- Low Pressure Column Pressure Gages
- High Pressure Product Pressure Gages
- Phase Separator Liquid Level Gage
- High Pressure Column Liquid Level Gages
- Low Pressure Column Liquid Level Gages
- Air Separator Temperature Indicator

ELECTRICAL CONTROL PANEL

Description

The electrical controls shall be contained within a National Electrical Manufacturers’ Association Type One enclosure, and all visual indicators and manual controls shall be flush mounted on the face of the enclosure cover. The electrical controls shall consist of the following: power distribution circuit breakers, an indoor switchgear unit complete with alternating current voltmeter, ammeter, current transformer, and all controls necessary for alternating-current generator operation.

INSULATION

Description

The fiberglass insulation for the air separator shall be Owens-Corning Fiberglass Corporation Basic Fiber No. 26, Type E.
### SECTION V

**GENERATOR MASTER VALVE AND TEMPERATURE INDEX**

For identification and reference purposes, the Generator valves and temperature indicators shall be assigned letter-and-number symbols. Insofar as possible, the letter in each valve symbol shall be the initial of the fluid normally controlled by the valve. The letters in each temperature indicator symbol shall denote the type of instrument used to determine the temperature. Temperature indicators shall be either dial thermometers, or millivolt-type, direct-reading pyrometers. This system of identification has been applied in the flow diagrams of Figures 1, 2, 3 and 4.

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Names of Valves</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1-A</td>
<td>Air Expansion to Oxygen Column</td>
</tr>
<tr>
<td>A1-B</td>
<td>Air Expansion to Nitrogen Column</td>
</tr>
<tr>
<td>A7</td>
<td>Expansion-Engine Air Inlet</td>
</tr>
<tr>
<td>A10</td>
<td>First-Stage Condensate-Trap Blow-Off</td>
</tr>
<tr>
<td>A11</td>
<td>Second-Stage Condensate-Trap Blow-Off</td>
</tr>
<tr>
<td>A12</td>
<td>Third-Stage Condensate-Trap Blow-Off</td>
</tr>
<tr>
<td>A16</td>
<td>Heat Exchanger Blow-Off</td>
</tr>
<tr>
<td>A20</td>
<td>First-Stage Pressure-Gage Shut-Off</td>
</tr>
<tr>
<td>A21</td>
<td>Second-Stage Pressure-Gage Shut-Off</td>
</tr>
<tr>
<td>A22</td>
<td>Third-Stage Pressure-Gage Shut-Off</td>
</tr>
<tr>
<td>A26</td>
<td>Air Flow Control</td>
</tr>
<tr>
<td>A30</td>
<td>Main-Air Shut-Off</td>
</tr>
<tr>
<td>A54</td>
<td>High-Pressure Blow-Down</td>
</tr>
<tr>
<td>A61</td>
<td>Moisture Accumulator Tank Drain</td>
</tr>
<tr>
<td>A84</td>
<td>Expansion-Engine Inlet Blow-Off</td>
</tr>
<tr>
<td>A82-A</td>
<td>Dry-Supply-Air Shut-Off</td>
</tr>
<tr>
<td>A86-B</td>
<td>Wet-Supply-Air Shut-Off</td>
</tr>
<tr>
<td>A106</td>
<td>High-Pressure-Air Exchanger Bypass</td>
</tr>
<tr>
<td>A103</td>
<td>Defrost-Air Exchanger Bypass</td>
</tr>
<tr>
<td>A106</td>
<td>Defrost-Air Exchanger Bypass Shut-Off</td>
</tr>
<tr>
<td>A107</td>
<td>High-Pressure-Air Leak Vent</td>
</tr>
<tr>
<td>A110</td>
<td>Exchanger Bypass</td>
</tr>
<tr>
<td>A111</td>
<td>Aftercooler Bypass</td>
</tr>
<tr>
<td>A128</td>
<td>Supply-Air Pressure Regulator</td>
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<tr>
<td>A129</td>
<td>Supply-Air Reservoir Drain</td>
</tr>
<tr>
<td>A130</td>
<td>Expander Discharge Column Feed</td>
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**OXYGEN VALVES**

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Names of Valves</th>
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<tbody>
<tr>
<td>01</td>
<td>Crude Oxygen Expansion</td>
</tr>
<tr>
<td>07</td>
<td>Oxygen-Pump Feed Control</td>
</tr>
<tr>
<td>010</td>
<td>Pure-Oxygen Test</td>
</tr>
<tr>
<td>014-A</td>
<td>Low-Pressure-Oxygen-Column Defrost</td>
</tr>
<tr>
<td>014-B</td>
<td>Low-Pressure-Nitrogen-Column Defrost</td>
</tr>
<tr>
<td>020</td>
<td>Low-Pressure-Column Gage Shut-Off</td>
</tr>
</tbody>
</table>
NITROGEN VALVES

