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Summary of Paper:

1. Hydraulic Resistance of Columns Packed with a Granulated Catalyst, BA Zakharov and AV Frost, Izvestiya Akademii Nauk, SSSR, Otdelenie Tekhnicheskikh Nauk, 1946, 421-39 constitutes a discussion of the Chilton-Colburn and Zhavoronkov formulae used for the determination of the hydraulic resistance of a tower packed with catalyst, and derivation of a third formula for the same purpose, which is held by the authors to be more advantageous than the other two.

General Evaluation:

2. The type of operation and the catalysts referred to in this article are those frequently employed in the refining industry, thus making the discussion pertinent. This is a mathematical discussion and only after a thorough study of the mathematics involved and perhaps also after verification of the experimental data given could an evaluation of the importance of this contribution be made. [redacted] the work is well done.

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3. [redacted]ct.

Other Comments:

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4. AV Frost, the second of these authors [redacted] He has previously published a considerable amount of good research on thermodynamics and related subjects. He must be regarded as a reliable research worker.

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Petroleum Technology

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August 26, 1949
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HYDRAULIC RESISTANCE OF COLUMNS PACKED WITH A GRANULATED CATALYST

B. A. Zakharov and A. V. Frost

(Institute of Mineral Fuels,
Academy of Sciences, USSR)

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IZVESTIYA AKADEMII NAUK SSSR,
OTDELENIE TEKHNICHESKIKH NAUK
(Bulletin de l'Academie des
Sciences URSS, Classe des Sciences
Techniques)
1946, 421 - 39

This is a complete translation of the original article.

CONCLUSIONS

1. The formula of Chilton and Colburn gives too low values for the dependence of the hydraulic resistance upon the average grain size and the linear rate of flow of the gas, and gives incorrect values for the dependence of the hydraulic resistance upon the diameter of the column; this formula is unsuitable for calculation of the hydraulic resistance of a column packed with a granulated catalyst.

2. The formula of Zhavoronkov, based on an analysis of extensive experimental material is suitable for calculations, but does not directly indicate the effect upon the hydraulic resistance of the grain size of the catalyst and the diameter of the column.

3. An equation is suggested which is based on the formula of Zhavoronkov and is suitable for the calculation of the performance of a catalytic column; it characterizes the hydraulic resistance of the column with respect to three elements, i.e., gas flow (linear velocity, density, kinematic viscosity of the gas); granulated catalyst (average grain diameter); dimensions of the column (altitude, diameter).

In many branches of the chemical industry, especially those in which heterogeneous catalytic and adsorption phenomena are made use of, as well as in the fuel and petroleum technology, the value of the hydraulic resistance exerted by a layer or contact column packed with granulated material is important. It is possible to estimate and to compare the hydraulic resistance exerted by the walls of a catalytic tower, the surface of the granules of the packing and the entire column, as well as to determine the extent of the effect upon the hydraulic resistance of the average diameter of the grains of the catalyst, the diameter of the column and the linear velocity of the gas.

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Hydraulic Resistance of Empty Towers

The hydraulic resistance of catalytic columns without the packing can be calculated by the formula of d'Arcy

$$\Delta p = \frac{\Delta 1 \rho \overline{w}^2 G}{2d} , \qquad /1/$$

where Δp is the loss of pressure in kg./sq.m., ρ is the density of the gas in kg. sec.^{2}/m^4, $\overline{w}$ is the average linear velocity of the gas in m./sec, $\Delta 1$ is the length and d the diameter of the column in meters, G the coefficient of resistance, depending upon the Reynolds number $Re_d = \overline{w}d/\gamma$, in which γ is the coefficient of the kinematic viscosity in sq. m./sec.

For a streamline flow (Re_d less than 2,320)

$$G = \frac{64}{Re_d} \qquad /1a/$$

while for a turbulent flow (Re_d more than 2,320) the coefficient of resistance can be expressed, depending upon the Reynolds number, as follows:
At Re_d from 3,000 to 100,000, according to the law of Blasius

$$G = \frac{0.3164}{Re_d^{0.25}} \qquad /2/$$

At Re_d from 10^5 to 3×10^6, the formula given by Nikuradze can be made use of:

$$G = 0.0032 + \frac{0.221}{Re_d^{0.237}} \qquad /3/$$

To determine the order of magnitude of the hydraulic resistance of a contact column without a catalyst, comparative calculations were carried out by the authors. Air served as the viscous medium and its temperature was 15 and 500°. The column consisted of a single tube or identical tubes (for instance, 180 tubes per column). In one case the altitude of the column was 1 m., diameter 0.1 m. In the second case the altitude was 2.544 m., the diameter 0.2 m. The rate of flow of air by weight is connected with the linear velocity by the relationship $\varphi = 3600\ v_o s^c m \gamma$, where φ is the rate

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of flow in kg./hr., v_o linear velocity in m./sec., s^o cross sectional area of the tube in sq. m., m number of tubes in the column, and γ specific gravity of the air for the given temperature. The rate of flow so determined changed within 2.28 and 18,304 kg./hr. The physical parameters for air given by Kirpichev et al (1) were used. The results of the calculations for an empty column are shown in Table 1 for given conditions of performance of this column. This table shows that the resistance of the column walls to the gas flow is quite small as compared to that exerted by the surface of the catalyst grains.

Hydraulic Resistance of Packed Columns

On the basis of analysis of experimental data, Chilton and Colburn suggested (2) a formula for the calculation of the hydraulic resistance of columns packed with granulated material. Perry gives (3) this formula in the metric system as follows:

$$\triangle p = \frac{202 f^o c v_o^2 L}{D_g} \qquad /4/$$

In this formula $\triangle p$ is the pressure drop in kg./sq. m. due to the hydraulic resistance, v_o the linear velocity in m./sec., through the tube, L the thickness of the layer of packing in meters, D_g average diameter of a grain of the packing in mm., f^o the resistance coefficient depending upon the modified Reynolds number $Re' = D_p v_o \gamma / z$, in which γ is the specific gravity of the gas in kg./cu. m., and z is the coefficient of viscosity in centipoises: $z = \mu g$. Here μ is the coefficient of viscosity in kg. sec./sq. m., g acceleration due to gravity in m./sec.^{2}, c a factor which is a function of the ratio D_p/D_{tube}; D_p is the average diameter of the particle in meters, defined as a mean arithmetical value of three sizes, while D_{tube} is the diameter of the tube in meters.

A calculation of c and f^o is quite difficult and inexact if attempted graphically. For this reason mathematical expressions were derived by the authors for the dependencies $f^o = f(Re')$ and $c = f(\frac{D_p}{D_{tube}})$, based on the graphs given by Perry.

Fig. 1 shows two curves characterizing the first of these dependencies. Curve 1 refers to streamline conditions, while curve 2 refers to turbulent conditions. The critical value of the Re' number is 44.1 The points on the curves give values found from this graph, and the curves correspond to the obtained equations. For the streamline flow (Re' less than 44.1)

$$f^o_{str} = \frac{912}{Re'}; \qquad /5/$$

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for turbulent flow (Re' more than 44.1)

$$f_t^o = \frac{30.2}{Re'^{0.1}} \qquad /6/$$

Fig. 2 shows two curves for the dependence $c = f\,(D_p/D_{tube})$. The points on the curve also indicate values graphically found and the curves correspond to equations obtained. The curves for both conditions consist of two parts described by different equations. The critical value, again D_p/D_{tube}, is 0.037. For streamline flow (curve 1) the following are valid: For D_p/D_{tube} less than 0.037

$$c_{str} = \frac{0.838}{\left(\frac{D_p}{D_{tube}}\right)^{0.03384}} \qquad /7/$$

and when this ratio is more than 0.037

$$c_{str} = \frac{0.604}{\left(\frac{D_p}{D_{tube}}\right)^{0.1327}} \qquad /8/$$

For the turbulent flow (curve 2) the case of D_p/D_{tube} less than 0.037 is represented by equation

$$c_t = \frac{0.732}{\left(\frac{D_p}{D_{tube}}\right)^{0.0578}} \qquad /9/$$

while, when the value of D_p/D_{tube} is more than 0.037

$$c_t = \frac{0.424}{\left(\frac{D_p}{D_{tube}}\right)^{0.22}} \qquad /10/$$

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In 1944 Zhavoronkov published (4) a study of the hydraulic resistance of scrubbers packed with solid granulated material, which constitutes a part of his doctoral dissertation (5). The experimental data are generalized as follows:

$$\triangle p = \frac{2f' \rho v_o^2 H}{D_e v_{free}^2} \qquad /11/$$

where $\triangle p$ is the hydraulic resistance in kg./sq. m.; v_o is linear velocity in m./sec., calculated for the complete cross section of the empty tube; H, altitude of the packed tube in meters; ρ density of the air in kg. sec^2/m.^{4}; f', coefficient of resistance which depends upon the Reynolds number

$$Re = \frac{d_e v_o}{\gamma v_{free}}$$

γ being the coefficient of kinematic viscosity in sq. m./sec., d_e the equivalent diameter of the tube in meters, v_{free} the free volume of the packing. For streamline flow at values of the Reynolds number less than 40 to 50, $f' = 100/Re$. For an unstable turbulent flow within the Reynolds numbers from 50 - 5,000, $f' = 3.8\ Re^{-0.2}$ and, finally, for a stable turbulent flow at Reynolds numbers above 5,000, f' will be independent of Re and amount to 0.7

$$d_e = \frac{4V_{tube} v_{free}}{s_{tube}}$$

where V_{tube} is the volume of the packed tube in cubic meters, s_{tube} the total surface which exerts the hydraulic resistance, square meters, i.e., $s' + s''$. Here s' is the surface of the granules of the packing and s'' the surface of the wall of the tube.

For a cylindrical tube

$$s'' = \pi D_{tube} H, \qquad s' = s_3 n \qquad n = \frac{(1 - v_{free})\ V_{tube}}{v_3}$$

where n is the number of particles in the packing, s_3 and v_3 are the average surface and the average volume of a granule of the packing, respectively. For calculation of the hydraulic resistance of the packed contact

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column by the Zhavoronkov formula, it is necessary to determine experimentally the values of n, s_3, v_{free}, in addition to knowing the values of the basic parameters of the column and of the gas stream.

By correlation of the values of the free volume, experimentally determined by Zhavoronkov and by the present authors for different granulated packings (Table 2), with the value of the average grain size, the dependence shown in Fig. 3 was established.

In Fig. 3 points on the curve correspond to experimentally determined values of the free space of the catalyst bed and the average particle diameter, and the curve is represented by

$$v_{free} = 0.222D_g^{0.252} \qquad /12/$$

Dependence of the Hydraulic Resistance of a Column Upon the Average Diameter of the Catalyst Grain

It is quite important to find whether there is any interdependence between the hydraulic resistance of the contact column and the average diameter of the grain size. For this purpose calculations were carried out by the authors, using the formulas of Chilton and Colburn and of Zhavoronkov, respectively. A particular case was considered under the following conditions: Diameter of the column, 0.2 m; altitude, 2.544 m.; air temperature, 500°; linear velocity of the air in the streamline flow region, 0.068; that under turbulent conditions, 1 m./sec.; $\rho = 0.0459$ kg. sec.^{2}/m.^{4}; $\nu = 8.0410^{-5}$ sq. m./sec.; $\gamma = 0.45$ kg./cu. m.; $z = 0.03617$ centipoises; average grain diameter within 0.004 and 0.0127m. The catalyst was shaped into cylinders.

The results are shown in Fig. 4, where the dots represent calculated values and the curves mathematical expressions derived. Figs. 4 and 3 characterize streamline flow corresponding to the formulas of Chilton and Colburn and of Zhavoronkov. Curves 1 and 2 refer to turbulent flow and the first of these is based on the Chilton and Colburn formula, the second on the Zhavoronkov formula. For streamline flow the following expression corresponds to the Chilton and Colburn formula:

$$\triangle p_{c.c.} = \frac{0.001667}{D_p^{2.076}} \qquad /13/$$

TABLE 1. HYDRAULIC RESISTANCE OF CATALYTIC TOWERS WITHOUT THE CATALYST AND WITH IT

No.	Temp., °C.	Dimensions of the tube, m.		Rate of flow of the air		Number of tubes in the tower	Character of the flow	Δp, pressure drop		
		Diameter D_{tube}	Altitude Δl (H)	Q, kg./hr.	$w(v_0)$, m./sec.			In the empty column: According to d'Arcy, Blasius, Nikuradze	In the empty column: According to Zhavoronkov	According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
1	15	0,1	1	2,28	0,068	1	streamline	$4{,}03 \cdot 10^{-4}$	0,054	53,2
2	15	0,1	1	33,5	1	1	turbulent	0,019	35,2	219,2
3	500	0,2	2,544	3,46	0,068	1	streamline	$1{,}09 \cdot 10^{-5}$	0,07	67,6
4	500	0,2	2,544	3,46	0,0004 (0,000378)	180	»	$6{,}07 \cdot 10^{-8}$	0,07	67,6
5	500	0,2	2,544	50,9	1	1	turbulent	0,013	7,93	492,8
6	500	0,2	2,544	50,9	0,0055	180	streamline	0,004	0,01	985
7	500	0,2	2,544	18304	360	1	turbulent	446,4	$3{,}09 \cdot 10^5$	$1{,}96 \cdot 10^7$
8	500	0,2	2,544	18304	2	180	»	0,044	$4{,}85 \cdot 10^1$	$3{,}07 \cdot 10^7$

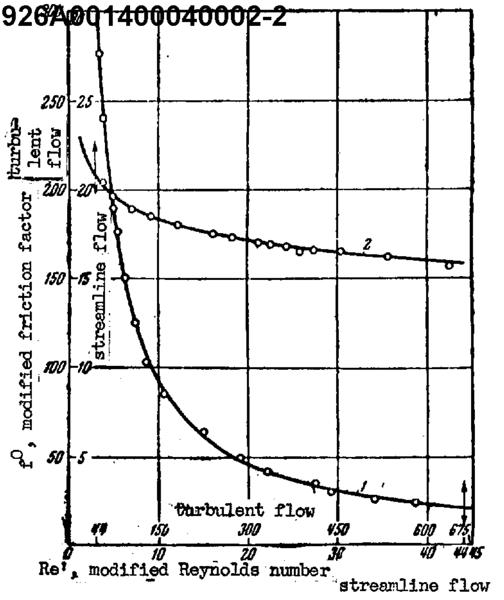

FIG. 1. DEPENDENCE OF THE MODIFIED FRICTION FACTOR f^0 UPON THE MODIFIED REYNOLDS NUMBER Re' BY THE FORMULA OF CHILTON AND COLBURN. 1 - streamline flow; 2 - turbulent flow

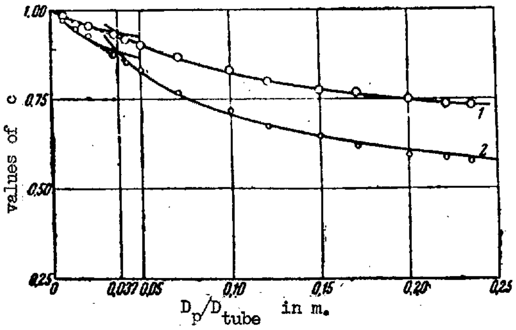

FIG. 2. DEPENDENCE OF THE COEFFICIENT OF THE EFFECT OF THE WALLS c UPON THE RATIO OF THE AVERAGE DIAMETER OF THE PARTICLES TO THE DIAMETER OF THE TUBE D_p/D_{tube} BY THE FORMULA OF CHILTON AND COLBURN. 1 - for streamline flow; 2 - for turbulent flow

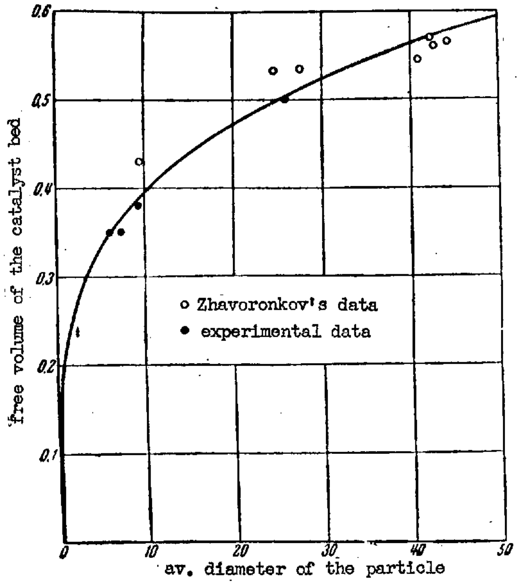

FIG. 3. DEPENDENCE OF THE FREE VOLUME OF THE CATALYST BED UPON THE AVERAGE DIAMETER OF THE PARTICLES.

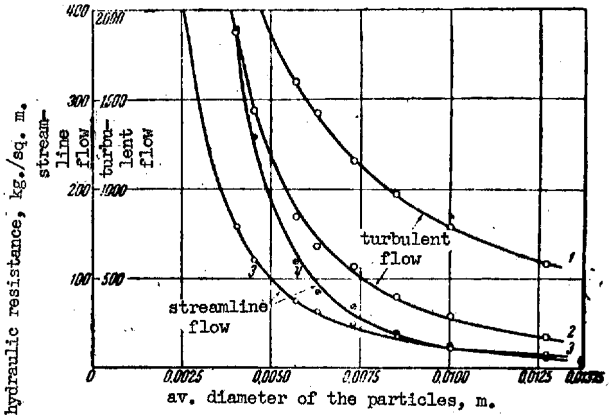

FIG. 4. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYST BED Δp UPON THE AVERAGE DIAMETER OF THE CATALYST GRAINS. For turbulent flow: 1 - according to Chilton and Colburn; 2 - according to Zhavoronkov. For streamline flow: 3 - according to Zhavoronkov; 4 - according to Chilton and Colburn.

TABLE 2. INTERDEPENDENCE BETWEEN THE FREE SPACE OF THE PACKING AND THE AVERAGE DIAMETER OF THE GRAIN

No.	Type of packing	Shape	Dimensions of the grains, mm.	Av. diameter of the grain, mm.	Free space
1*	Glass rods	Cylinders	5 × 5 × 8	6,0	0,35
2*	Aluminosilicate catalyst	Cylindrical tablets	9 × 9 × 4	7,3	0,35
3	Catalyst for conversion of CO	Tablets	11 × 11 × 6	9,3	0,38
4	Vanadium catalyst	"	11 × 11 × 6,5	9,5	0,43
5	Coke	Irregular	29,6 × 25,8 × 18	24,5	0,532
6*	Glass granules	Pear-shaped	20 × 20 × 37,5	25,8	0,500
7	Coke	Irregular	35,6 × 28,8 × 18	27,5	0,535
8	"	"	47,6 × 41,5 × 33,4	40,8	0,545
9	Gravel	Spherical	56,8 × 40,8 × 29	42,2	0,570
10	Coke	Irregular	52 × 40,3 × 35,3	42,6	0,560
11	Andesite	"	56 × 43,7 × 32,6	44,1	0,565

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* Catalyst tested in this work

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1946, 421 ff.

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The expression corresponding to the Zhavoronkov formula /11/ is given by:

$$\triangle p_{zh} = \frac{1.866 \times 10^{-5}}{D_p^{3.044}} \qquad /14/$$

The interrelationship of these expressions for small values of the average particle diameter, below 0.0065, is

$$\triangle p_{zh} = 3 \triangle p_{c.c.} - 100 \qquad /15/$$

while for values above 0.0065 it is:

$$\triangle p_{zh} = 1.49 \triangle p_{c.c.} - 9 \qquad /16/$$

For turbulent flow the following obtain:

$$\triangle p_{c.c.} = \frac{2.6}{D_p^{1.241}} \qquad /17/$$

$$\triangle p_{zh} = \frac{0.016}{D_p^{2.116}} \qquad /18/$$

The equations 17 and 18 can be combined as follows:

$$\triangle p_{zh} = 0.0038 \triangle p_{c.c.}^{1.68} \qquad /19/$$

Dependence of the Hydraulic Resistance of a Column Packed with Granulated Catalysts Upon its Diameter

Inasmuch as the basic equations under discussion show no clear connection between the hydraulic resistance of the contact column and its diameter, this problem was also considered in the study under report. The conditions and parameters of the principal hydrodynamic values were in the main the same as for the expression $\triangle p = f(D_p)$ discussed before. The difference consists in the values of D_p and D_{tube}. The average grain diameter was constant, 0.0073 meters. v_{free} was 0.359. Silica-alumina catalyst was

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used, shaped as cylindrical tablets, 9 x 9 x 4 mm. The diameter of the catalyst column, consisting of a single tube, varied from 0.04 to 0.7 meters.

