AD-A086 534 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH F/G 21/9.2
USE OF CHANNELS WITH POROUS WALLS FOR STUDYING FLOWS WHICH OCCU--ETC(U)
MAR 80 V I YAGODKIN
UNCLASSIFIED FTD-ID(RS)T-0323-80 NL

FTD-ID(RS)T-0323-80

FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

USE OF CHANNELS WITH POROUS WALLS FOR STUDYING FLOWS WHICH OCCUR DURING COMBUSTION OF SOLID PROPELLANTS

by

V. I. Yagodkin

FOREIGN TECHNOLOGY DIVISION

FTD-ID(RS)T-0323-80

EDITED TRANSLATION

(11) 5 Mar 80

(14) FTD-ID(RS)T-0323-80 5 March 1980

MICROFICHE NR: FTD-80-C-000713

(6) USE OF CHANNELS WITH POROUS WALLS FOR STUDYING FLOWS WHICH OCCUR DURING COMBUSTION OF SOLID PROPELLANTS,

By (10) V. I. Yagodkin (12) 12

English pages: 12

(21) Edited trans. of Proceedings from

Source: International Astronautical Federation, International Astronautical Congress (USSR) n18 v3

[redacted] Belgrade, Yugoslavia [redacted]r

[redacted] 196[redacted] Proceedings [redacted]

Vol[redacted] Propulsion and Re-entry, 1968 [redacted] p69-79. 1967, by

Country of origin: USSR
Translated by: SSgt Martin J. Folan.
Requester: PHE
Approved for public release; distribution unlimited.

141600

slt

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

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

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

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

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

Russian	English
rot	curl
lg	log

USE OF CHANNELS WITH POROUS WALLS FOR STUDYING FLOWS WHICH OCCUR DURING COMBUSTION OF SOLID PROPELLANTS

V. I. Yagodkin, Academy of Sciences USSR, Moscow

1

The laws of gas flows in a channel of burning charge of solid propellant is of great interest for internal ballistics. The rate of burning of fuel depends not only on its physical-chemical properties, but also on the conditions of gas flow - laminar or turbulent, and also on the characteristics of turbulence near the fuel's surface. An increase in the speed of the gas along the burning surface above some threshold value leads to an increase in the speed of burning of fuel. This effect, called erosion, is connected, in the majority of cases, with an increase in the convective flow of heat to the fuels surface. We propose that in charges of simple form, the presence of a threshold speed is explained by the phenomenon of transition from a laminar mode of flow to turbulent. Although, in view of experimental difficulties, this transition has not been studied under burning-charge conditions, this proposition was refuted on the basis of the fact that the value of threshold Reynolds number is 10-100 times greater than the Reynolds number for transition in tubes. In the solution to this problem, much aid can be rendered by simulating the flow and combustion which occur in the charge channel by using the channels with porous walls.

Experimental works devoted to the study of flows in channels with porous walls are very rare. In the works of J. Taylor [1] and V. Veydzhman and F. Gevar [2] they acquired support for the generality of distribution of speed in tubes with porous walls with one closed end in connection with the theoretical solution of A. Berman [3] for a laminar flow of viscous liquid. The theoretical distribution of the axial component of speed has the form:

$$\frac{u}{v} = \cos \frac{\pi}{2} \left(\frac{r}{a}\right)^2$$

where a - radius of the tube, v - speed on its axis (v~x with blowing of gas through the wall with a constant speed v_0). This relationship is valid for high values of Reynolds blowing number $Re_0=av_0/\nu$ and is a good approximation with $Re_0>100$.
Turbulent flows were studied by R. Olson and Ye. Ekkert [4] with the feed of gas not only through the wall but also through one end of the tube. It was established that this flow strongly differs from a flow formed only by blowing through the wall.

2

In the present work we have continued the experiments which were recalled earlier in articles [5,6]. Their purpose was to determine the transition from a laminar mode of flow to turbulent and the characteristics of turbulence in porous tubes with the feed of gas through the wall. Some tests were done also with suction and blowing through the leading end of the tube which is closed by a porous head. We used tubes made from various materials (graphite, metal, ceramics), with diameters from 30 to 90 mm and with a length of up to 1 m, with different thicknesses of the walls and with dimensions of the pores from 10 to 60 um. Measurements were done with the aid of a thermoanemometer with a constant temperature of the filament, which had a diameter of 12 μm and a length of 1.5 mm. The sound of the thermoanemometer was introduced into the flow through the tube with an internal diameter of 2.6 mm, glued to the wall of the porous tube (Figure 1). Tests were done with a pressure within the tube from 0.2 to 1 atm.