N1-A
Oxygen-Column Crude Oxygen Expansion Valve
N1-B
Nitrogen-Column Crude-Nitrogen Expansion Valve
N1.2
Noncondensible-Gas Blow-Off
N1.3
Exchanger Defrost Outlet
N1.4-A
High-Pressure-Oxygen-Column Defrost
N1.4-B
High-Pressure-Nitrogen-Column Defrost
N1.5
Air-Separator-Jacket Nitrogen Feed
N20
High-Pressure-Column Gas Shut-Off
N30
Noncondensible-Gas Shut-Off
N37
Pump-Nitrogen Feed Control
N56
Oxygen-Pump Defrost Inlet
N83
High-Pressure-Nitrogen-Gas Shut-Off
N104
Hydrocarbon-Adsorber Defrost Inlet
N105
Hydrocarbon-Adsorber Defrost Outlet
N106
Expander Defrost Inlet
N108
Crude-Nitrogen Upper Liquid-Level-Gage Shut-Off
N109
Crude-Nitrogen Lower Liquid-Level-Gage Shut-Off
N110
Crude-Nitrogen Upper Liquid-Level-Gage Vent
N111
Crude-Nitrogen Lower Liquid-Level-Gage Vent
N112
Crude-Nitrogen Liquid-Level-Gage Equalizer
N117
Nitrogen-Column Noncondensible-Gas Shut-Off
N127
High Purity Nitrogen Post
N137
Pure-Nitrogen Subcooler Inlet
N142
Pure-Nitrogen Column Pressure Gage Shut-Off
N146
Nitrogen Pump Defrost Inlet
N151
Nitrogen Condenser Upper Liquid-Level-Gage Inlet
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>N152</td>
<td>Nitrogen Condenser Lower Liquid-Level-Gage Inlet</td>
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<tr>
<td>N153</td>
<td>Nitrogen Condenser Upper Liquid-Level-Gage Vent</td>
</tr>
<tr>
<td>N154</td>
<td>Nitrogen Condenser Lower Liquid-Level-Gage Vent</td>
</tr>
<tr>
<td>N155</td>
<td>Nitrogen Condenser Liquid-Level-Gage Equalizer</td>
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</tbody>
</table>

Symbols

**Temperatures Indicated**

**THERMOMETER TEMPERATURES**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>TH1</td>
<td>Air Leaving First-Stage-Intercooler of Air-Compressor</td>
</tr>
<tr>
<td>TH2</td>
<td>Air Leaving Second-Stage-Intercooler of Air-Compressor</td>
</tr>
<tr>
<td>TH3</td>
<td>Air Leaving Third-Stage-Aftercooler of Air-Compressor</td>
</tr>
<tr>
<td>TH4</td>
<td>Air Leaving Oxygen-Vaporiser</td>
</tr>
<tr>
<td>TH5</td>
<td>Gaseous Product Leaving Vaporiser</td>
</tr>
</tbody>
</table>

**GENERATOR MASTHER VALVE AND TEMPERATURE INDEX**

Symbols

**Temperatures Indicated**

**THERMOMETER INDICATED TEMPERATURES**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Air Entering (Air Leaving) Warm-Heat-Exchanger</td>
</tr>
<tr>
<td>T2</td>
<td>Air Entering (Air Entering) Warm-Heat-Exchanger</td>
</tr>
<tr>
<td>T3</td>
<td>Air Entering (Air Entering) Cold-Heat-Exchanger</td>
</tr>
<tr>
<td>T4</td>
<td>Air Entering (Air Entering) Cold-Heat-Exchanger</td>
</tr>
<tr>
<td>T5</td>
<td>Nitrogen-Mixin-Air Entering Turbo-Generator</td>
</tr>
<tr>
<td>T6</td>
<td>Nitrogen-Mixin-Air Entering Turbine-Generator</td>
</tr>
<tr>
<td>T7</td>
<td>Nitrogen-Mixin-Air Entering Air Liquidifier</td>
</tr>
<tr>
<td>T8</td>
<td>Pure-Liquid-Oxygen Entering Liquid-Oxygen-Pre-cooler</td>
</tr>
<tr>
<td>T9</td>
<td>Pure-Liquid-Oxygen Entering Liquid-Oxygen-Pre-cooler</td>
</tr>
<tr>
<td>T10</td>
<td>Dehumidified Air Entering Air Liquidifier</td>
</tr>
<tr>
<td>T1.1</td>
<td>Dehumidified Air Entering Air Liquidifier</td>
</tr>
<tr>
<td>T1.2</td>
<td>Dehumidified Air Entering Air Liquidifier</td>
</tr>
<tr>
<td>T1.3</td>
<td>Dehumidified Air Entering Air Liquidifier</td>
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</tbody>
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