Fig. 5 shows the results of the calculation for particular cases, based on the formulas of Chilton and Colburn /4/ and of Zhavoronkov /11/. The four curves shown each consist of two branches corresponding to the mathematical expressions for the dependency $\triangle p = f(D_{tube})$ for tubes with small or large diameters. The points represent values calculated by the formulas /4/ and /11/.

The formula of Chilton and Colburn for streamline conditions is represented by the curve 4. The critical value of the tube diameter is 0.162. At smaller values

$$\triangle p_{c.c.} = 2.363 D_{tube}^{0.1343} \qquad /20/$$

For cases where the diameter exceeds 0.162

$$\triangle p_{c.c.} = 1.992 D_{tube}^{0.035} \qquad /21/$$

The curve 2 is valid for the regions of turbulent flow. At values of the tube diameter below 0.2042

$$\triangle p_{c.c.} = 1663 D_{tube}^{0.221} \qquad /22/$$

and for diameters exceeding 0.2042, the relationship

$$\triangle p_{c.c.} = 1287 D_{tube}^{0.0568} \qquad /23/$$

Data pertaining to the hydraulic resistance of columns with granulated packing as a function of the column diameter obtained with the aid of the Zhavoronkov formula, are represented by the curves 3 and 1. The first of these refers to streamline conditions, the second to turbulent conditions. For tubes with a small diameter, i.e., below 0.074

$$\triangle p_{sh} = \frac{31.9}{D_{tube}^{0.3158}} \qquad /24/$$

[redacted]

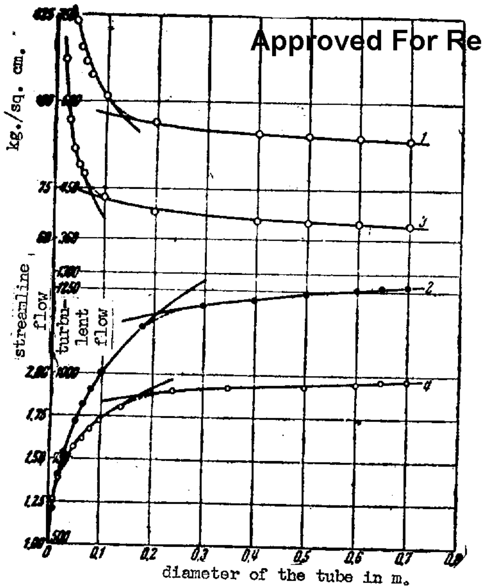

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

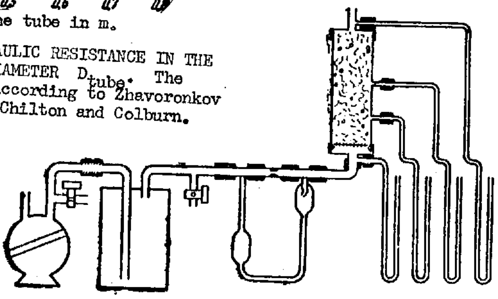

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

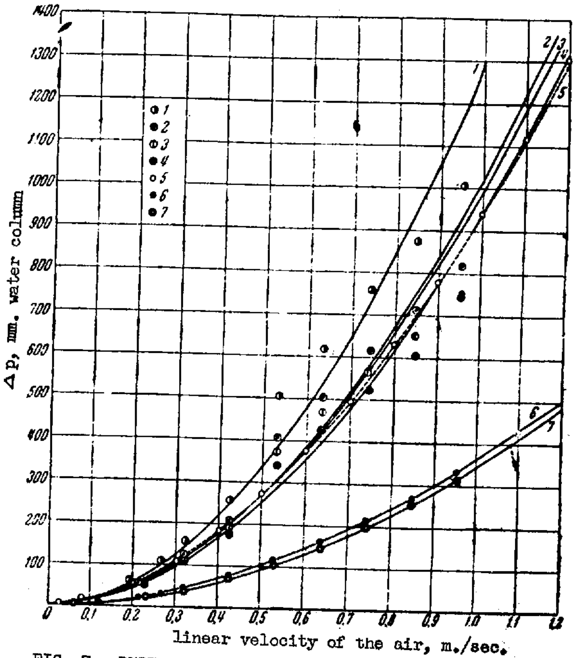

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	(2,64; 2,97) $\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	(2,22; 2,12) $\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\ \frac{1}{D_p^{0,06}}$	(0,5; 0,2)	(1,35; 1,33) $\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\ \frac{1}{D_p^{0,109}}$	(0,15; 0.09)	(1,05; 1,06) $\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for D_{tube} ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	(3,2; 3,14) $\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	$17,62\ D_p^{0,629}$	(0,017; 0,003)	(8,5)* $\frac{1}{D_{tube}^{0,268}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005—0,0073)	> 0,73	$51,33\ D_p^{0\ 13}$	(3; 0,8)	(51,9; 49) $\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	$17,6\ \frac{1}{D_p^{0,098}}$	(0,7; 0,06)	(16,6; 17,67) $\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005—0,015	0,058—0,222	$85,6\ D_p^{0,873}$	(0,05; 0,02)	(85;89) $\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0;022—0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	(165,2)* $\frac{1}{D_{tube}^{0,428}}$

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* The numerical value of K for [illegible] is c[illegible] D_p and D_{tube}

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while those with a larger diameter

$$\triangle p_{zh} = \frac{62.7}{D_{tube}^{0.056}} \qquad /25/$$

In the case of the turbulent flow (curve 1) the critical value of the diameter of the column for the conditions and parameters discussed is 0.138. For smaller diameters of the column the equation

$$\triangle p_{zh} = \frac{374}{D_{tube}^{0.211}} \qquad /26/$$

was derived, while for diameters exceeding 0.138, the equation

$$\triangle p_{zh} = \frac{525}{D_{tube}^{0.04}} \qquad /27/$$

is valid.

The mathematical expressions 20 - 27 for the determination of the effect of the diameter of the column on the hydraulic resistance, which were obtained by using the formulas of Chilton and Colburn and of Zhavoronkov are mutually related as follows (Fig. 5). For streamline flow at diameters of the tube smaller than 0.065

$$\triangle p_{zh} = -110.7 \triangle p_{c.c.} + 256.5 \qquad /28/$$

and diameters larger than 0.065

$$\triangle p_{zh} = -32.3 \triangle p_{c.c.} + 128.4 \qquad /29/$$

For turbulent flow at diameters of the tube below 0.117

$$\triangle p_{zh} = -0.7164 \triangle p_{c.c.} + 1324 \qquad /30/$$

and at diameters larger than this value, the relationship

$$\triangle p_{zh} = -0.222 \triangle p_{c.c.} + 817 \qquad /31/$$

obtains.

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Effect of Rate of Gas Flow Upon the Hydraulic Resistance of Columns Packed with Granulated Catalysts

In this work most attention was concentrated on the effect of the rate of the gas flow on the hydraulic resistance of contact columns, inasmuch as the basic formulas under discussion here contain a value representing the rate of flow and taken to the degree of 1.8 for the region of turbulent flow. This problem was subjected to additional experimental study. *

The linear velocity of the air varied in these experiments within 0.064 and 1 m./sec. Thus, the regions of streamline and turbulent flows were covered. The general appearance of the experimental unit is shown in Fig. 6. The metallic catalytic tower of 0.1 m. diameter and 1 m. height had two branches and was closed on both sides with lids with welded-on pipes. The catalyst, shaped into cylinders 9 x 9 x 4 mm. and $D_p = 0.0073$ m.; $v_{free} =$ 0.359, was charged into the tube to form a layer 1 m. thick. The vertical layer of the catalyst was supported by a thin wire metallic grating with mesh 3 x 3 mm. Four glass U-tubes served as manometers indicating the pressure at the inlet at 0.25 and 0.5 m. from the inlet and at the exit. Air was charged at 15° with the aid of a powerful blower, and in order to create a stable flow it was first passed through a large tank, then through a glass kerosene flow meter with a set of diaphragms and into the bottom of the vertical catalyst tower. All communication lines were no smaller than 20 mm. in diameter. The pressure indicated by all the manometers was registered after the air flow reached stability at a given velocity. All parts of the unit were airtight.

A set of seven curves is shown in Fig. 7, which describes the experimental data pertaining to the dependence of the hydraulic resistance of the catalyst layer 1 m. high upon the rate of flow of air and the results of calculations with the aid of the formulas /4/ and /11/ used before. **

As before, the points correspond to determined or calculated values, while the curves were drawn in accordance with the mathematical expressions derived. Curve 1 reflects the pressure drop at the inlet to the catalyst column point (pressure drop of the air stream between the inlet and 0.25 m./from the inlet). The equation for this case is:

$$\Delta p_{inlet} = 1288 v_0^{1.948} \qquad /32/$$

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* This work was carried out in 1942 in the Laboratory of Motor Fuels of the Institute of Mineral Fuels, Academy of Sciences, USSR.

** Air at 15° was considered to have $\Upsilon = 1.185$; $z = 0.018$ $\rho = 0.125$ $\nu = 1.48 \times 10^{-5}$.

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For the middle of the column (at the height of 0.5 m.)

$$\Delta p_{middle} = 1012 v_0^{1.901} \qquad /33/$$

which is represented by curve 2. The pressure drop at the exit from the catalyst column (hydraulic resistance of the layer 1 m. thick) is represented by the curve 4 based on the equation

$$\Delta p_{exit} = 935.4 v_0^{1.891} \qquad /34/$$

Curve 3 gives the average value of the hydraulic resistance

$$\Delta p_{average} = 984 v_0^{1.873} \qquad /35/$$

which is an average of the values shown by the curves 1, 2 and 4. It should be noted that the scattering of the points observed for high air velocity is connected with a certain degree of inexactness in the flow meter scale, which is built on extrapolated values. The curve 5 joins points calculated by the formula /11/ of Zhavoronkov for the experimental conditions and parameters used in this study and is described by two equations. The critical value of the rate of flow is 0.1122. For streamline conditions where v_0 is less than 0.1122

$$\Delta p_{zh} = 158.5 v_0 \qquad /36/$$

The region of turbulent flow with v_0 exceeding 0.1122 is characterized by the equation 37. Formula /4/ of Chilton and Colburn is represented by the points of the curve 6 for the conditions used here. The critical value is 0.089 m./sec. The streamline section of the curve can be expressed by the equation 38.

$$\Delta p_{zh} = 9312 v_0^{1.8} \qquad /37/$$

$$\Delta p_{c.c.} = 52.5 v_0 \qquad /38/$$

The section of the curve describing the turbulent conditions, that is, where v_0 exceeds 0.089, is described by the equation

$$\Delta p_{c.c.} = 359.7 v_0^{1.8} \qquad /39/$$

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For the sake of comparison, the curve 7 was drawn from data obtained by the Chilton and Colburn formula for the case where the average grain diameter is a cubic root of three dimensions.

The values of the pressure drop in the air flow passing through the catalytic column according to Zhavoronkov /36/ and /37/, and according to Chilton and Colburn /38/ and /39/, are connected between themselves and with the average values of the pressure drop established by the present authors /35/ as follows:

$$\triangle p_{zh} = 2.6 \triangle p_{c.c.} \qquad /40/$$

$$\triangle p_{zh} = 0.9352 \triangle p_{aver.} + 21.6 \qquad /41/$$

$$\triangle p_{c.c.} = 0.3697 \triangle p_{aver.} \qquad /42/$$

The pressure drop at the inlet /32/ and at the exit /34/ from the contact column is connected with the average value /35/ as follows:

$$\triangle p_{inlet} = 1.3 \triangle p_{aver.} \qquad /43/$$

$$\triangle p_{exit} = 0.944 \triangle p_{aver.} \qquad /44/$$

The pressure drop of the air at the inlet /32/ into the column is expressed according to Zhavoronkov /36/ and /37/ as follows:

$$\triangle p_{inlet} = 1.437 \triangle p_{zh} - 6 \qquad /45/$$

General Discussion

It is of interest to compare the values of hydraulic resistance of catalytic columns, empty as well as packed, and to appraise the effect of the number of tubes in a collector contact column upon the hydraulic resistance. The numerical values are given in Table 1. The hydraulic resistance of the empty catalytic column, as dependent upon the Reynolds number, was calculated by the formula of d'Arcy /1/ and /1a/ for streamline conditions (cases 1, 4 and 6). For turbulent conditions the law of Blasius /2/,(cases 2, 5 and 8) and the formula of Nikuradze /3/ (case 7) were made use of. Considering that the Zhavoronkov formula has two members which describe, respectively, the hydraulic resistance caused by the surface of the walls of the column and the surface of the grains of the catalyst, the question can be answered whether this formula permits a correct evaluation of the hydraulic resistance of the

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empty column. For this column the following is valid for streamline conditions:

$$\triangle p_{str.} = \frac{200 \rho \gamma v_o H}{D_{tube}^2 v_{free}^3}$$

For the turbulent region the following obtains:

$$\triangle p_t = \frac{7.6 \rho \gamma^{0.2} v_o^{1.8} H}{D_{tube}^{1.2} v_{free}^3}$$

As follows from Table 1, the hydraulic resistance of the empty catalytic tower calculated by the Zhavoronkov formula has a considerably higher value for all cases under consideration here (100 - 1,000 times), as compared with the value obtained with the aid of hydrodynamic formulas widely employed in practice. It is possible, therefore, to conclude that the hydraulic resistance of empty catalytic columns cannot be calculated from the Zhavoronkov formula. For packed catalytic columns the hydraulic resistance, as calculated from the Zhavoronkov formula, is represented in the last column of Table 1. The catalyst consisted of cylindrical tablets 9 x 9 x 4 mm., of average diameter 0.0073 m. and free volume 0.359. By correlating the values of the hydraulic resistance in the empty and catalyst-packed columns, one observes that the hydraulic resistance of the columns with the catalyst exceeds the resistance of empty columns 100,000 times or more. Hence, the hydraulic resistance to the gas flow exerted by the walls of the contact column is quite negligible.

In commercial practice catalytic columns are of a special value, made up of a bundle of tubes of the same diameter. In streamline flow and at a constant value of the weight rate of gas flow, a change in the number of tubes in a packed column of this type exerts no effect upon the resistance of the column. The linear velocity is used in the equation for hydraulic resistance in the first degree; consequently for the cases 3 and 4 in Table 1, the following will be valid:

$$\frac{\triangle p_4}{\triangle p_3} = \frac{mv_4}{v_3} = \frac{mv_4}{mv_4} = 1$$

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because $v_3 = v_4m$ (m is the number of tubes in the column). A totally different situation obtains in the regions of turbulent flow. Here the linear velocity is used in the formula in the degree of 1.8. Discussing the cases numbers 8 and 7 of Table 1, it is seen that, inasmuch as the weight rate is constant, $v_7 = mv_8$:

$$\frac{\Delta p_8}{\Delta p_7} = \frac{mv_8^{1.8}}{(mv_8)^{1.8}} = \frac{1}{m^{0.8}}$$

The hydraulic resistance of a catalytic collector column decreases in proportion to the number of tubes taken to the degree of 0.8; consequently, if the technology of the process is connected with high rates of flow by weight of the gas in the region of turbulent flow, and the value of the hydraulic resistance exerted by the catalyst or the dimensions of the column do not permit to realize these velocities in the column, consisting of a single tube, then in order to remove these hindrances a collector catalytic column should be used with a number of tubes equal to the ratio of the linear velocities for a simple and a collector column. (Thus, for the cases 7 and 8 of Table 1, $m = \frac{v_7}{v_8} = 180$).

The effect of the average grain diameter upon the hydraulic resistance is described qualitatively by the Chilton and Colburn formula /4/ and that of Zhavoronkov /11/ . The hydraulic resistance of the catalytic power drops with increase of the grain size. The Chilton and Colburn formula gives for both hydrodynamic conditions a lower drop of the hydraulic resistance of the column with increase of the average grain size, as compared to the Zhavoronkov formula. An exception is presented by some cases in the streamline region, where D_{tube}/D_p exceeds 30. Here a reverse situation obtains and the Chilton and Colburn formula shows a larger drop in the hydraulic resistance, with increase of the grain size as compared to the data given by the Zhavoronkov formula. The connection between the two formulas with respect to the dependence $\Delta p = f(D_p)$ is a straight line for streamline conditions (/15/ and /16/) and an exponential for turbulent conditions (/19/).

A very interesting result was obtained by the authors in the study of the effect of the diameter of the contact column upon the hydraulic resistance. According to equations /20/ through /27/ and Fig. 5, the two formulas show contrasting effects of the diameter of the catalytic column upon the

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hydraulic resistance. With increase of the diameter of the catalytic column the hydraulic resistance for both hydrodynamic conditions increases, according to Chilton and Colburn, but drops according to Zhavoronkov. The connection between the two formulas is straightline in character (equations /28/ through /31/).

By correlating the quantitative interpretation of the dependence of the hydraulic resistance of the catalytic columns with the granulated packing upon the linear velocity of the gas stream, average grain size and diameter of the column, as expressed by the Chilton and Colburn and Zhavoronkov formulas, the following characteristic of the Chilton and Colburn formula is obtained: In $\triangle p = f(v_o)$ considerable lowering of the values of $\triangle p$ is noted; for $\triangle p = f(D_p)$ a considerable decrease of the value of $\triangle p$ and, finally, in $\triangle p = f(D_{tube})$ a totally abnormal character of the functional dependence, as compared to conventional concepts is manifested.

Additional calculations of the dependence of the hydraulic resistance of columns packed with granulated catalyst upon average grain size of the packing and diameter of the column, which were based on the Zhavoronkov formula, made it possible to write a general formula embracing all principal factors which determine the performance of catalytic towers. These factors characterize the contact column (altitude H, diameter D_{tube}), the granulated catalyst (average grain diameter D_p) and the viscous medium N (where N is the product obtained by multiplying the density ρ, kinematic viscosity ν and the linear velocity of the gas v_c) :

$$\triangle p = \frac{KNH}{D_p^{m6} D_{tube}^{n0}} \qquad /46/$$

The hydraulic condition of the performance of the catalytic column determines the exponent of the components of N. For streamline conditions $N_{str} = \rho \nu v_o$, while for turbulent conditions $N_t = \rho \nu^{0.2} v_o^{1.8}$. To establish the character of the hydraulic conditions prevailing in the catalytic column with granulated packing, and considering that the critical value of the Reynolds number corresponding to the transition from the streamline to turbulent state is 40 - 50, the Reynolds number should be determined from the expression $Re = \frac{D_p v_o}{\nu v_{free}}$. In this equation the equivalent diameter of the column with the catalyst (d_e) was substituted by the average grain diameter D_p, which is valid when D_{tube} considerably exceeds the value of D_p.

In order to compare the value of K in equation /46/ and the extent of the effect upon it of D_p and D_{tube}, additional calculations were performed.

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For this purpose into the Zhavoronkov formula /11/ intermediate values were included, and it was connected with equation /46/. The values of m_o and n_o were taken from the corresponding particular expressions with consideration of the value of $\frac{D_{tube}}{D_p}$. For the streamline conditions m_o for D_p was taken from equation /14/, n_o for D_{tube} from equations /24/ and /25/ ; for the turbulent flow m_o from equation /18/ and n_o from equations /26/ and /27/.

Catalyst grains had uniformly the shape of a cylinder, with a ratio of the diameter to the altitude $D_3 = 2h_3$, unlike the varying ratios of D_3/h_3 when particular expressions for the dependencies $\Delta p = f(D_p)$ and $\Delta p = f(D_{tube})$ were to be found. In the determination of the effect upon the coefficient K in the equation /46/ of the average grain diameter D_p, the latter was changed within 0.0005 to 0.05 m. at D_{tube} values of 0.7 and 0.04 m. In the determination of the effect on K of the diameter of the cylindrical catalyst tower consisting of a single tube, the value of D_{tube} was changed within 7 and 0.008 m., while the value of D_p was kept constant at 0.0073 m. The free volume of the catalyst bed for various values of D_p was determined from equation /12/.