In these experiments we acquired the following results:

1) With an increase in consumption of gas through the wall of the tube, i.e. with an increase in the value of the Reynolds blowing number Re_0, greater than some value, with a fixed distance x the sound from the closed end of the tube, there occurred in the flow fluctuations of speed directly in its entire cross section. The maximum amplitude of the fluctuations was found at a distance of approximately 0.2 radius of the tube from the wall. In tubes with sufficiently fine and uniformly distributed pores, these fluctuations first had a periodic character (Figure 2).

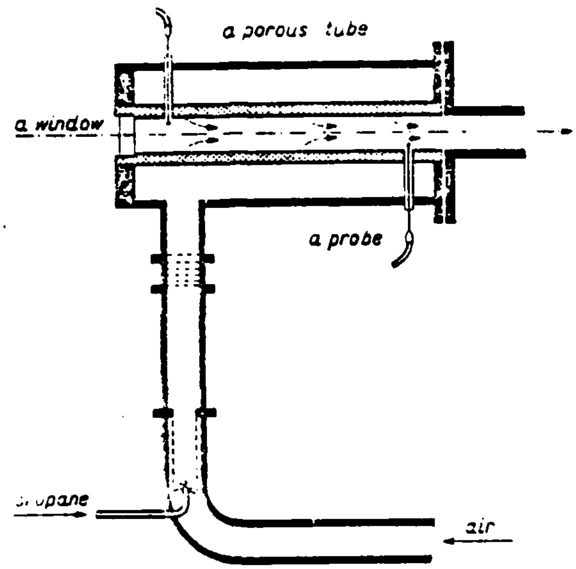

Figure 1. Schematic of the device.

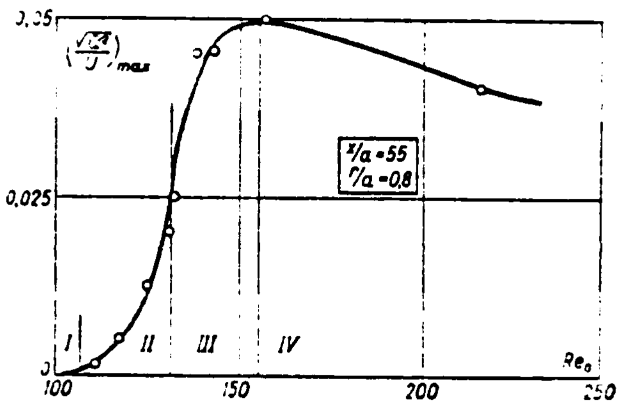

Figure 3. Mean-square values of fluctuations of speed in transition zone.

This circumstance positively showed the fact that the transition was connected with the hydrodynamic stability of the flow. Figure 3 constructs the dependence of the mean-square value of pulsations of the longitudinal component of speed on the Reynold's blowing number. The graph notes the zones of laminar flow (I), periodic fluctuations (II), intermittance of the periodic and turbulent fluctuations (III) and turbulent pulsations (IV).

The distribution along the radius of the tube of the mean-square and instantaneous values of amplitude of periodic fluctuations of speed are shown in Figures 4 and 4a. These fluctuations occur in some relatively narrow layer which, in connection with the theory of hydrodynamic stability, can be called critical. The frequency of the pre-transition periodic fluctuations changed with a change in the length of the tube and pressure so that the Strukhal number $Sh_0=af/v_0$ remained constant and equalled 11 with a change in the Reynold's blowing number from 100 to 300.

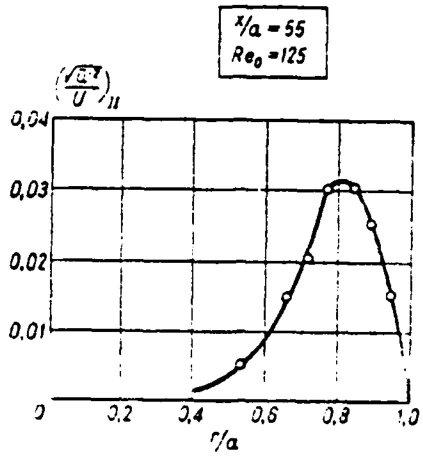

Figure 4. Mean-square values of periodic speed fluctuations in the critical layer.