The results of the calculations are given in Table 3. The values obtained for $K = f(D_p)$ and $K = f(D_{tube})$ should be introduced into equation /46/. The equation

$$\Delta p = \frac{K_o N H}{D_p^{m} D_{tube}^{n}} \qquad /47/$$

will finally be obtained. The numerical values of K_o and those of the exponents of D_p and D_{tube} are shown in Table 4. These values differ and refer to a definite region of values of D_{tube}/D_p and to the prevailing hydraulic conditions.

The value of K_o in equation /47/ is a physical factor of the order of magnitude m , which has so far not yet been determined. For streamline conditions it is close to 1 ; for turbulent conditions, of the order of 0.8.

Concerning the effect upon hydraulic resistance of the geometrical form of the granulated catalyst, which will affect the coefficient K_o in the equation /47/, two groups of geometrical forms can be considered, within

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TABLE 4. NUMERICAL VALUE OF K_o AND OF m AND n IN EQUATION /47/ FOR DIFFERENT INTERVALS OF THE RATIO OF THE DIAMETER OF THE TUBE TO THE AVERAGE DIAMETER OF THE PARTICLE

No.	Flow	Interval of D_{tube}/D_p	Numerical value of K_o	Values of	
				m for D_p	n for D_{tube}
1	turbulent	> 470	3.00	2.030	0.040
2	"	470 - 77	2.11	2.086	0.040
3	"	77 - 25	1.38	2.176	0.040
4	"	25 - 12	1.16	2.225	0.040
5	"	12 - 2.3	3.08	1.914	0.211
6	"	< 2.3	8.50	1.487	0.480
1	streamline	> 100	51.33	2.924	0.056
2	"	< 100	17.60	3.142	0.056
3	"	8 - 3	85.60	2.670	0.316
4	"	3 - 1.2	165.20	2.205	0.742

which the ratio of the surface of the grain to its volume s_3/v_3 and consequently K_o will be constant: I. cylinders of $h_3 = 0.5D_3$ and a longer cylinder of $h_3 = 2D_3$; and further, II. a regular cylinder ($h_3 = D_3$), a cube and a sphere. Here h_3 and D_3 are, respectively, the altitude and the diameter of the grain in meters.

For an appraisal of the effect of the dimensions of the grain D_p upon the connection of K_o with the geometrical form, the value of D_p was varied in size 100 times in the calculations performed, keeping the diameter of the catalytic column constant at 0.7 m. The results are shown in Table 5. The dimension of the grain D_p does not markedly affect the relationship between K_o and the geometrical form of the grain. For the group II, lower values of K_o were obtained, and for streamline conditions a more considerable drop of K_o is observed, 20% as compared to 10% for turbulent flow. Thus, a more compact geometrical form of the grain, i.e., a regular cylinder, a cube or a sphere, exerts a smaller hydraulic resistance to a gas flow than a longer form (group I).

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TABLE 5

D_p, m.	Conditions					
	Streamline			Turbulent		
	0.0005	0.005	0.05	0.0005	0.005	0.05
K_o, I group	20.65	26.47	23.60	1.57	1.80	1.60
K_o, II "	16.18	20.98	18.77	1.40	1.61	1.44
ΔK_o, %	21.6	20.7	20.4	11.1	10.7	10.6

The formulas of Chilton and Colburn /4/, of Zhavoronkov /11/ and of the present author /47/ describe the interdependencies as applied to a uniformly granulated catalyst, i.e., to a catalyst consisting of granules of uniform dimensions, forming a narrow fraction of material by sieve analysis.

Hydraulic Resistance of Non-uniform Granulated Material

For the sake of completion, the hydraulic resistance of a catalyst column or layer consisting of non-uniform granulated material should be discussed. For the case of the gas flow through a layer of sand, L. S. Leibenson modified (6) the formula of Slichter (7) for flow of water, and obtained the following expression:

$$\frac{p_1^2 - p_2^2}{p} = \frac{192 Q \mu K_m^{II}}{\alpha F d_{ed}^2} \qquad /48/$$

Here p_1 and p_2 are respectively the pressure at the inlet to the layer and exit from it given in kg./sq. m.; $p = \gamma RT$ in absolute atmospheres (1 kg./sq. cm.) Q = consumption of gas in cu.m./sec.; μ = coefficient of

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viscosity in kg. sec./sq. m.; a and K_m = coefficients, the second of which depends upon the relative porosity; H = thickness of the layer in meters; ξ = specific gravity of the gas with respect to air; F = cross-sectional area of the layer in sq. m.; d_{ef} = average effective diameter of a sand particle in mm.

$$d_{ef}^2 = \frac{1}{100}\sum\frac{\psi i}{d_i^2}$$

where d_i is the diameter of the sand particles and ψi weight per cent of individual fractions.

Using the experimental data of the Institute of Mineral Fuels pertaining to the hydraulic resistance of a tube packed with sand, as reported by Leĭbenson, and the equations of the present authors, the following results were obtained: For the average effective diameter of particles of fine sand, the Leĭbenson formula gave 0.22 mm.; the Slichter curve, based on weight units, gave 0.223. A similar value of d_{ef} (0.225) can be directly found if the average diameter of particles of the predominating fraction of the sand layer (over 50 per cent) is considered. The relative porosity of the sand determined from specific gravity is 2.5 times larger than the free space in the layer calculated from equation /12/, considering that $D_g = d_{ef}$. It should be noted especially that the equation /46/ given by Leĭbenson was verified only for streamline flow, inasmuch as the experiments of the State Institute of Mineral Fuels were performed at Reynolds number not exceeding 21 and the critical value of the Reynolds number was 50 - 60. Correlation of experimental values of the hydraulic resistance of a sand layer with the value calculated from equation /47/ gave:

V_o in m./sec.	p_1	p_2	$\triangle p_{exper.}$, kg./sq. m.	$\triangle p$ according to /47/
0.279	11000	940	1.0×10^4	0.8×10^4
1.141	22180	1040	2.1×10^4	3.3×10^4

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These data show that the formula /47/ is applicable also for evaluation of the hydraulic resistance of a column packed with a non-uniform catalyst.

In conclusion, it should be noted that instead of three experimentally determined values characterizing the catalyst material (number of granules, surface of the granules and free volume of the catalyst bed) which are required for calculations by the Zhavoronkov formula, the formula derived by the present authors requires only a single determination of the free volume of the catalyst bed (from the volume of water or fine sand filling that space). The factor characterizing the catalyst packing according to this formula, i.e., the average grain diameter, can be found from equation /12/.

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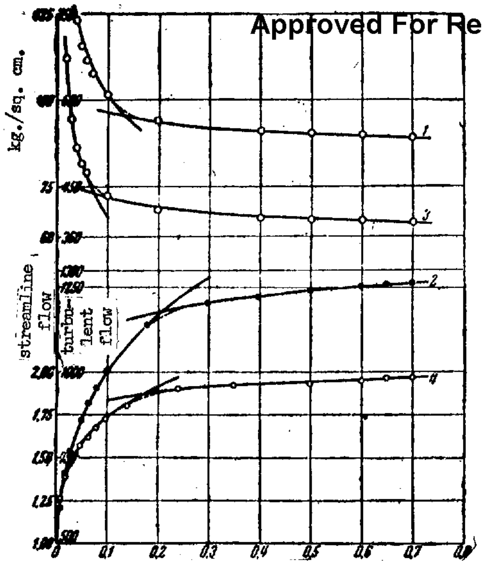

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

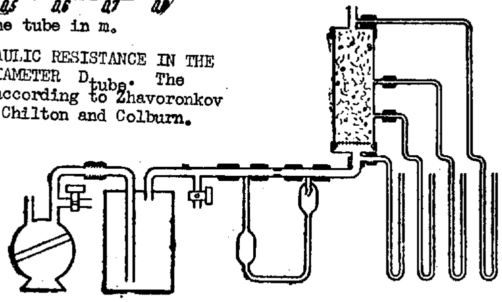

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

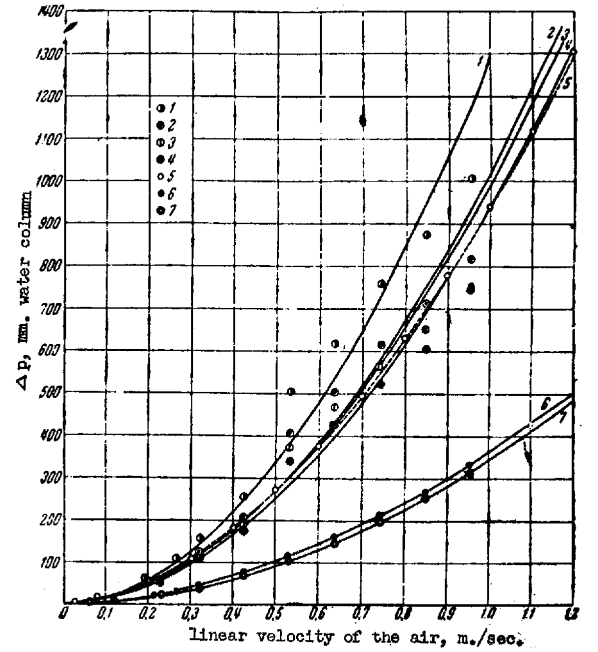

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м $< 0,0015$	$> 3,43$	$3D_p^{0,085}$	(7; 4)	$(2,64; 2,97)\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\,D_p^{0,03}$	(3; 0,8)	$(2,22; 2,12)\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\frac{1}{D_p^{0,06}}$	(0,5; 0,2)	$(1,35; 1,33)\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\frac{1}{D_p^{0,103}}$	(0,15; 0.09)	$(1,05; 1,06)\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for D tube ~~Для D тр~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\,D_p^{0,202}$	(0,07; 0,018)	$(3,2; 3,14)\frac{1}{D_{tube}^{0,211}}$
6	»	$< 2,3$	$> 0,017$	$< 0,017$	$17,62\,D_p^{0,629}$	(0,017; 0,003)	$(8,5)^{*}\frac{1}{tube^{0,28\,8}}$
1	streamline	> 100	for D_{tube} = 0,07 м $< 0,0073$ (0,0005—0,0073)	$> 0,73$	$51,33\,D_p^{0\ 13}$	(3; 0,8)	$(51,9; 49)\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	$> 0,0073$ (0,0073—0,05)	$< 0,73$	$17,6\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	$(16,6; 17,67)\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005—0,015	0,058—0,222	$85,6\,D_p^{0,373}$	(0,05; 0,02)	$(85;89)\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\,D_p^{0,339}$	(0,03; 0,008)	$(165,2)^{*}\frac{1}{D_{tube}^{0,428}}$

* The numerical value [illegible] D_{tube} [illegible] to D_p and D_{tube}

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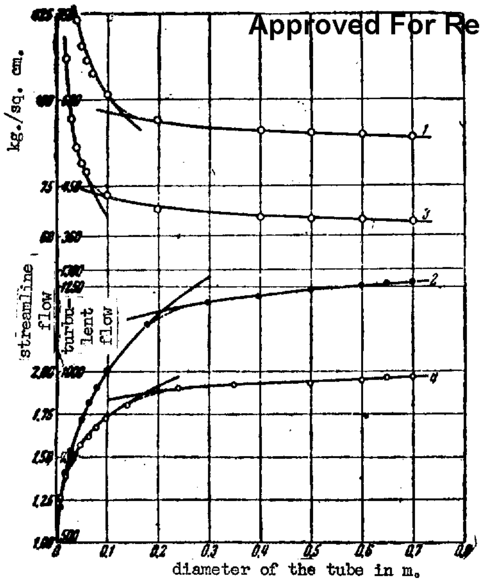


FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

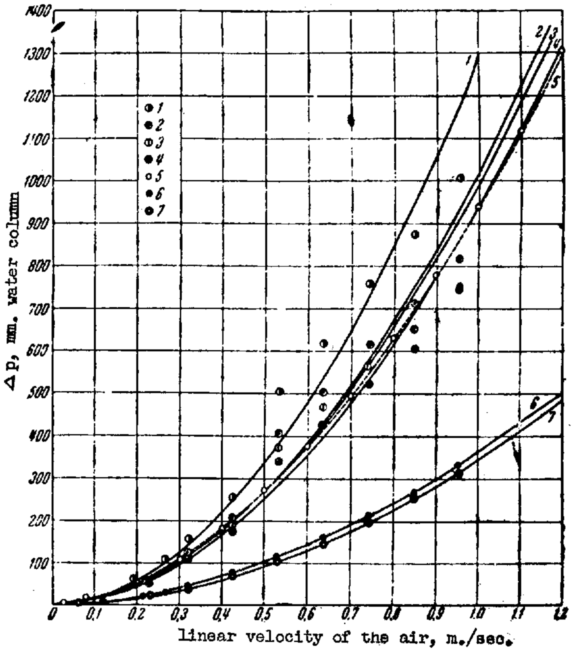


FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

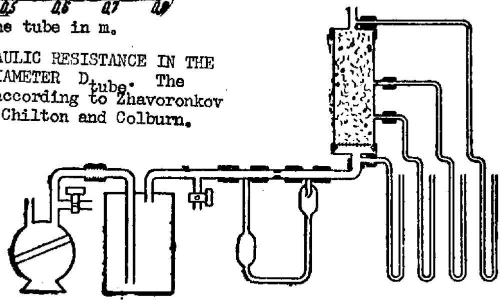


FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	$(2,64; 2,97)\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	$(2,22; 2,12)\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\frac{1}{D_p^{0,06}}$	(0,5; 0,2)	$(1,35; 1,33)\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\frac{1}{D_p^{0,103}}$	(0,15; 0.09)	$(1,05; 1,06)\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for Dtube ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	$(3,2; 3,14)\frac{1}{D_{tube}^{0,211}}$
6	»	<2,3	>0,017	< 0,017	$17,62\ D_p^{0,629}$	(0,017; 0,003)	$(8,5)^{*}\frac{1}{D_{tube}^{0,268}}$
1	streamline	>100	for D_{tube} = 0,07 м < 0,0073 (0,0005—0,0073)	> 0,73	$51,33\ D_p^{0,12}$	(3; 0,3)	$(51,9; 49)\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	$17,6\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	$(16,6; 17,67)\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005—0,015	0,058—0,222	$85,6\ D_p^{0,873}$	(0,05; 0,02)	$(85;89)\frac{1}{D_{tube}^{0,311}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	$(165,2)^{*}\frac{1}{D_{tube}^{0,428}}$

* The numerical valu[illegible] D_{tube} [illegible] to D_p and D_{tube}

[redacted]

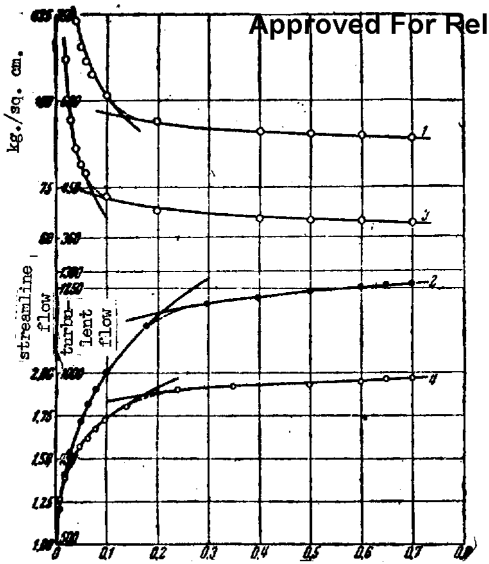
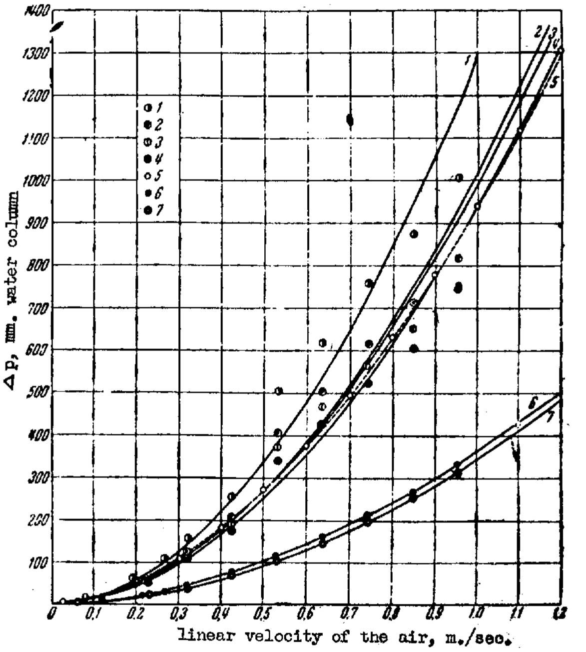


FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.



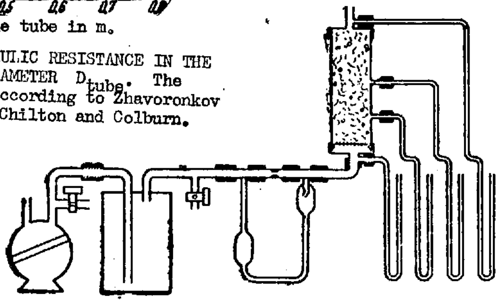


FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 – Δp at the air inlet to the column; 2 – Δp at the middle of the column; 3 – average values of Δp; 4 – Δp at the exit from the column; 5 – Δp according to Zhavoronkov; 6 – Δp according to Chilton and Colburn; 7 – Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	(2,64; 2,97) $\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	2,11 $D_p^{0,03}$	(3; 0,8)	(2,22; 2,12) $\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	1,38 $\frac{1}{D_p^{0,06}}$	(0,5; 0,2)	(1,35; 1,33) $\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	1,16 $\frac{1}{D_p^{0,103}}$	(0,15; 0.09)	(1,05; 1,06) $\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for D tube ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	3,08 $D_p^{0,202}$	(0,07; 0,018)	(3,2; 3,14) $\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	17,62 $D_p^{0,629}$	(0,017; 0,003)	(8,5)* $\frac{1}{D_{tube}^{0,288}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005 – 0,0073)	> 0,73	51,33 $D_p^{0,11}$	(3; 0,3)	(51,9; 49) $\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073 – 0,05)	< 0,73	17,6 $\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	(16,6; 17,67) $\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005 – 0,015	0,058—0,222	85,6 $D_p^{0,373}$	(0,05; 0,02)	(85;89) $\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	600 $D_p^{0,839}$	(0,03; 0,008)	(165,2)* $\frac{1}{D_{tube}^{0,428}}$

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* The numerical valu[illegible] D_{tube} [illegible] to D_p and D_{tube}

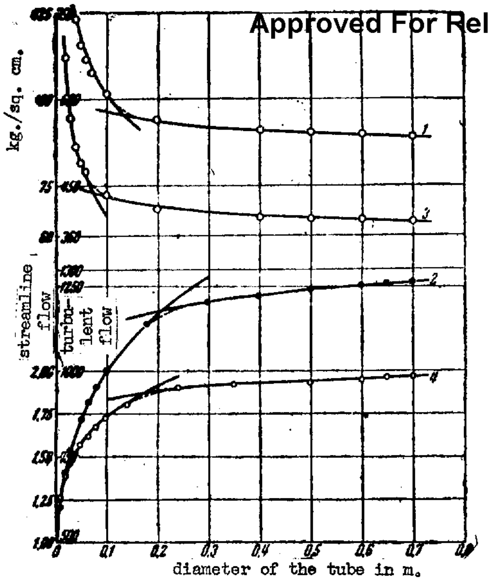

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

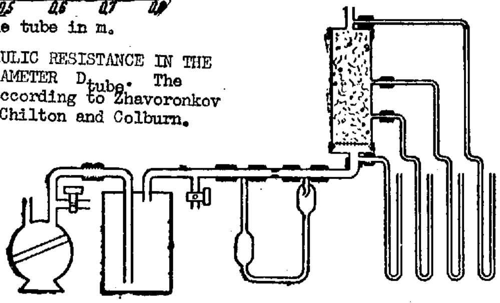

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

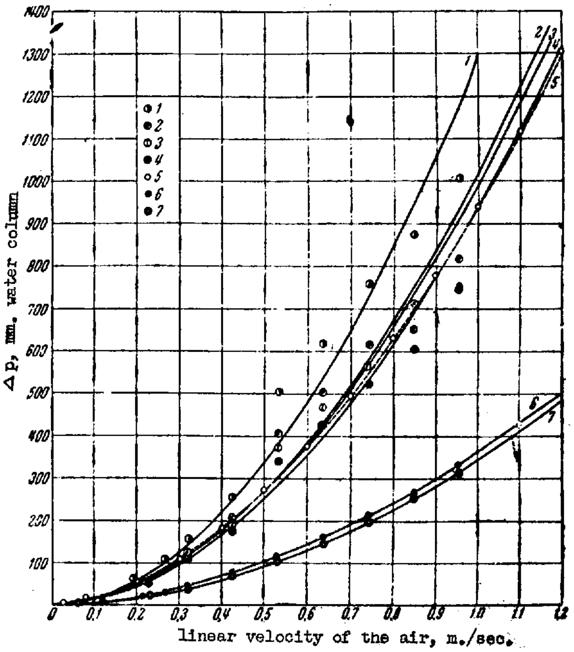

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for $D_p = 0.0073$ m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for $D_{tube} = 0,7$ м $< 0,0015$	$> 3,43$	$3D_p^{0,065}$	(7; 4)	$(2,64; 2,97)\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	$(2,22; 2,12)\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\frac{1}{D_p^{0,06}}$	(0,5; 0,2)	$(1,35; 1,33)\frac{1}{D_{\ e}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\frac{1}{D_p^{0,109}}$	(0,15; 0.09)	$(1,05; 1,06)\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for Dtube Для $D_{тр} = 0,04$ м 0,0033—0,017	0,087—0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	$(3,2; 3,14)\frac{1}{D_{tube}^{0,211}}$
6	»	$<2,3$	$>0,017$	$< 0,017$	$17,62\ D_p^{0,629}$	(0,017; 0,003)	$(8,5)^{*}\frac{1}{{}_{ube}^{0,26\ 8}}$
1	streamline	>100	for $D_{tube} = 0,07$ м $< 0,0073$ (0,0005—0,0073)	$> 0,73$	$51,33\ D_p^{0\ 12}$	(3; 0,8)	$(51,9; 49)\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	$> 0,0073$ (0,0073—0,05)	$< 0,73$	$17,6\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	$(16,6; 17,67)\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for $D_{tube} = 0,04$ м 0,005—0,015	0,058—0,222	$85,6\ D_p^{0,373}$	(0,05; 0,02)	$(85;89)\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	$(165,2)^{*}\frac{1}{D_{tube}^{0,426}}$

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* The numerical valu [illegible] D_{tube} [illegible] to D_p and D_{tube}

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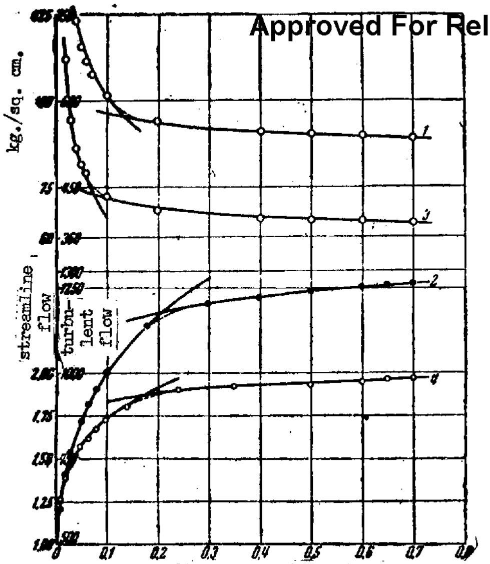

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

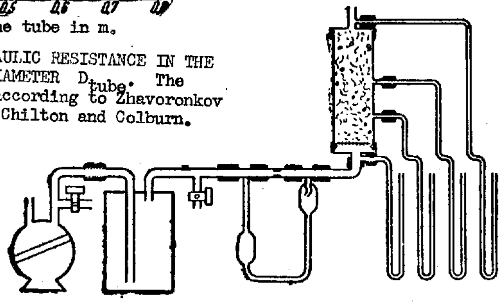

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

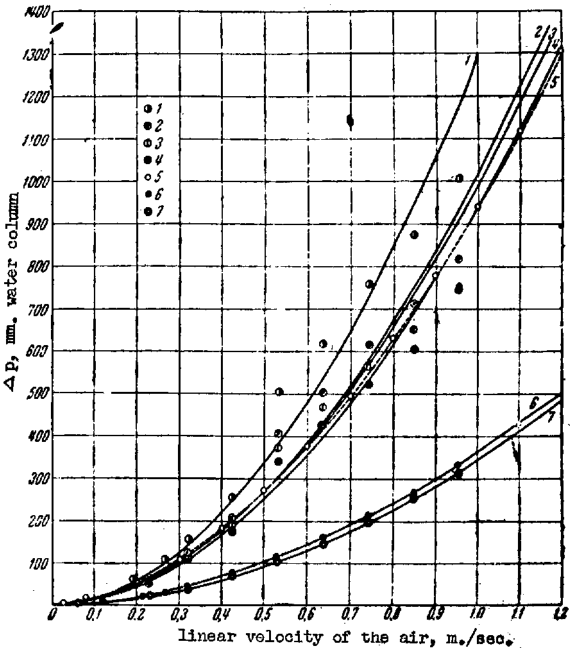

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 – Δp at the air inlet to the column; 2 – Δp at the middle of the column; 3 – average values of Δp; 4 – Δp at the exit from the column; 5 – Δp according to Zhavoronkov; 6 – Δp according to Chilton and Colburn; 7 – Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	(2,64; 2,97) $\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	(2,22; 2,12) $\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\ \frac{1}{D_p^{0,08}}$	(0,5; 0,2)	(1,35; 1,33) $\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\ \frac{1}{D_p^{0,103}}$	(0,15; 0.09)	(1,05; 1,06) $\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for Dtube ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	(3,2; 3,14) $\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	$17,62\ D_p^{0,629}$	(0,017; 0,003)	(8,5)* $\frac{1}{tube^{0,288}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005—0,0073)	> 0,73	$51,33\ D_p^{0,13}$	(3; 0,3)	(51,9; 49) $\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	$17,6\ \frac{1}{D_p^{0,098}}$	(0,7; 0,06)	(16,6; 17,67) $\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005—0,015	0,058—0,222	$85,6\ D_p^{0,873}$	(0,05; 0,02)	(85;89) $\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	(165,2)* $\frac{1}{D_{tube}^{0,428}}$

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* The numerical valu[illegible] D_{tube} [illegible] to D_p and D_{tube}

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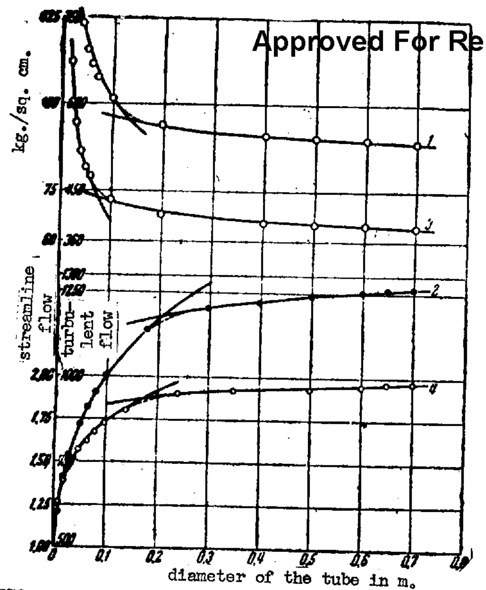
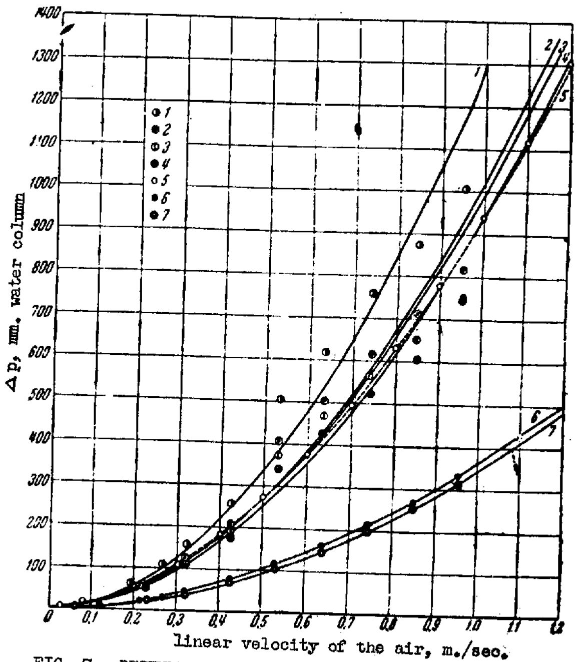


FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.



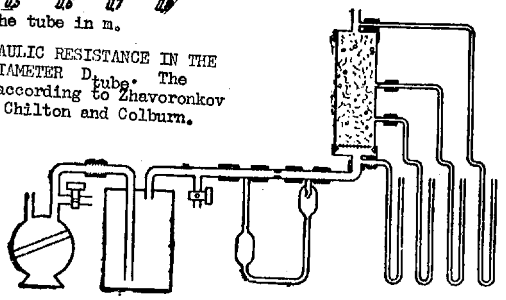


FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
						from D_{tube}	
					From D_p of the entire interval	Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	(2,64; 2,97) $\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	(2,22; 2,12) $\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\ \frac{1}{D_p^{0,06}}$	(0,5; 0,2)	(1,35; 1,33) $\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\ \frac{1}{D_p^{0,103}}$	(0,15; 0.09)	(1,05; 1,06) $\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for D tube ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	(3,2; 3,14) $\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	$17,62\ D_p^{0,629}$	(0,017; 0,003)	(8,5)* $\frac{1}{\text{cube}^{0,268}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005 − 0,0073)	> 0,73	$51,33\ D_p^{0\ 13}$	(3; 0,8)	(51,9; 49) $\frac{1}{D_{tube}^{0,036}}$
2	»	< 100	> 0,0073 (0,0073 − 0,05)	< 0,73	$17,6\ \frac{1}{D_p^{0,098}}$	(0,7; 0,06)	(16,6; 17,67) $\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005—0,015	0,058—0,222	$85,6\ D_p^{0,873}$	(0,05; 0,02)	(85;89) $\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0;022—0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	(165,2)* $\frac{1}{D_{tube}^{0,428}}$

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* The numerical value of K for [illegible] D_p [illegible] D_{tube}

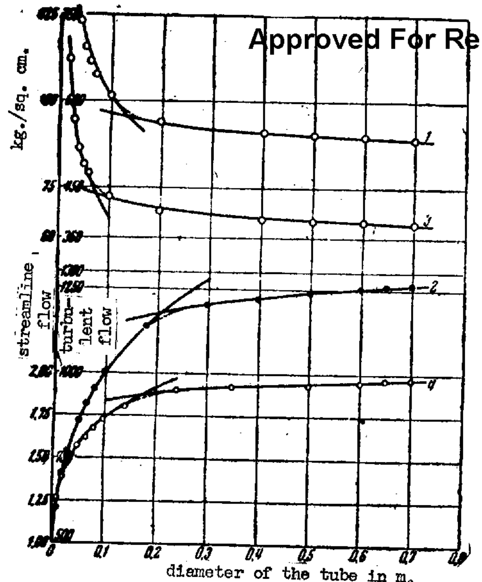

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

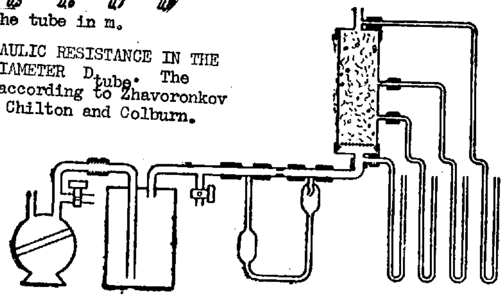

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

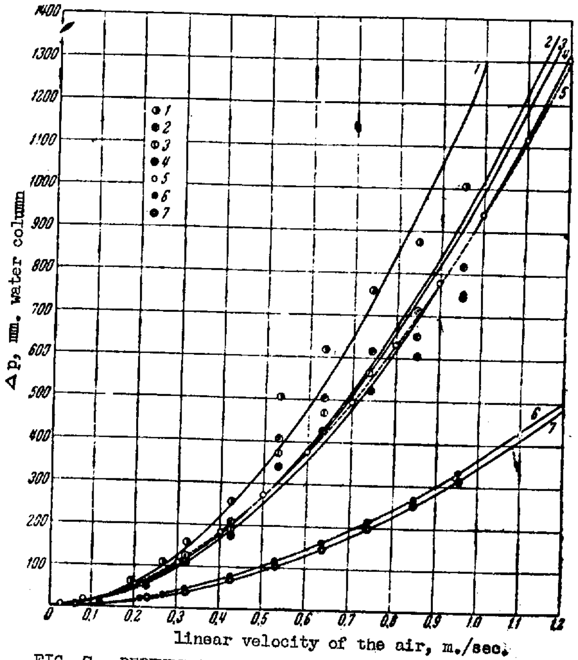

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	$(2,64; 2,97)\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	$(2,22; 2,12)\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\frac{1}{D_p^{0,06}}$	(0,5; 0,2)	$(1,35; 1,33)\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\frac{1}{D_p^{0,103}}$	(0,15; 0.09)	$(1,05; 1,06)\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for D tube ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	$(3,2; 3,14)\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	$17,62\ D_p^{0,629}$	(0,017; 0,003)	$(8,5)^*\frac{1}{cube^{0,268}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005—0,0073)	> 0,73	$51,33\ D_p^{0,13}$	(3; 0,8)	$(51,9; 49)\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	$17,6\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	$(16,6; 17,67)\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005—0,015	0,058—0,222	$85,6\ D_p^{0,373}$	(0,05; 0,02)	$(85;89)\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	$(165,2)^*\frac{1}{D_{tube}^{0,426}}$

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* The numerical value of K for [illegible] D_p and D_{tube}

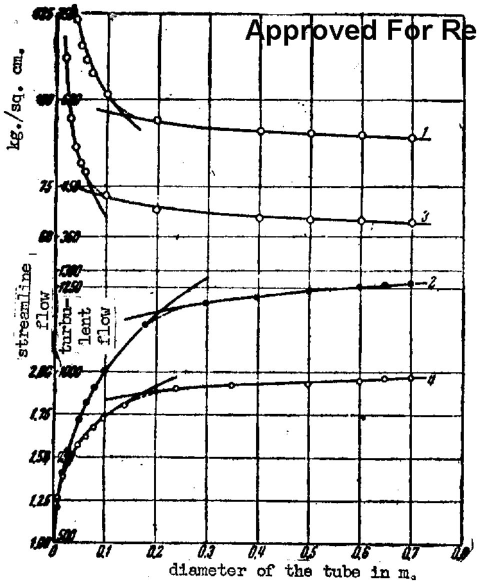

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

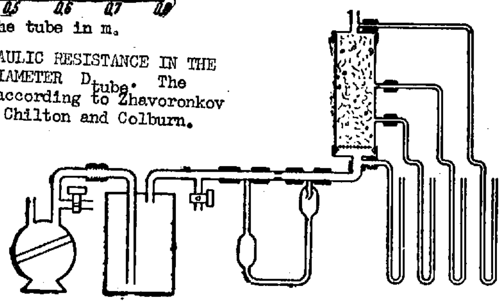

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

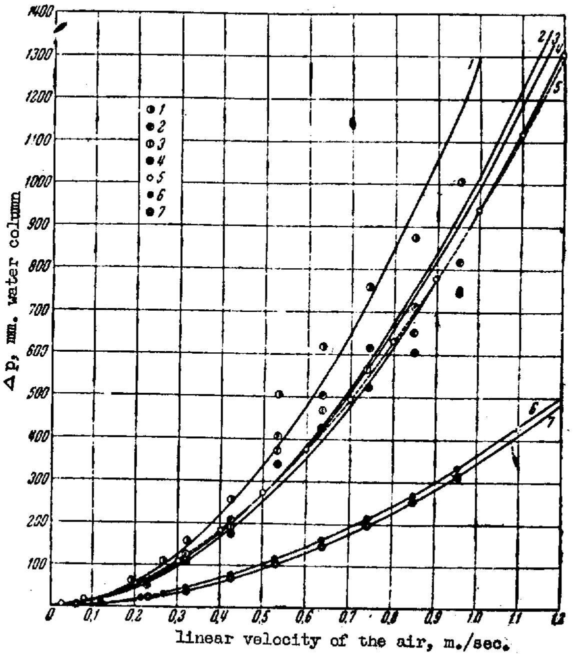

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0{,}085}$	(7; 4)	(2,64; 2,97) $\frac{1}{D_{tube}^{0{,}04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2{,}11\,D_p^{0{,}03}$	(3; 0,8)	(2,22; 2,12) $\frac{1}{D_{tube}^{0{,}04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1{,}38\,\frac{1}{D_p^{0{,}06}}$	(0,5; 0,2)	(1,35; 1,33) $\frac{1}{D_{tube}^{0{,}04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1{,}16\,\frac{1}{D_p^{0{,}103}}$	(0,15; 0.09)	(1,05; 1,06) $\frac{1}{D_{tube}^{0{,}04}}$
5	»	12—2,3	for Dtube ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3{,}08\,D_p^{0{,}202}$	(0,07; 0,018)	(3,2; 3,14) $\frac{1}{D_{tube}^{0{,}211}}$
6	»	< 2,3	> 0,017	< 0,017	$17{,}62\,D_p^{0{,}629}$	(0,017; 0,003)	(8,5)* $\frac{1}{\text{cube}^{0{,}268}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005−0,0073)	> 0,73	$51{,}33\,D_p^{0{,}13}$	(3; 0,8)	(51,9; 49) $\frac{1}{D_{tube}^{0{,}056}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	$17{,}6\,\frac{1}{D_p^{0{,}098}}$	(0,7; 0,06)	(16,6; 17,67) $\frac{1}{D_{tube}^{0{,}056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005−0,015	0,058—0,222	$85{,}6\,D_p^{0{,}373}$	(0,05; 0,02)	(85;89) $\frac{1}{D_{tube}^{0{,}313}}$
4	»	3−1,2	0,016—0,034	0,022—0,0087	$600\,D_p^{0{,}839}$	(0,03; 0,008)	(165,2)* $\frac{1}{D_{tube}^{0{,}428}}$

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* The numerical value [illegible] D_{tube} [illegible] D_p and D_{tube}

[redacted]