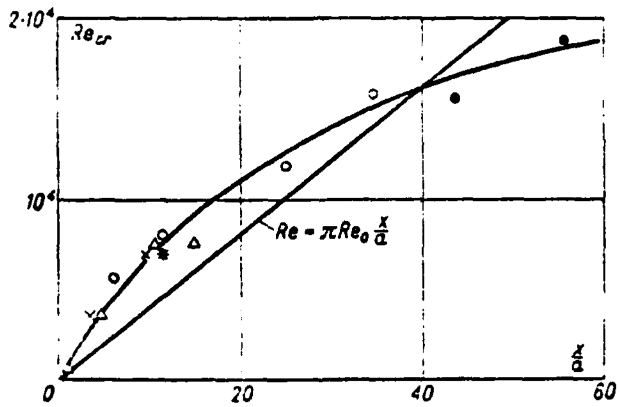

Figure 5. Dependence of critical Reynold's number on tube's length.

2). We determined the critical value of the Reynold's number of the axial flow $Re=av/\nu$, which corresponds to the beginning of the occurrence of speed fluctuations. Measurements which were conducted in different tubes showed that this value depends on the dimensionless coordinate of transition point x/a. The critical value of the Reynold's number of flow grew together with a growth in the coordinate and reached a value of ~20,000 with x/a=55 (Figure 5).

If we accept, according to A. Berman's theory, a general distribution of speeds along the tube's radius, then from the equation of consumption we can acquire a dependence of the Reynold's flow number on the coordinate x and the Reynold's blowing number:

$$Re = \pi Re_0 \frac{x}{a}$$

with the condition that $Re_0>100$. Using this dependence, we can acquire a coordinate of the beginning of transition x_{cr}/a as a function of only the Reynold's blowing number (Figure 6). Let us note that this conclusion also follows from the theory of dimensionality.

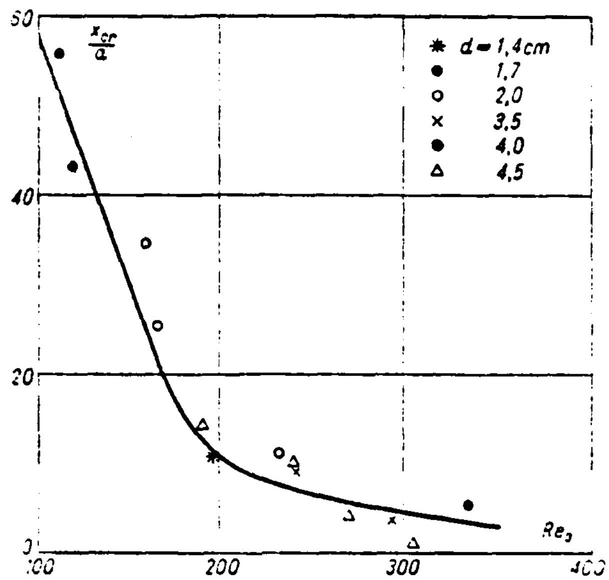

Figure 6. Dependence of point of beginning of transition on the Reynold's blowing number.

A strong influence of the Reynold's blowing number on the stability of flow is determined, apparently, by the presence of the transverse component of flow speed, which is not considered in the theory of stability of parallel flows. At small lengths we also see as possible the influence of vortical zones near the channel's head. Recently, V. N. Varapayev, upon our request, accomplished an estimate of the flow in the first part of a planar channel with porous walls. With $Re_0>50$ alongside the head of the channel, there are actually formed two stationary vortices (Figure 7). They influence flow on a length equal, approximately, to the width of the channel (Figure 8). At a greater length, a general distribution of speeds is established.

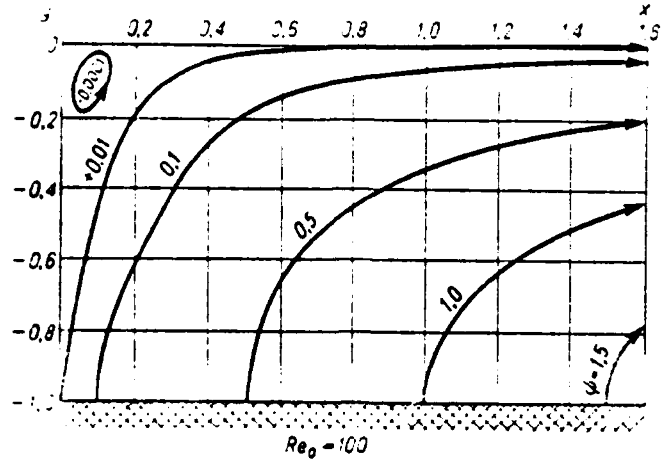

Figure 7. Lines of flow in planar channel with permeable walls.