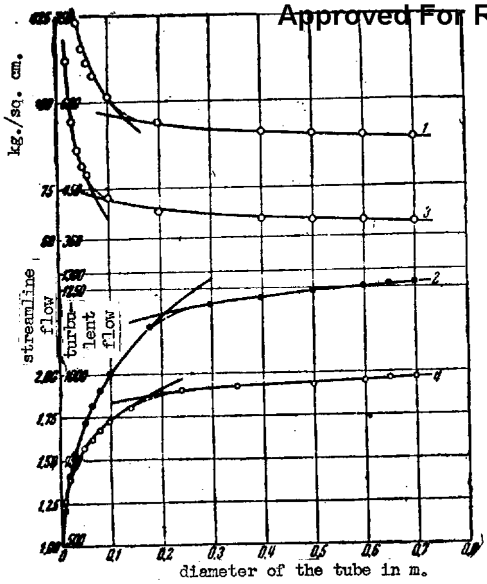

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

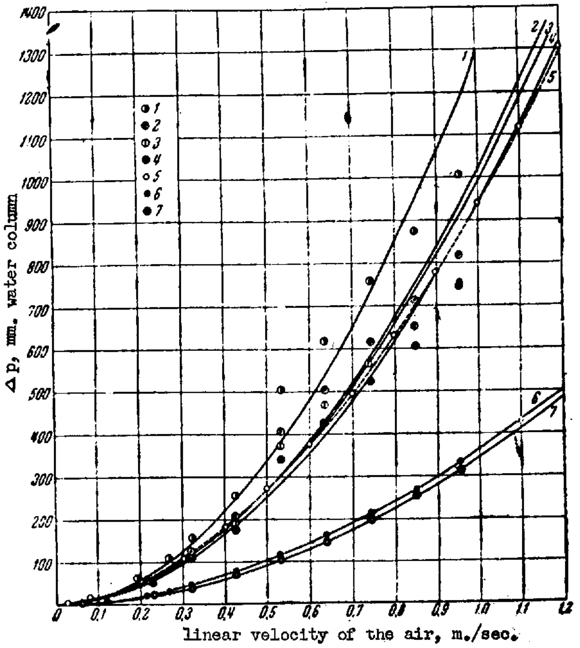

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

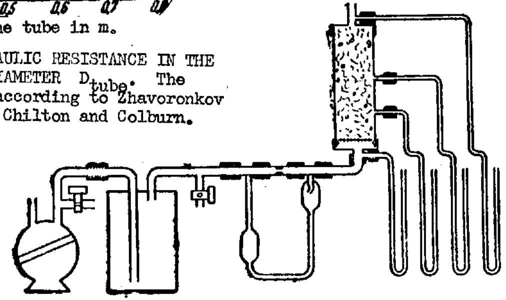

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	(2,64; 2,97) $\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	(2,22; 2,12) $\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\ \frac{1}{D_p^{0,06}}$	(0,5; 0,2)	(1,35; 1,33) $\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\ \frac{1}{D_p^{0,103}}$	(0,15; 0.09)	(1,05; 1,06) $\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for Dtube ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	(3,2; 3,14) $\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	$17,62\ D_p^{0,629}$	(0,017; 0,003)	(8,5)* $\frac{1}{D_{tube}^{0,268}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005—0,0073)	> 0,73	$51,33\ D_p^{0,13}$	(3; 0,8)	(51,9; 49) $\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	$17,6\ \frac{1}{D_p^{0,098}}$	(0,7; 0,06)	(16,6; 17,67) $\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005—0,015	0,058—0,222	$85,6\ D_p^{0,373}$	(0,05; 0,02)	(85;89) $\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	(165,2)* $\frac{1}{D_{tube}^{0,426}}$

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* The numerical value of K for D_{tube} is common to D_p and D_{tube}

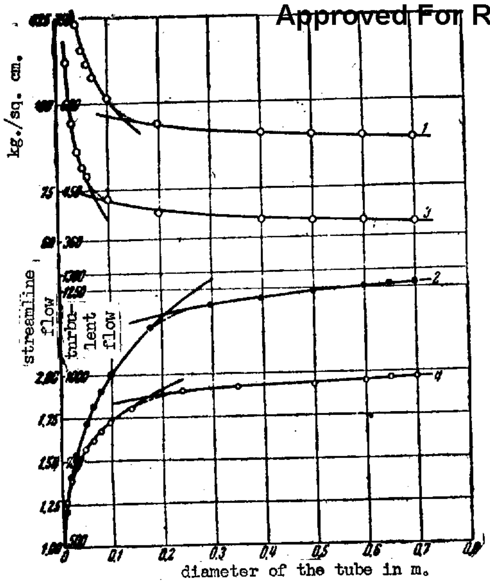

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

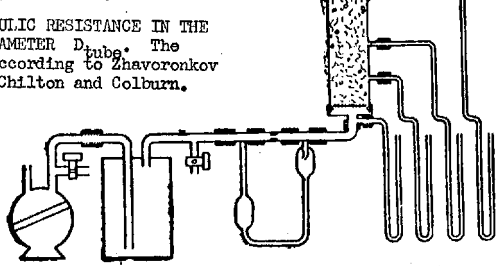

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

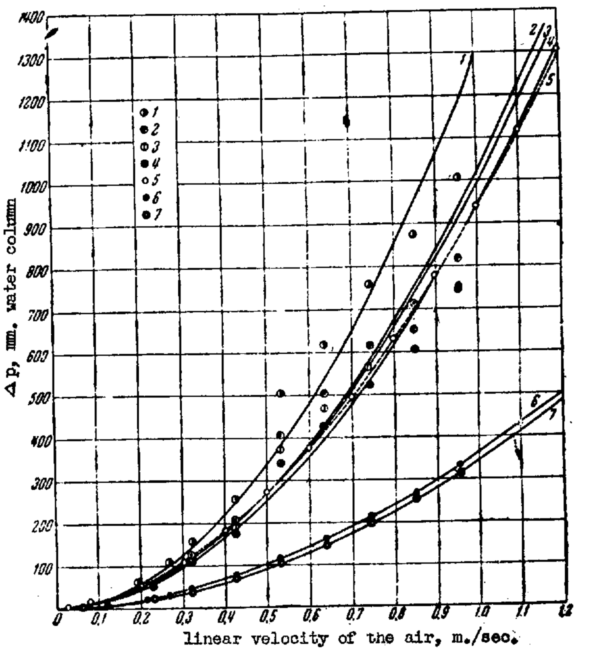

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	(2,64; 2,97) $\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	2,11 $D_p^{0,03}$	(3; 0,8)	(2,22; 2,12) $\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	1,38 $\frac{1}{D_p^{0,06}}$	(0,5; 0,2)	(1,35; 1,33) $\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	1,16 $\frac{1}{D_p^{0,103}}$	(0,15; 0.09)	(1,05; 1,06) $\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for Dtube ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	3,08 $D_p^{0,202}$	(0,07; 0,018)	(3,2; 3,14) $\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	17,62 $D_p^{0,629}$	(0,017; 0,003)	(8,5)* $\frac{1}{\text{cube}^{0,288}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005—0,0073)	> 0,73	51,33 $D_p^{0\ 13}$	(3; 0,8)	(51,9; 49) $\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	17,6 $\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	(16,6; 17,67) $\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005—0,015	0,058—0,222	85,6 $D_p^{0,373}$	(0,05; 0,02)	(85;89) $\frac{1}{D_{tube}^{0,913}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	600 $D_p^{0,839}$	(0,03; 0,008)	(165,2)* $\frac{1}{D_{tube}^{0,426}}$

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* The numerical value of K for D_{tube} is common to D_p and D_{tube}

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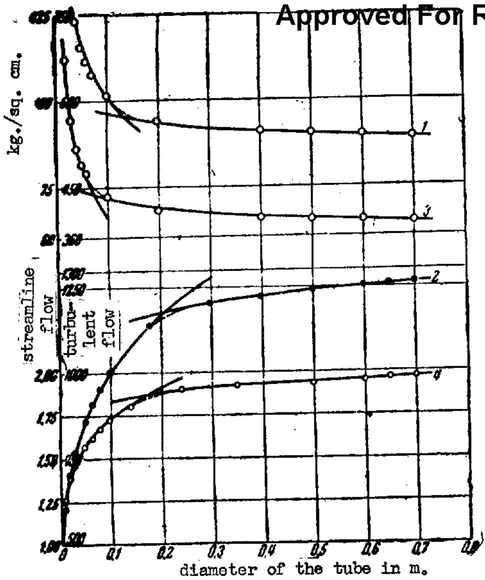

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

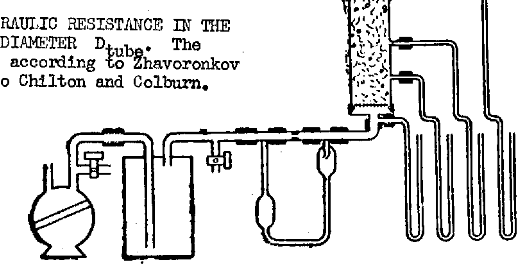

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

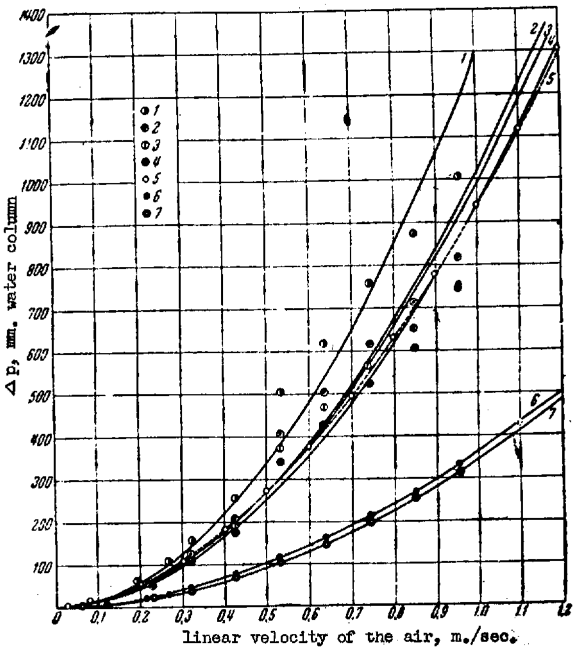

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	(2,64; 2,97) $\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	(2,22; 2,12) $\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\ \frac{1}{D_p^{0,06}}$	(0,5; 0,2)	(1,35; 1,33) $\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\ \frac{1}{D_p^{0,103}}$	(0,15; 0.09)	(1,05; 1,06) $\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for D_{tube} ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	(3,2; 3,14) $\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	$17,62\ D_p^{0,629}$	(0,017; 0,003)	(8,5)* $\frac{1}{D_{tube}^{0,268}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005—0,0073)	> 0,73	$51,33\ D_p^{0,12}$	(3; 0,8)	(51,9; 49) $\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	$17,6\ \frac{1}{D_p^{0,098}}$	(0,7; 0,06)	(16,6; 17,67) $\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,01 м 0,005—0,015	0,058—0,222	$85,6\ D_p^{0,373}$	(0,05; 0,02)	(85;89) $\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	(165,2)* $\frac{1}{D_{tube}^{0,428}}$

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* The numerical value of K for D_{tube} is common to D_p and D_{tube}

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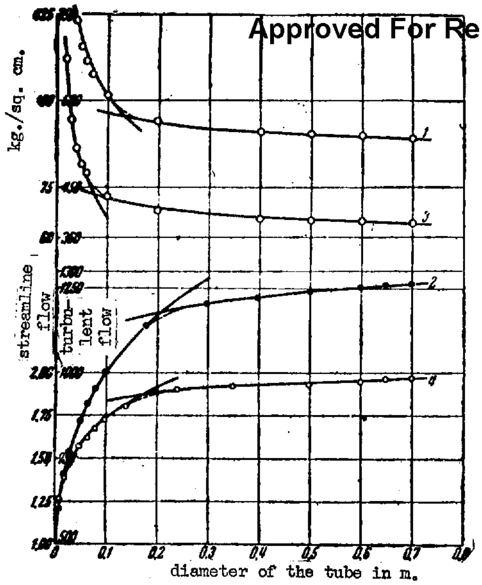

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

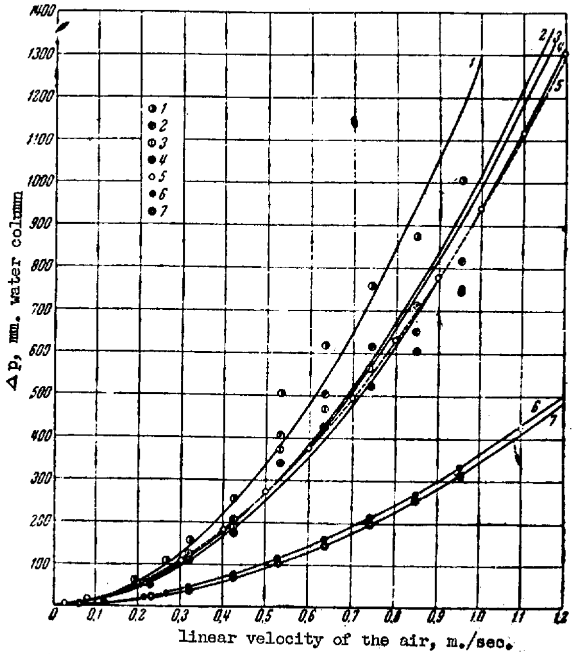

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

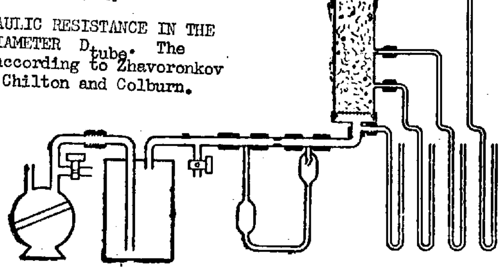

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	(2,64; 2,97) $\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	(2,22; 2,12) $\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\ \frac{1}{D_p^{0,06}}$	(0,5; 0,2)	(1,35; 1,33) $\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\ \frac{1}{D_p^{0,103}}$	(0,15; 0.09)	(1,05; 1,06) $\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for D tube ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	(3,2; 3,14) $\frac{1}{D_{tube}^{0,211}}$
6	»	<2,3	>0,017	< 0,017	$17,62\ D_p^{0,629}$	(0,017; 0,003)	(8,5)* $\frac{1}{D_{tube}^{0,288}}$
1	streamline	>100	for D_{tube} = 0,07 м < 0,0073 (0,0005 - 0,0073)	> 0,73	$51,33\ D_p^{0,13}$	(3; 0,8)	(51,9; 49) $\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	$17,6\ \frac{1}{D_p^{0,098}}$	(0,7; 0,06)	(16,6; 17,67) $\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005—0,015	0,058—0,222	$85,6\ D_p^{0,873}$	(0,05; 0,02)	(85;89) $\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	(165,2)* $\frac{1}{D_{tube}^{0,428}}$

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* The numerical value [illegible] D_{tube} [illegible] D_p and D_{tube}

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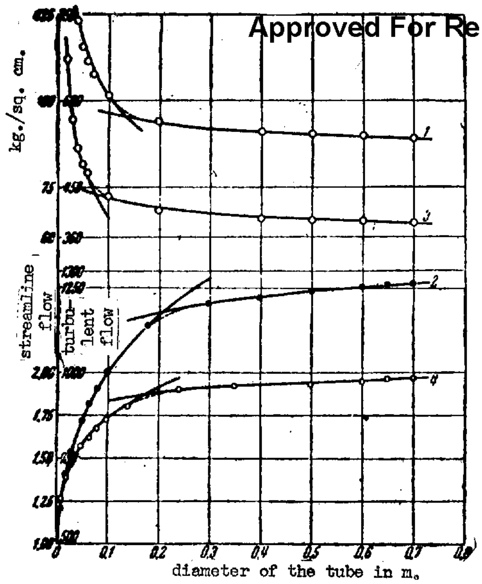

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

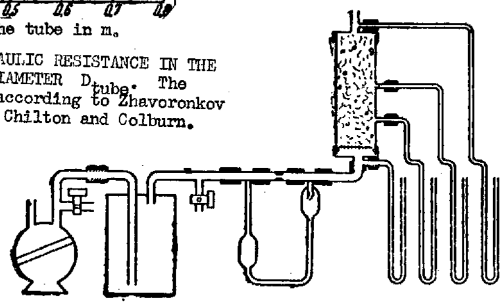

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

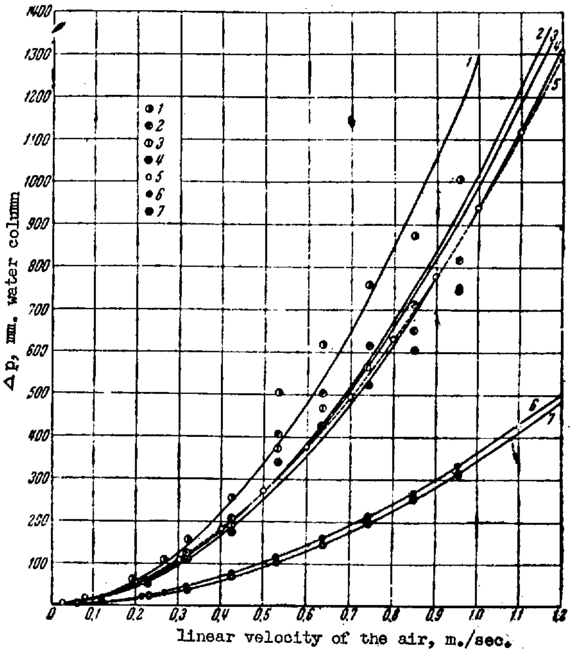

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	$(2,64; 2,97)\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\,D_p^{0,03}$	(3; 0,8)	$(2,22; 2,12)\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\frac{1}{D_p^{0,06}}$	(0,5; 0,2)	$(1,35; 1,33)\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\frac{1}{D_p^{0,109}}$	(0,15; 0.09)	$(1,05; 1,06)\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for D Tube ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\,D_p^{0,202}$	(0,07; 0,018)	$(3,2; 3,14)\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	$17,62\,D_p^{0,629}$	(0,017; 0,003)	$(8,5)^*\frac{1}{cube^{0,268}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005—0,0073)	> 0,73	$51,33\,D_p^{0,13}$	(3; 0,8)	$(51,9; 49)\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	$17,6\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	$(16,6; 17,67)\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,01 м 0,005—0,015	0,058—0,222	$85,6\,D_p^{0,373}$	(0,05; 0,02)	$(85;89)\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\,D_p^{0,839}$	(0,03; 0,008)	$(165,2)^*\frac{1}{D_{tube}^{0,428}}$

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* The numerical value [illegible] D_{tube} [illegible] D_p and D_{tube}

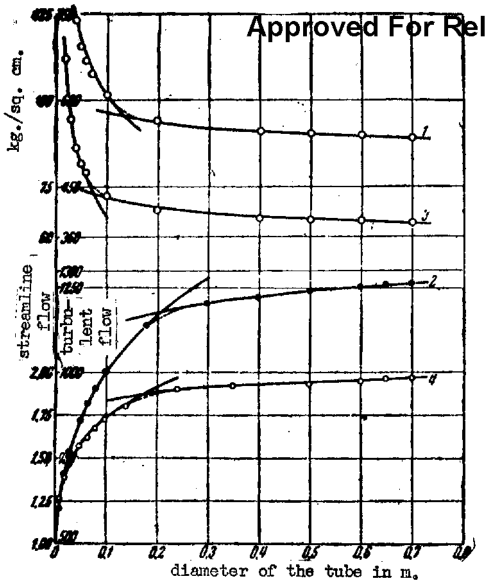

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

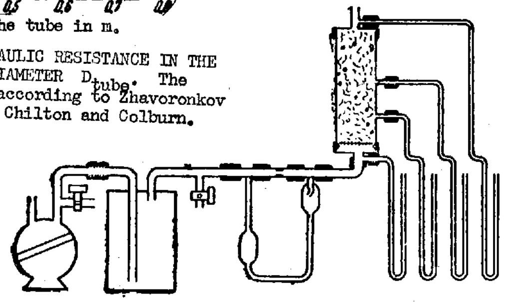

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

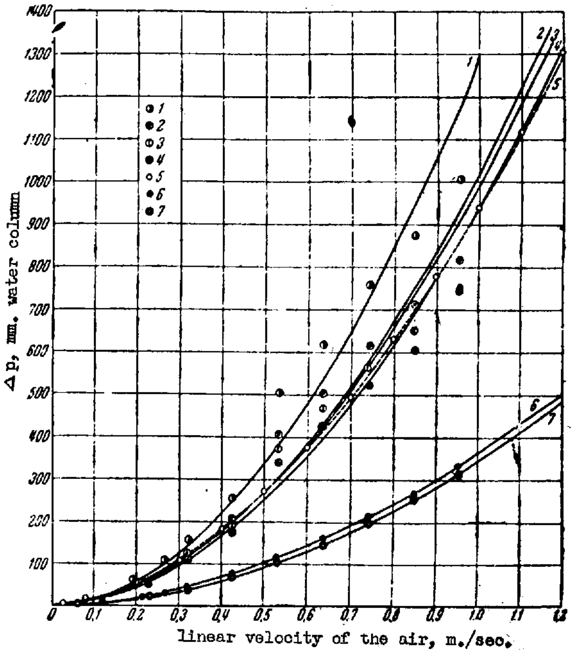

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for $D_p = 0.0073$ m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for $D_{tube} = 0,7$ м $< 0,0015$	$> 3,43$	$3D_p^{0,085}$	(7; 4)	$(2,64; 2,97)\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	$(2,22; 2,12)\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\frac{1}{D_p^{0,06}}$	(0,5; 0,2)	$(1,35; 1,33)\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\frac{1}{D_p^{0,103}}$	(0,15; 0.09)	$(1,05; 1,06)\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	For D tube ~~Для $D_{тр}$~~ $= 0,04$ м 0,0033—0,017	0,087—0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	$(3,2; 3,14)\frac{1}{D_{tube}^{0,211}}$
6	»	$< 2,3$	$> 0,017$	$< 0,017$	$17,62\ D_p^{0,629}$	(0,017; 0,003)	$(8,5)^{*}\frac{1}{\text{cube}^{0,26\,8}}$
1	streamline	> 100	for $D_{tube} = 0,07$ м $< 0,0073$ (0,0005—0,0073)	$> 0,73$	$51,33\ D_p^{0\,13}$	(3; 0,8)	$(51,9; 49)\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	$> 0,0073$ (0,0073—0,05)	$< 0,73$	$17,6\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	$(16,6; 17,67)\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for $D_{tube} = 0,04$ м 0,005—0,015	0,058—0,222	$85,6\ D_p^{0,873}$	(0,05; 0,02)	$(85;89)\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	$(165,2)^{*}\frac{1}{D_{tube}^{0,428}}$