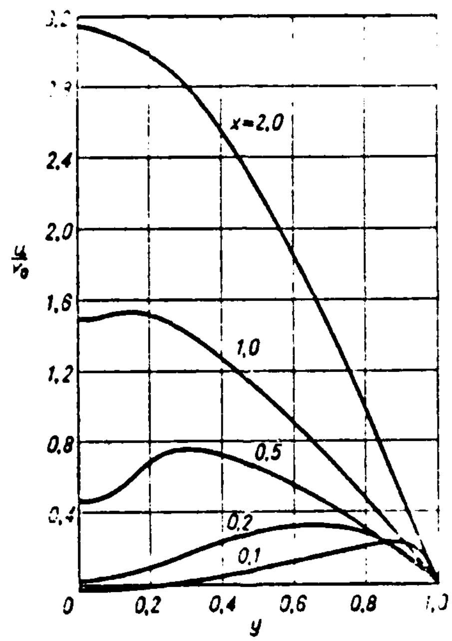

Figure 8. Distribution of speeds in first part of the planar channel.

3) After transition to a turbulent mode, the distribution along the radius of the mean speed remained near the distribution in the laminar flow (Figure 9). It is known that in tubes with impermeable walls, there occurs during transition a sudden filling of the Poiseuille distribution in speed. This difference attests to a different character of distribution of pulsation speed and Reynold's stresses in channels with porous walls.

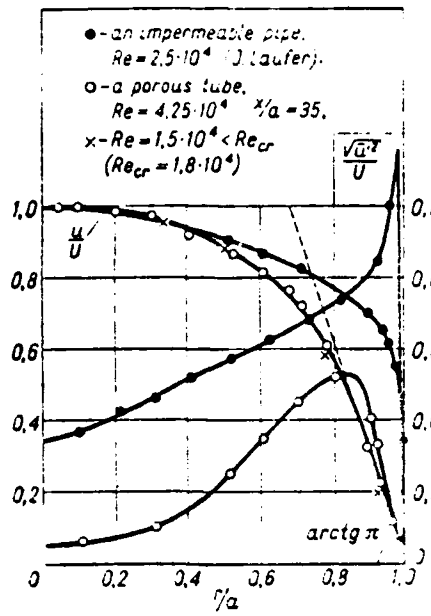

Figure 9. Distribution of mean and pulsation speeds in tubes with porous and impermeable walls.

The mean-square value of pulsations of the longitudinal component of speed in the turbulent mode proved to be substantially lower than in tubes with impermeable walls with the same values of Reynold's number and relative length of the tube. For a comparison, Figure 9 also presents the results of measurements of J. Laufer [7]. We should point out the particularly large difference of values of pulsation speeds near the axis and wall of the tube.

4) With the feed of gas through the front end of the tube which is closed by a porous head, it was shown that the transition was accomplished with lower values of the Reynold's blowing number Re_0 (Fig. 10). Conversely, with suction through the head the Reynold's blowing number, which corresponds to the beginning of the transition, increased 1.5 times in the tube with a relative length of x/a=11.4. The basic reasonf for this growth can be considered the removal of vortical zones in the tube's head.

3

In the second part of the work, we studied the distribution of the front of a flame in a uniform propane-air mixture fed within the tube through the porous wall (Fig. 1). In the tests we determined the position and form of the flame front with the aid of ionization sounding and photographing through a quartz window which served as the channel head.

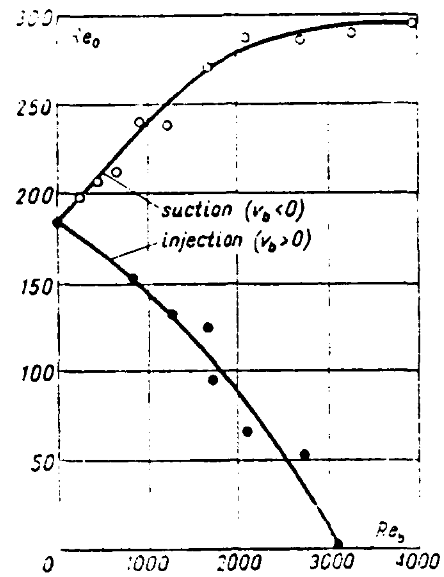

Figure 10. Dependence of Reynold's blowing number through the wall with transition on the Reynold's number of flow through the wall's head.