* The numerical value [illegible] D_{tube} [illegible] D_p and D_{tube}

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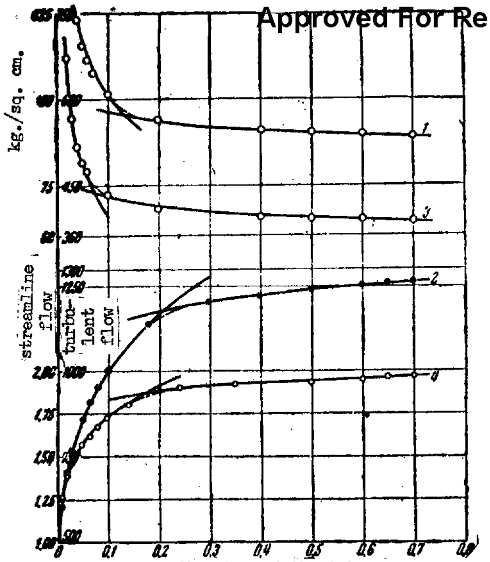

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

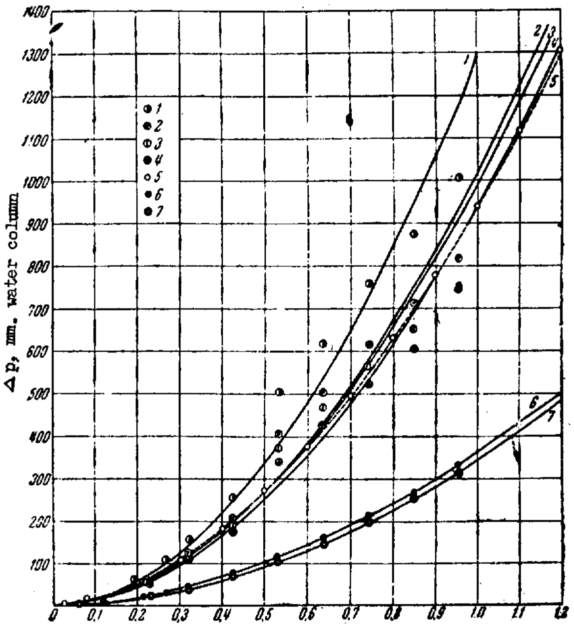

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

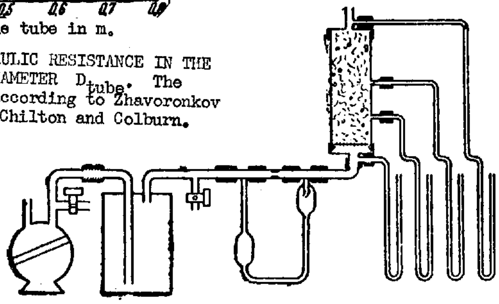

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for $D_p = 0.0073$ m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for $D_{tube} = 0{,}7$ м $< 0{,}0015$	$> 3{,}43$	$3D_p^{0{,}085}$	(7; 4)	$(2{,}64;\ 2{,}97)\frac{1}{D_{tube}^{0{,}04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2{,}11\ D_p^{0{,}03}$	(3; 0,8)	$(2{,}22;\ 2{,}12)\frac{1}{D_{tube}^{0{,}04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1{,}38\frac{1}{D_p^{0{,}06}}$	(0,5; 0,2)	$(1{,}35;\ 1{,}33)\frac{1}{D_{\ \ e}^{0{,}04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1{,}16\frac{1}{D_p^{0{,}103}}$	(0,15; 0.09)	$(1{,}05;\ 1{,}06)\frac{1}{D_{tube}^{0{,}04}}$
5	»	12—2,3	for Dtube ~~Для Dтр.~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3{,}08\ D_p^{0{,}202}$	(0,07; 0,018)	$(3{,}2;\ 3{,}14)\frac{1}{D_{tube}^{0{,}211}}$
6	»	$< 2{,}3$	$> 0{,}017$	$< 0{,}017$	$17{,}62\ D_p^{0{,}620}$	(0,017; 0,003)	$(8{,}5)^{*}\frac{1}{{cube}^{0{,}28\ 8}}$
1	streamline	> 100	for $D_{tube} = 0{,}07$ м $< 0{,}0073$ (0,0005—0,0073)	$> 0{,}73$	$51{,}33\ D_p^{0\ 13}$	(3; 0,8)	$(51{,}9;\ 49)\frac{1}{D_{tube}^{0{,}056}}$
2	»	< 100	$> 0{,}0073$ (0,0073—0,05)	$< 0{,}73$	$17{,}6\frac{1}{D_p^{0{,}098}}$	(0,7; 0,06)	$(16{,}6;\ 17{,}67)\frac{1}{D_{tube}^{0{,}056}}$
3	»	8—3	for $D_{tube} = 0{,}04$ м 0,005—0,015	0,058—0,222	$85{,}6\ D_p^{0{,}373}$	(0,05; 0,02)	$(85;89)\frac{1}{D_{tube}^{0{,}313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\ D_p^{0{,}839}$	(0,03; 0,008)	$(165{,}2)^{*}\frac{1}{D_{tube}^{0{,}428}}$

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* The numerical value of K for D_{tube} is common to D_p and D_{tube}

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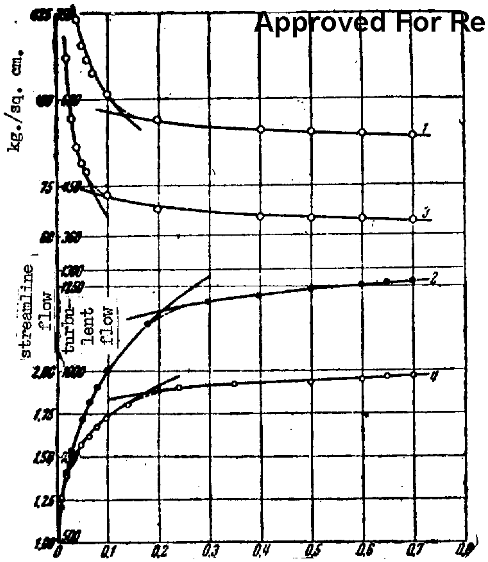

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

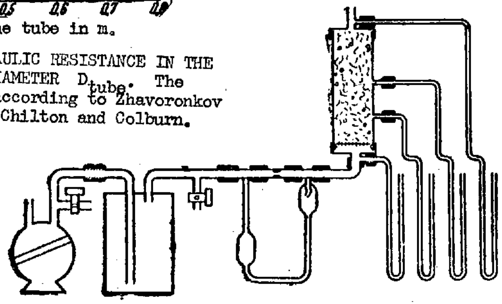

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

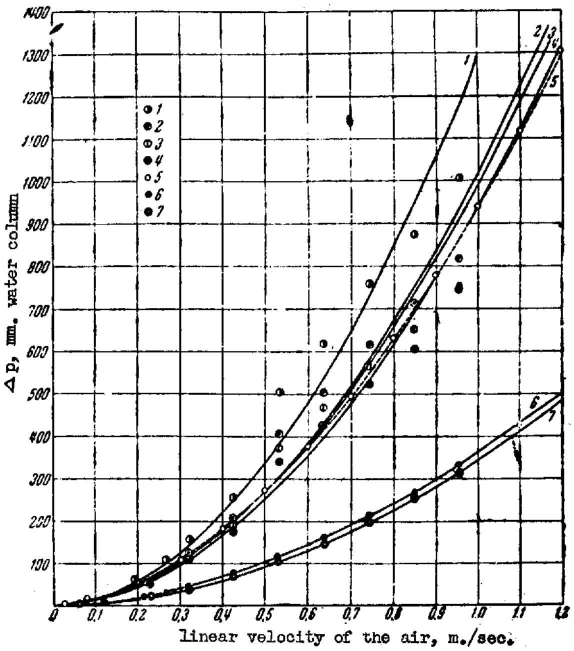

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}: Extreme values D_{tube} given for the interval	from D_{tube}: Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	$(2,64; 2,97)\frac{1}{D_{tube}^{0,04}}$
2	»	470–77	0,0015–0,009	3,43–0,562	$2,11\ D_p^{0,08}$	(3; 0,8)	$(2,22; 2,12)\frac{1}{D_{tube}^{0,04}}$
3	»	77–25	0,009–0,0028	0,562–0,182	$1,38\frac{1}{D_p^{0,06}}$	(0,5; 0,2)	$(1,35; 1,33)\frac{1}{D_{tube}^{0,04}}$
4	»	25–12	0,0028–0,0583	0,182–0,087	$1,16\frac{1}{D_p^{0,103}}$	(0,15; 0.09)	$(1,05; 1,06)\frac{1}{D_{tube}^{0,04}}$
5	»	12–2,3	for Dtube ~~Для $D_{тр}$~~ = 0,04 м 0,0033–0,017	0,087–0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	$(3,2; 3,14)\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	$17,62\ D_p^{0,629}$	(0,017; 0,003)	$(8,5)^*\frac{1}{D_{tube}^{0,288}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005–0,0073)	> 0,73	$51,33\ D_p^{0,13}$	(3; 0,8)	$(51,9; 49)\frac{1}{D_{tube}^{0,058}}$
2	»	< 100	> 0,0073 (0,0073–0,05)	< 0,73	$17,6\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	$(16,6; 17,67)\frac{1}{D_{tube}^{0,058}}$
3	»	8–3	for D_{tube} = 0,04 м 0,005–0,015	0,058–0,222	$85,6\ D_p^{0,873}$	(0,05; 0,02)	$(85;89)\frac{1}{D_{tube}^{0,313}}$
4	»	3–1,2	0,016–0,034	0,022–0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	$(165,2)^*\frac{1}{D_{tube}^{0,428}}$

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* The numerical valu[illegible] D_{tube} [illegible] D_p and D_{tube}

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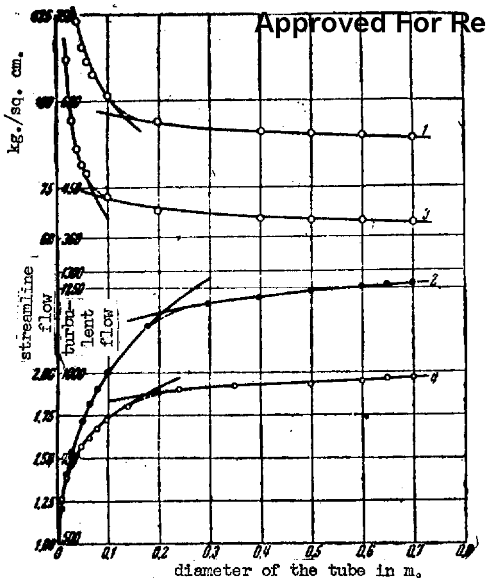

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

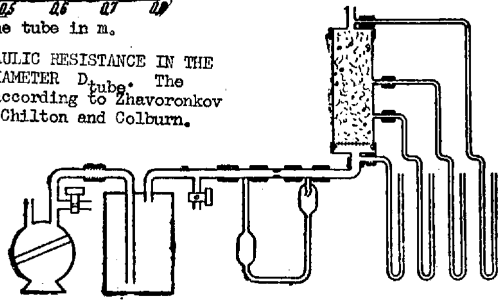

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

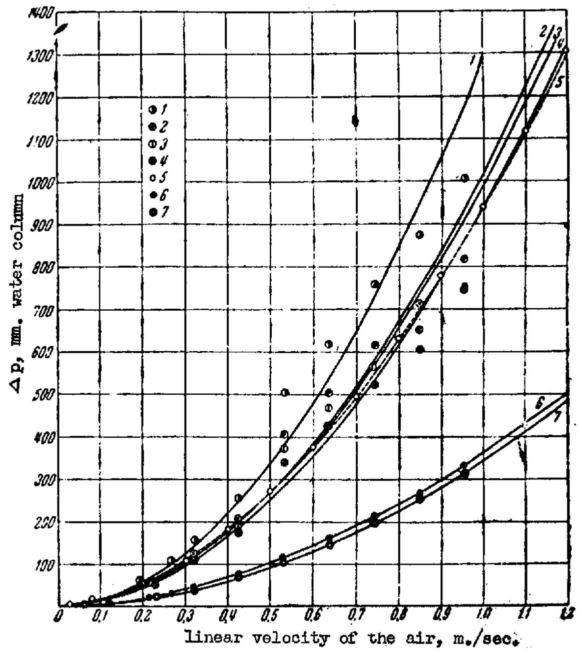

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 – Δp at the air inlet to the column; 2 – Δp at the middle of the column; 3 – average values of Δp; 4 – Δp at the exit from the column; 5 – Δp according to Zhavoronkov; 6 – Δp according to Chilton and Colburn; 7 – Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for $D_p = 0.0073$ m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	$(2,64; 2,97)\frac{1}{D_{tube}^{0,04}}$
2	»	470–77	0,0015–0,009	3,43–0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	$(2,22; 2,12)\frac{1}{D_{tube}^{0,04}}$
3	»	77–25	0,009–0,0028	0,562–0,182	$1,38\frac{1}{D_p^{0,06}}$	(0,5; 0,2)	$(1,35; 1,33)\frac{1}{D_{tube}^{0,04}}$
4	»	25–12	0,0028–0,0583	0,182–0,087	$1,16\frac{1}{D_p^{0,103}}$	(0,15; 0.09)	$(1,05; 1,06)\frac{1}{D_{tube}^{0,04}}$
5	»	12–2,3	for D tube ~~Для $D_{тр}$~~ = 0,04 м 0,0033–0,017	0,087–0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	$(3,2; 3,14)\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	$17,62\ D_p^{0,629}$	(0,017; 0,003)	$(8,5)^*\frac{1}{cube^{0,288}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005–0,0073)	> 0,73	$51,33\ D_p^{0\ 13}$	(3; 0,8)	$(51,9; 49)\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073–0,05)	< 0,73	$17,6\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	$(16,6; 17,67)\frac{1}{D_{tube}^{0,056}}$
3	»	8–3	for D_{tube} = 0,04 м 0,005–0,015	0,058–0,222	$85,6\ D_p^{0,873}$	(0,05; 0,02)	$(85;89)\frac{1}{D_{tube}^{0,311}}$
4	»	3–1,2	0,015–0,034	0,022–0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	$(165,2)^*\frac{1}{D_{tube}^{0,426}}$

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* The numerical valu[illegible] D_{tube} [illegible] D_p and D_{tube}

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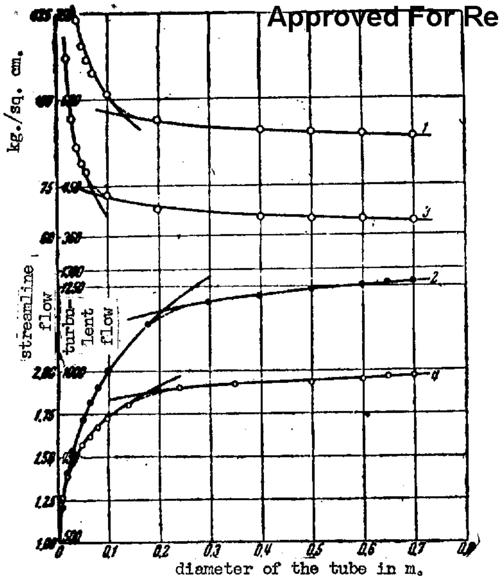

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

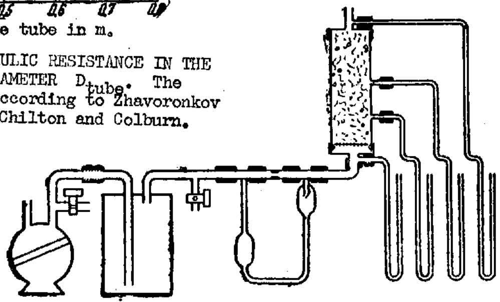

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

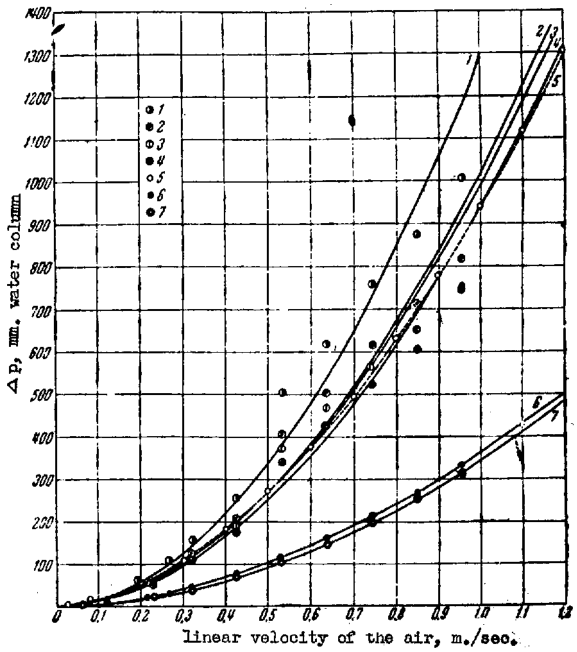

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	$(2,64; 2,97)\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\,D_p^{0,03}$	(3; 0,8)	$(2,22; 2,12)\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\frac{1}{D_p^{0,08}}$	(0,5; 0,2)	$(1,35; 1,33)\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\frac{1}{D_p^{0,103}}$	(0,15; 0.09)	$(1,05; 1,06)\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for Dtube ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\,D_p^{0,202}$	(0,07; 0,018)	$(3,2; 3,14)\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	$17,62\,D_p^{0,629}$	(0,017; 0,003)	$(8,5)^{*}\frac{1}{\text{tube}^{0,28\ 8}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005—0,0073)	> 0,73	$51,33\,D_p^{0,13}$	(3; 0,8)	$(51,9; 49)\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	$17,6\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	$(16,6; 17,67)\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005—0,015	0,058—0,222	$85,6\,D_p^{0,373}$	(0,05; 0,02)	$(85;89)\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\,D_p^{0,839}$	(0,03; 0,008)	$(165,2)^{*}\frac{1}{D_{tube}^{0,428}}$

* The numerical value of K for D_{tube} is common to D_p and D_{tube}

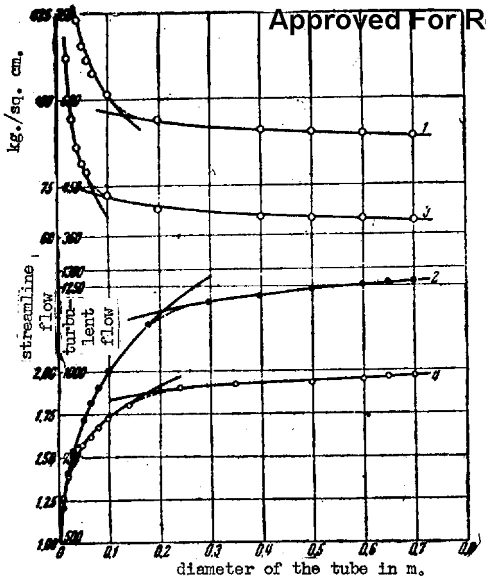

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

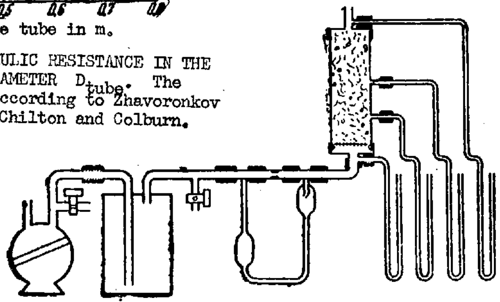

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

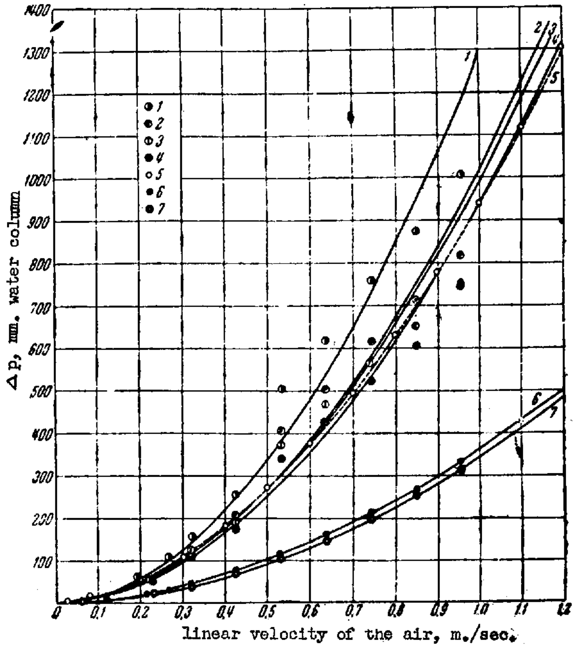

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	$(2,64; 2,97)\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	$(2,22; 2,12)\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\frac{1}{D_p^{0,06}}$	(0,5; 0,2)	$(1,35; 1,33)\frac{1}{D_{tube}^{0.04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\frac{1}{D_p^{0,103}}$	(0,15; 0.09)	$(1,05; 1,06)\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for D_{tube} ~~Для $D_{тр}$~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	$(3,2; 3,14)\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	$17,62\ D_p^{0,629}$	(0,017; 0,003)	$(8,5)^*\frac{1}{D_{tube}^{0,268}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005—0,0073)	> 0,73	$51,33\ D_p^{0,13}$	(3; 0,8)	$(51,9; 49)\frac{1}{D_{tube}^{0,056}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	$17,6\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	$(16,6; 17,67)\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005—0,015	0,058—0,222	$85,6\ D_p^{0,373}$	(0,05; 0,02)	$(85;89)\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	$(165,2)^*\frac{1}{D_{tube}^{0,428}}$

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* The numerical value [illegible] for D_{tube} [illegible] to D_p and D_{tube}

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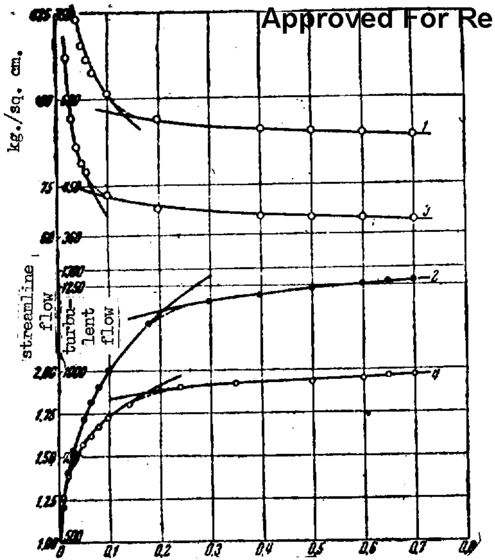

FIG. 5. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYTIC TOWER Δp UPON ITS DIAMETER D_{tube}. The curves 1 and 3 were calculated according to Zhavoronkov and curves 2 and 4 according to Chilton and Colburn.

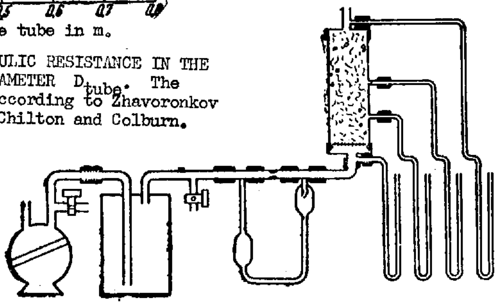

FIG. 6. EXPERIMENTAL UNIT FOR THE STUDY OF THE EFFECT OF THE LINEAR VELOCITY OF A STREAM OF GAS UPON THE HYDRAULIC RESISTANCE OF A COLUMN WITH SOLID GRANULATED CATALYST

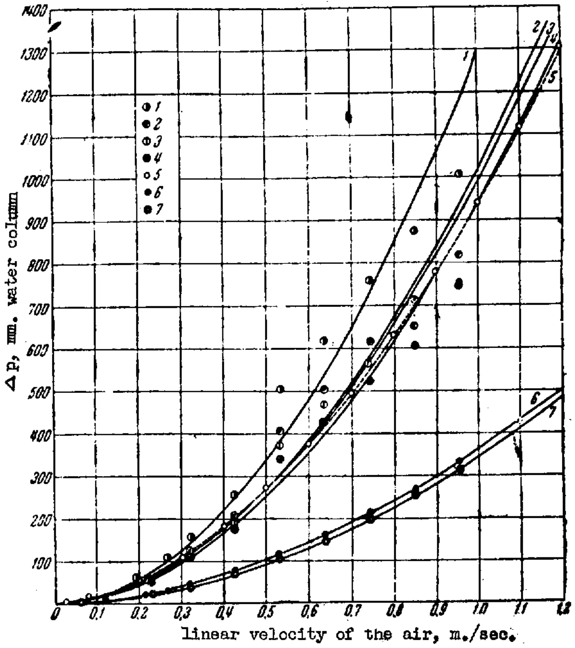

FIG. 7. DEPENDENCE OF THE HYDRAULIC RESISTANCE Δp OF A COLUMN WITH GRANULATED CATALYST UPON THE LINEAR VELOCITY OF THE GAS STREAM OBSERVED IN THIS WORK. 1 - Δp at the air inlet to the column; 2 - Δp at the middle of the column; 3 - average values of Δp; 4 - Δp at the exit from the column; 5 - Δp according to Zhavoronkov; 6 - Δp according to Chilton and Colburn; 7 - Δp according to Chilton and Colburn, assuming the average diameter of the particles to be equal to the cubic root of three dimensions.

TABLE 3. EFFECT OF THE AVERAGE GRAIN SIZE OF THE CATALYST (D_p) AND THE DIAMETER OF THE CONTACT COLUMN (D_{tube}) ON THE VALUE OF K IN EQUATION /46/

No.	Flow	Interval of values of D_{tube}/D_p	Interval of values of D_p for known D_{tube}, m.	Interval of values (in m.) of D_{tube} for D_p = 0.0073 m.	Value of K in equation /46/		
					From D_p of the entire interval	from D_{tube}	
						Extreme values D_{tube} given for the interval	Values of K corresponding to them
1	turbulent	> 470	for D_{tube} = 0,7 м < 0,0015	> 3,43	$3D_p^{0,085}$	(7; 4)	$(2,64; 2,97)\frac{1}{D_{tube}^{0,04}}$
2	»	470—77	0,0015—0,009	3,43—0,562	$2,11\ D_p^{0,03}$	(3; 0,8)	$(2,22; 2,12)\frac{1}{D_{tube}^{0,04}}$
3	»	77—25	0,009—0,0028	0,562—0,182	$1,38\frac{1}{D_p^{0,06}}$	(0,5; 0,2)	$(1,35; 1,33)\frac{1}{D_{tube}^{0,04}}$
4	»	25—12	0,0028—0,0583	0,182—0,087	$1,16\frac{1}{D_p^{0,109}}$	(0,15; 0.09)	$(1,05; 1,06)\frac{1}{D_{tube}^{0,04}}$
5	»	12—2,3	for Dтуб ~~Для Dтр~~ = 0,04 м 0,0033—0,017	0,087—0,017	$3,08\ D_p^{0,202}$	(0,07; 0,018)	$(3,2; 3,14)\frac{1}{D_{tube}^{0,211}}$
6	»	< 2,3	> 0,017	< 0,017	$17,62\ D_p^{0,629}$	(0,017; 0,003)	$(8,5)^{*}\frac{1}{D_{tube}^{0,268}}$
1	streamline	> 100	for D_{tube} = 0,07 м < 0,0073 (0,0005—0,0073)	> 0,73	$51,33\ D_p^{0,13}$	(3; 0,8)	$(51,9; 49)\frac{1}{D_{tube}^{0,058}}$
2	»	< 100	> 0,0073 (0,0073—0,05)	< 0,73	$17,6\frac{1}{D_p^{0,098}}$	(0,7; 0,06)	$(16,6; 17,67)\frac{1}{D_{tube}^{0,056}}$
3	»	8—3	for D_{tube} = 0,04 м 0,005—0,015	0,058—0,222	$85,6\ D_p^{0,373}$	(0,05; 0,02)	$(85;89)\frac{1}{D_{tube}^{0,313}}$
4	»	3—1,2	0,015—0,034	0,022—0,0087	$600\ D_p^{0,839}$	(0,03; 0,008)	$(165,2)^{*}\frac{1}{D_{tube}^{0,428}}$

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* The numerical value of K for D_{tube} is common to D_p and D_{tube}

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TABLE 1. HYDRAULIC RESI[illegible]ALYTIC TOWERS WITHOUT THE CATALYST AND WITH IT

No.	Temp., °C.	Dimensions of the tube, m.		Rate of flow of the air		Number of tubes in the tower	Character of the flow	Δp, pressure drop		
								In the empty column		
		Diameter D_{tube}	Altitude Δl (H)	Q, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
1	15	0,1	1	2,28	0,068	1	streamline	$4{,}03\cdot10^{-4}$	0,054	53,2
2	15	0,1	1	33,5	1	1	turbulent	0,019	35,2	219,2
3	500	0,2	2,544	3,46	0,068	1	streamline	$1{,}09\cdot10^{-5}$	0,07	67,6
4	500	0,2	2,544	3,46	0,0004 (0,000378)	180	»	$6{,}07\cdot10^{-8}$	0,07	67,6
5	500	0,2	2,544	50,9	1	1	turbulent	0,013	7,93	492,8
6	500	0,2	2,544	50,9	0,0055	180	streamline	0,004	0,01	985
7	500	0,2	2,544	18304	360	1	turbulent	446,4	$3{,}09\cdot10^{5}$	$1{,}96\cdot10^{7}$
8	500	0,2	2,544	18304	2	180	»	0,044	$4{,}85\cdot10^{3}$	$3{,}07\cdot10^{7}$

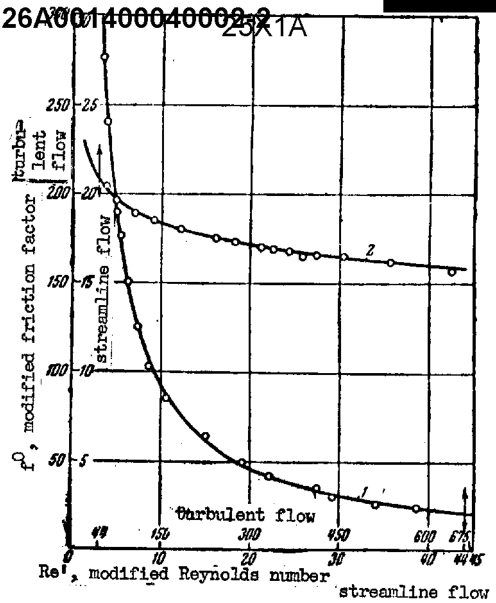

FIG. 1. DEPENDENCE OF THE MODIFIED FRICTION FACTOR f^0 UPON THE MODIFIED REYNOLDS NUMBER Re' BY THE FORMULA OF CHILTON AND COLBURN. 1 - streamline flow; 2 - turbulent flow

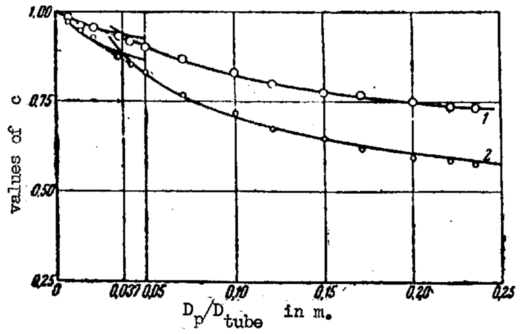

FIG. 2. DEPENDENCE OF THE COEFFICIENT OF THE EFFECT OF THE WALLS c UPON THE RATIO OF THE AVERAGE DIAMETER OF THE PARTICLES TO THE DIAMETER OF THE TUBE D_p/D_{tube} BY THE FORMULA OF CHILTON AND COLBURN. 1 - for streamline flow; 2 - for turbulent flow

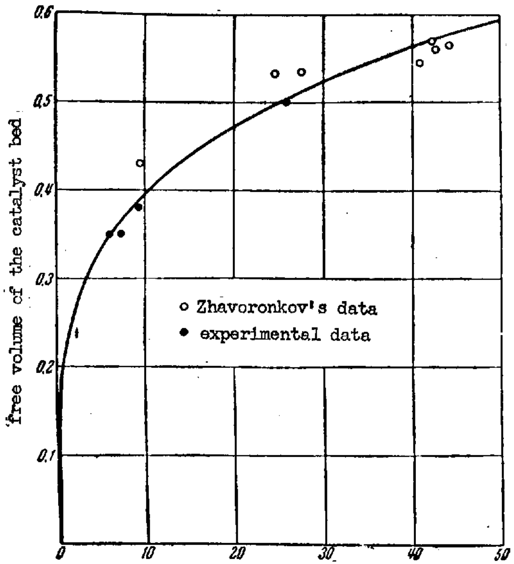

FIG. 3. DEPENDENCE OF THE FREE VOLUME OF THE CATALYST BED UPON THE AVERAGE DIAMETER OF THE PARTICLES.

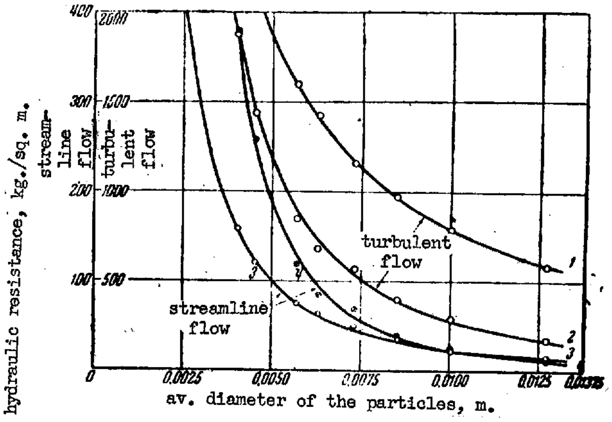

FIG. 4. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYST BED Δp UPON THE AVERAGE DIAMETER OF THE CATALYST GRAINS. For turbulent flow: 1 - according to Chilton and Colburn; 2 - according to Zhavoronkov. For streamline flow: 3 - according to Zhavoronkov; 4 - according to Chilton and Colburn.

TABLE 2. INTERDEPENDENCE BETWEEN THE FREE SPACE OF THE PACKING AND THE AVERAGE DIAMETER OF THE GRAIN

No.	Type of packing	Shape	Dimensions of the grains, mm.	Av. diameter of the grain, mm.	Free space
1*	Glass rods	Cylinders	5 × 5 × 8	6,0	0,35
2*	Aluminosilicate catalyst	Cylindrical tablets	9 × 9 × 4	7,3	0,35
3	Catalyst for conversion of CO	Tablets	11 × 11 × 6	9,3	0,38
4	Vanadium catalyst	"	11 × 11 × 6,5	9,5	0,43
5	Coke	Irregular	29,6 × 25,8 × 18	24,5	0,532
6*	Glass granules	Pear-shaped	20 × 20 × 37,5	25,8	0,500
7	Coke	Irregular	35,6 × 28,8 × 18	27,5	0,535
8	"	"	47,6 × 41,5 × 33,4	40,8	0,545
9	Gravel	Spherical	56,8 × 40,8 × 29	42,2	0,570
10	Coke	Irregular	52 × 40,3 × 35,5	42,6	0,560
11	Andesite	"	56 × 43,7 × 32,6	44,1	0,565

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*Catalysts tested in this work

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TABLE 1. HYDRAULIC RESISTANCE OF CATALYTIC TOWERS WITHOUT THE CATALYST AND WITH IT

No.	Temp., °C.	Dimensions of the tube m.		Rate of flow of the air		Number of tubes in the tower	Character of the flow	Δp, pressure drop		
								In the empty column		According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
		Diameter D_{tube}	Altitude Δl (H)	Q, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	
1	15	0,1	1	2,28	0,068	1	streamline	$4{,}03 \cdot 10^{-4}$	0,054	53,2
2	15	0,1	1	33,5	1	1	turbulent	0,019	35,2	219,2
3	500	0,2	2,544	3,46	0,068	1	streamline	$1{,}09 \cdot 10^{-5}$	0,07	67,6
4	500	0,2	2,544	3,46	0,0004 (0,000378)	180	»	$6{,}07 \cdot 10^{-8}$	0,07	67,6
5	500	0,2	2,544	50,9	1	1	turbulent	0,013	7,93	492,8
6	500	0,2	2,544	50,9	0,0055	180	streamline	0,004	0,01	985
7	500	0,2	2,544	18304	360	1	turbulent	446,4	$3{,}09 \cdot 10^{5}$	$1{,}96 \cdot 10^{7}$
8	500	0,2	2,544	18304	2	180	»	0,044	$4{,}85 \cdot 10^{3}$	$3{,}07 \cdot 10^{7}$

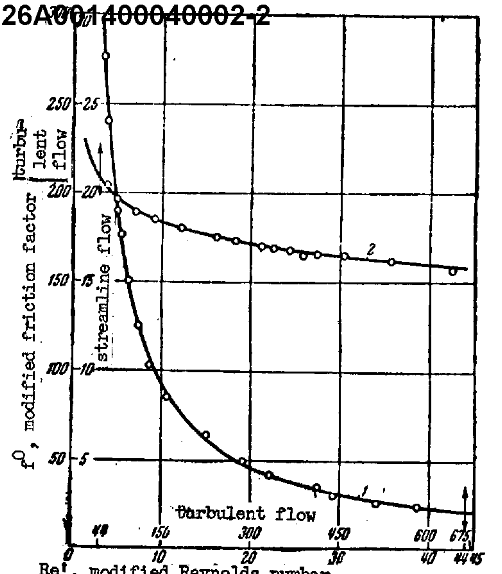

FIG. 1. DEPENDENCE OF THE MODIFIED FRICTION FACTOR f^0 UPON THE MODIFIED REYNOLDS NUMBER Re' BY THE FORMULA OF CHILTON AND COLBURN. 1 - streamline flow; 2 - turbulent flow

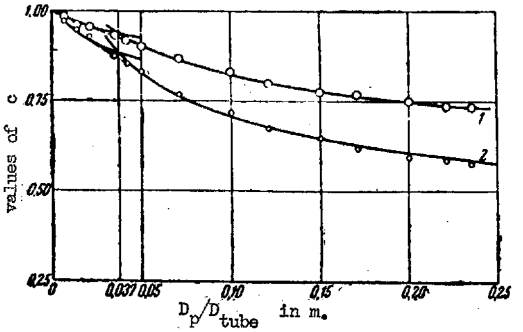

FIG. 2. DEPENDENCE OF THE COEFFICIENT OF THE EFFECT OF THE WALLS c UPON THE RATIO OF THE AVERAGE DIAMETER OF THE PARTICLES TO THE DIAMETER OF THE TUBE D_p/D_{tube} BY THE FORMULA OF CHILTON AND COLBURN.
1 - for streamline flow; 2 - for turbulent flow

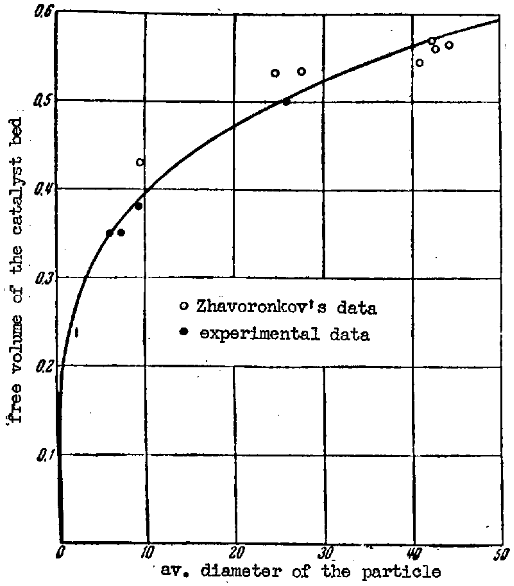

FIG. 3. DEPENDENCE OF THE FREE VOLUME OF THE CATALYST BED UPON THE AVERAGE DIAMETER OF THE PARTICLES.