We found two wave modes of propogation of the flame: with tangential waves in the form of longitudinal grooves (Figure 11a) and with longitudinal waves in the form of rings (Figure 11b). The tangential waves which were observed at great distances from the flame front to the wall were stationary, and for mixtures with a richer composition - running along the perimeter of the flame. The longitudinal waves proved to be stationary, since an oscillogram of the ionization current I_s showed periodic fluctuations, and the angular lines on the flame were immobile. Pictures of this form of fluctuations in Figure 11b were obtained in a tube made of graphite with a diameter of 90 mm with a low content in fuel mixture. The frequency of fluctuations was f=60 Hz, and wavelenth - λ=2 cm.

In this place, along the length of the tube where the longitudinal fluctuations are found, the heat transfer to the wall increased. The transition to a turbulent mode, determined by the oscillogram of the ionization flow, occured with a Reynold's flow number of Re_r= $a v/\nu$, (ν, coefficient of kinematic viscosity of combustion products) is less the further the front of the flame is positioned from the tube's wall. In this case, the flow is less stable than isothermic.

Similar phenomena of instability of flame, probably, are possible with combustion of solid fuels in narrow channels. Here, the speed of erosion combustion can become anomally larger if the width of the reaction zone in the gas phase is more than 0.2 of the radius of the channel.

With an approximation of flame to wall, it takes a cylindrical form and remained laminar with the same or another greater value of Reynolds flow number than for an isothermic flow.

Instability of a cylindrical form of the flame front toward bends follows from the Landau-Markshteyn theory. If in this theory we consider the cooling influence of the wall, we can say that upon nearing the wall th- flame becomes stable for all wavelengths. An unstable flame in the form of stationary longitudinal waves with a periodic mode over time is not explained by this theory. In this case, we propose that the flame amplifies the pre-transition fluctuations when it is found in critical layer.

The stabilizing influence of flame on flow, when it is found near the wall, is possible due to the effect which was studied by L. Liz [8] in the problem of stability of the boundary layer on a cooled surface. Similar distributions of density are established along the surface of a solid fuel, as a result of which the threshold Reynolds number is 5 - 10 times greater than the critical Reynolds isothermic-flow number.

In conclusion, let us note that some researchers of erosion combustion [9, 10] acquired threshold-speed values that were too low. From positions of the hydrodynamic theory of stability, this is explained by the fact that in their experiments, a flow of ext-aneous gas was fed into the charge channel, which also caused early transition to turbulence.

In this case, the flow was not general along the length of the charge. From the theoretical work of Tszui [11], we can conclude a general distribution of speed and temperature in the charge, the flow in which is formed only as a result of its combustion.

For creating a theory of erosion combustion, we must further study the characteristics of turbulence of flows in channels with porous walls. The use of normal laws for inpermeable tubes or a boundary layer cannot be considered justified.

Bibliography

[1] TAYLOR, G., *Proc. Roy. Soc.* **234**, No. 1199 (1956)
[2] WAGEMAN, W. E., GUEVARA, F. A., *Phys. Fluids* 3, No. 6 (1960)
[3] BERMAN, A. S., *J. Appl. Phys.* **24**, No. 24 (1953)
[4] OLSON, R. M., ECKERT, E. R. G., *J. Appl. Mech., Trans. ASME*, Ser. E, No. 1 (1961)
[5] Ягодкин, В. И., *ПММ*, т. XXIV, в. 5, (1960)
[6] Ягодкин В. И., *Инж. Журнал*, № 3, (1961)
[7] LAUFER, J., NACA, Rep. No. 1174 (1954)
[8] LEES, L., NACA, Rep. No. 876 (1947)
[9] LENOIR, J., ROBILLARD, G., Sixth Symposium on Combustion, 1957
[10] MARKLUND, T., LAKE, A., *ARS J.* 30, No. 2 (1960)
[11] TSUJI, H., Ninth Symposium on Combustion, 1963

8