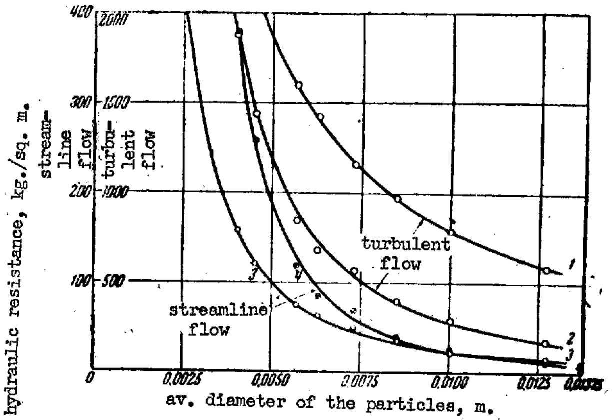

FIG. 4. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYST BED Δp UPON THE AVERAGE DIAMETER OF THE CATALYST GRAINS. For turbulent flow: 1 - according to Chilton and Colburn; 2 - according to Zhavoronkov. For streamline flow: 3 - according to Zhavoronkov; 4 - according to Chilton and Colburn.

TABLE 2. INTERDEPENDENCE BETWEEN THE FREE SPACE OF THE PACKING AND THE AVERAGE DIAMETER OF THE GRAIN

No.	Type of packing	Shape	Dimensions of the grains, mm.	Av. diameter of the grain, mm.	Free space
1*	Glass rods	Cylinders	5 × 5 × 8	6,0	0,35
2*	Aluminosilicate catalyst	Cylindrical tablets	9 × 9 × 4	7,3	0,35
3	Catalyst for conversion of CO	Tablets	11 × 11 × 6	9,3	0,38
4	Vanadium catalyst	"	11 × 11 × 6,5	9,5	0,43
5	Coke	Irregular	29,6 × 25,8 × 18	24,5	0,532
6*	Glass granules	Pear-shaped	20 × 20 × 37,5	25,8	0,500
7	Coke	Irregular	35,6 × 28,8 × 18	27,5	0,535
8	"	"	47,6 × 41,5 × 33,4	40,8	0,545
9	Gravel	Spherical	56,8 × 40,8 × 29	42,2	0,570
10	Coke	Irregular	52 × 40,3 × 35,5	42,6	0,560
11	Andesite	"	56 × 43,7 × 32,6	44,1	0,565

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* Catalyst tested in this work

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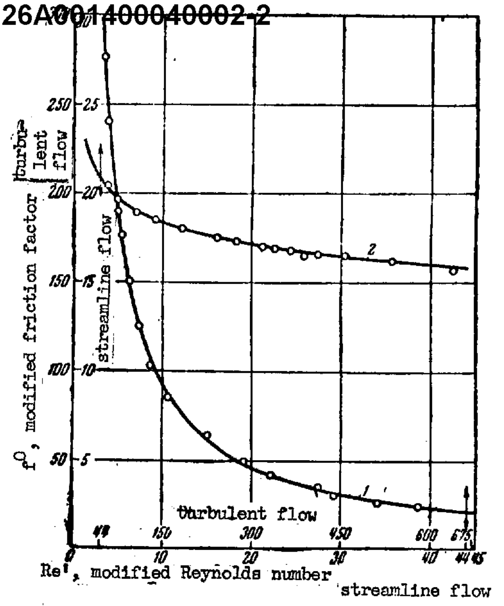
1946, 421 ff.

TABLE 1. HYDRAULIC RESISTANCE OF CATALYTIC TOWERS WITHOUT THE CATALYST AND WITH IT

No.	Temp., °C.	Dimensions of the tube, m.		Rate of flow of the air		Number of tubes in the tower	Character of the flow	Δp, pressure drop		
								In the empty column		According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
		Diameter D_{tube}	Altitude Δ l (H)	Q, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	
1	15	0,1	1	2,28	0,068	1	streamline	$4{,}03 \cdot 10^{-4}$	0,054	53,2
2	15	0,1	1	33,5	1	1	turbulent	0,019	35,2	219,2
3	500	0,2	2,544	3,46	0,068	1	streamline	$1{,}09 \cdot 10^{-5}$	0,07	67,6
4	500	0,2	2,544	3,46	0,0004 (0,000378)	180	»	$6{,}07 \cdot 10^{-8}$	0,07	67,6
5	500	0,2	2,544	50,9	1	1	turbulent	0,013	7,93	492,8
6	500	0,2	2,544	50,9	0,0055	180	streamline	0,004	0,01	985
7	500	0,2	2,544	18304	360	1	turbulent	446,4	$3{,}09 \cdot 10^{5}$	$1{,}96 \cdot 10^{7}$
8	500	0,2	2,544	18304	2	180	»	0,044	$4{,}85 \cdot 10^{3}$	$3{,}07 \cdot 10^{7}$



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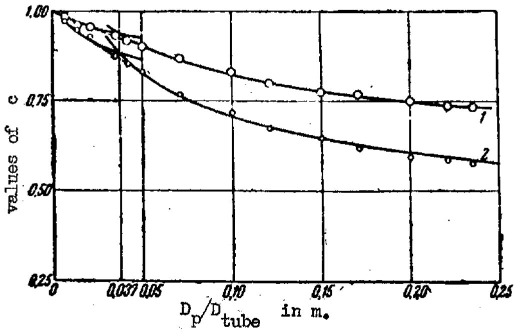

FIG. 2. DEPENDENCE OF THE COEFFICIENT OF THE EFFECT OF THE WALLS c UPON THE RATIO OF THE AVERAGE DIAMETER OF THE PARTICLES TO THE DIAMETER OF THE TUBE D_p/D_{tube} BY THE FORMULA OF CHILTON AND COLBURN. 1 - for streamline flow; 2 - for turbulent flow

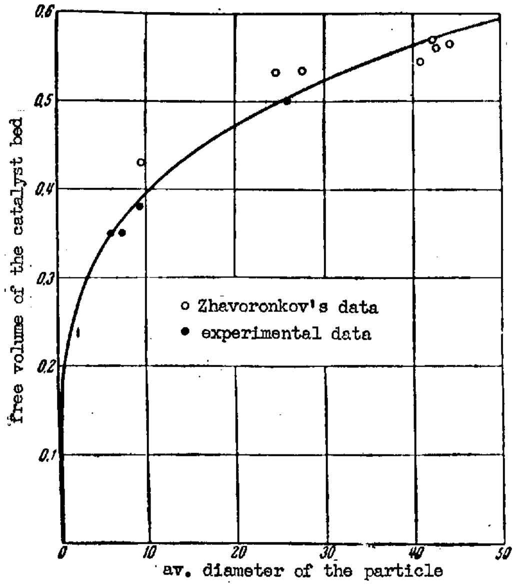

FIG. 3. DEPENDENCE OF THE FREE VOLUME OF THE CATALYST BED UPON THE AVERAGE DIAMETER OF THE PARTICLES.

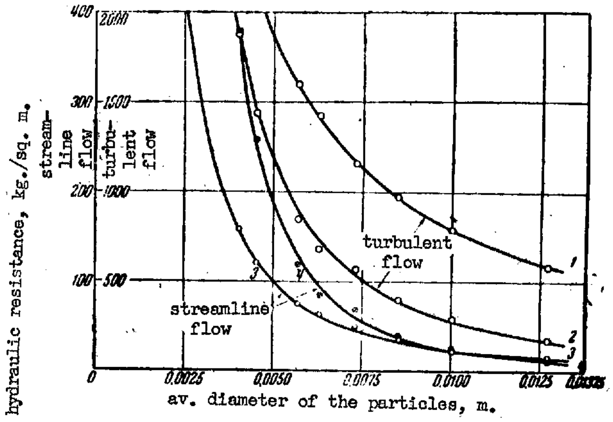

FIG. 4. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYST BED Δp UPON THE AVERAGE DIAMETER OF THE CATALYST GRAINS. For turbulent flow: 1 - according to Chilton and Colburn; 2 - according to Zhavoronkov. For streamline flow: 3 - according to Zhavoronkov; 4 - according to Chilton and Colburn.

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Izv. (tekh.)
1946, 421 ff.

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*Catalyst tested in this work

TABLE 1. HYDRAULIC RESISTANCE OF CATALYTIC TOWERS WITHOUT THE CATALYST AND WITH IT

No.	Temp., °C.	Dimensions of the tube m.		Rate of flow of the air		Number of tubes in the tower	Character of the flow	Δp, pressure drop		
								In the empty column		According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
		Diameter D_{tube}	Altitude Δl (H)	Q, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	
1	15	0,1	1	2,28	0,068	1	streamline	$4{,}03\cdot10^{-4}$	0,054	53,2
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3	500	0,2	2,544	3,46	0,068	1	streamline	$1{,}09\cdot10^{-5}$	0,07	67,6
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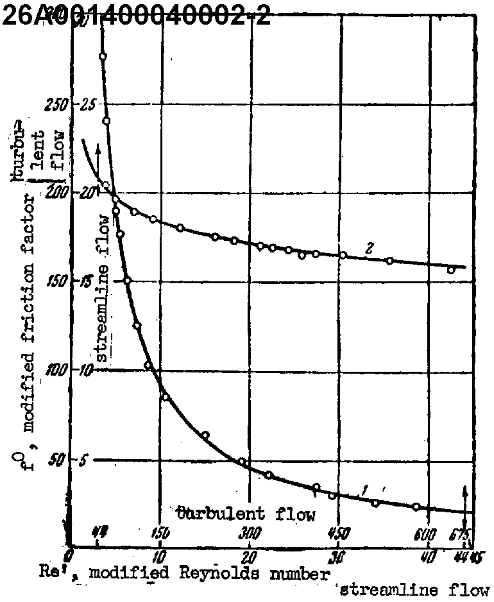
8	500	0,2	2,544	18304	2	180	»	0,044	$4{,}85\cdot10^{3}$	$3{,}07\cdot10^{7}$



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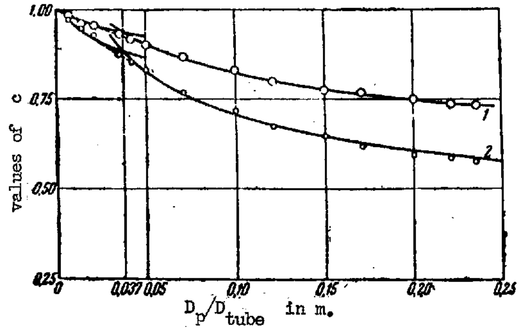

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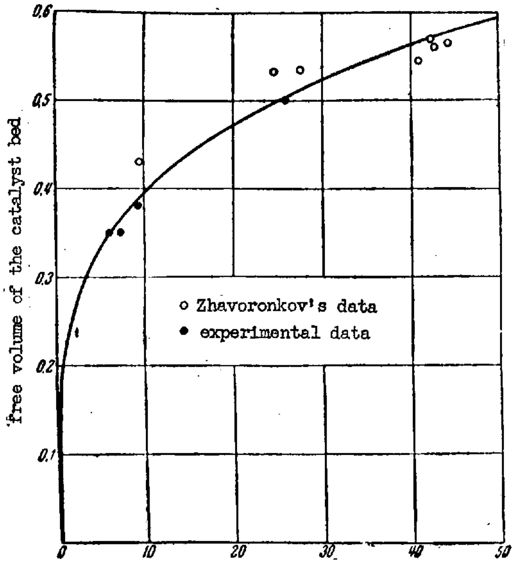

FIG. 3. DEPENDENCE OF THE FREE VOLUME OF THE CATALYST BED UPON THE AVERAGE DIAMETER OF THE PARTICLES.

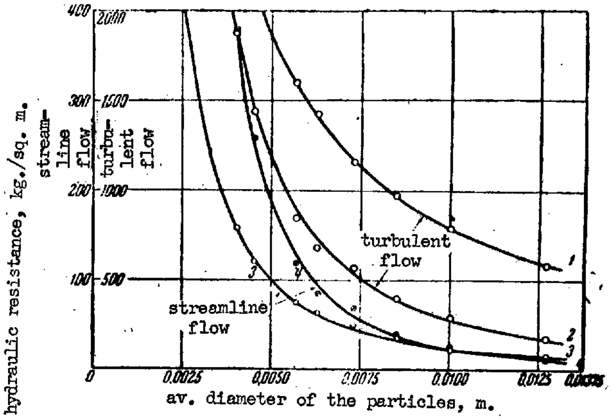

FIG. 4. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYST BED Δ p UPON THE AVERAGE DIAMETER OF THE CATALYST GRAINS. For turbulent flow: 1 - according to Chilton and Colburn; 2 - according to Zhavoronkov. For streamline flow: 3 - according to Zhavoronkov; 4 - according to Chilton and Colburn.

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Izv. (tekh.)
1946, 421 ff.

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* Catalyst [illegible]

TABLE 1. HYDRAULIC RESISTANCE OF CATALYTIC TOWERS WITHOUT THE CATALYST AND WITH IT

No.	Temp., °C.	Dimensions of the tube, m.		Rate of flow of the air		Number of tubes in the tower	Character of the flow	Δp, pressure drop		
								In the empty column		
		Diameter D_{tube}	Altitude Δl (H)	Q, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
1	15	0,1	1	2,28	0,068	1	streamline	$4{,}03\cdot10^{-4}$	0,054	53,2
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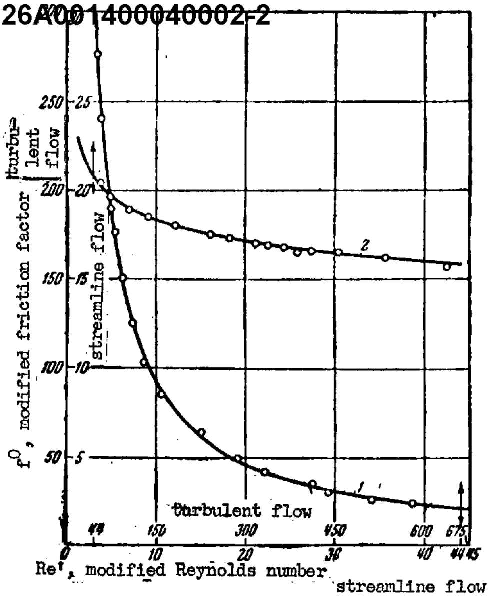

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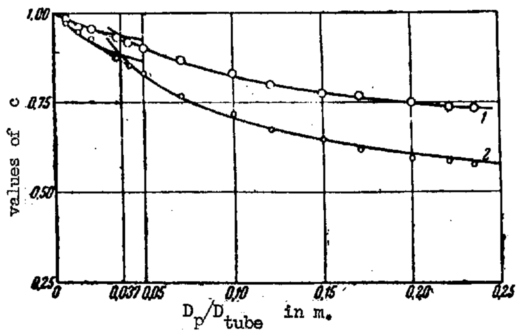

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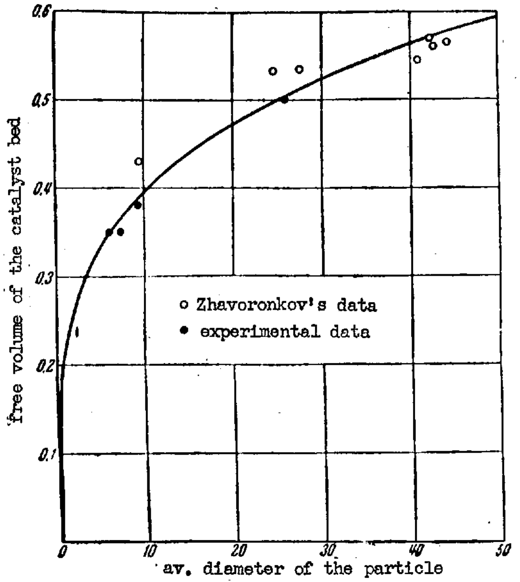
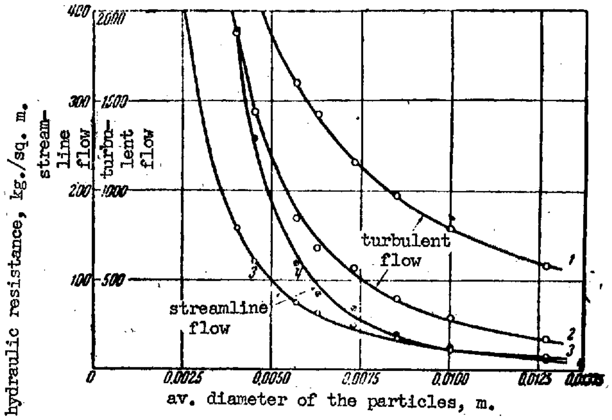


FIG. 3. DEPENDENCE OF THE FREE VOLUME OF THE CATALYST BED UPON THE AVERAGE DIAMETER OF THE PARTICLES.



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* catalyst [illegible]

Izv. (tekh.)
1946, 421 ff.

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								In the empty column		
		Diameter D_{tube}	Altitude Δ*l* (H)	$\mathcal{Q}$, kg./hr.	w(v_0), m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
1	15	0,1	1	2,28	0,068	1	streamline	$4{,}03\cdot10^{-4}$	0,054	53,2
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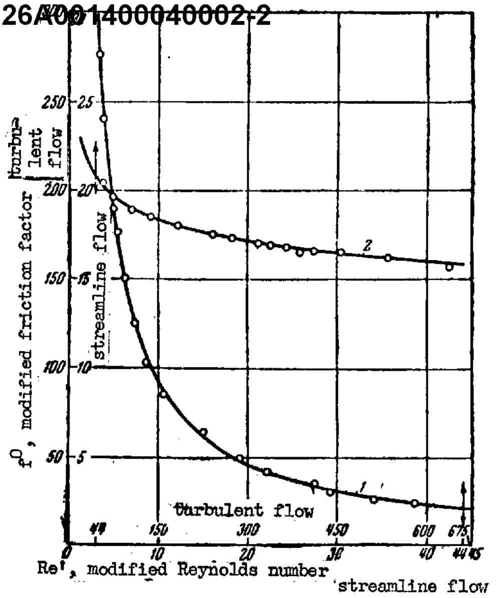

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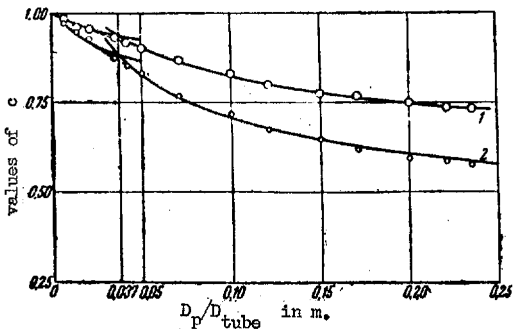

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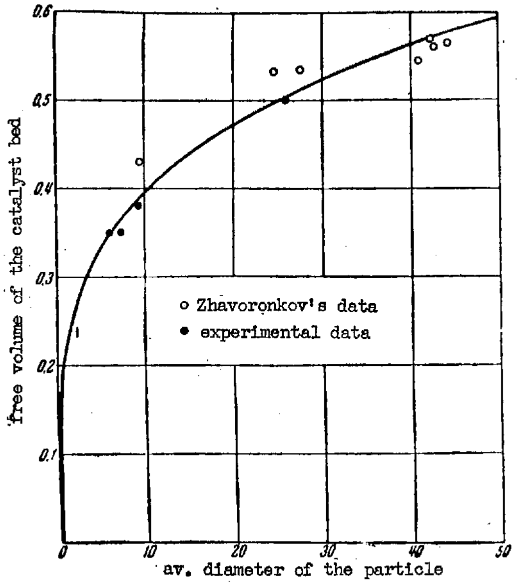

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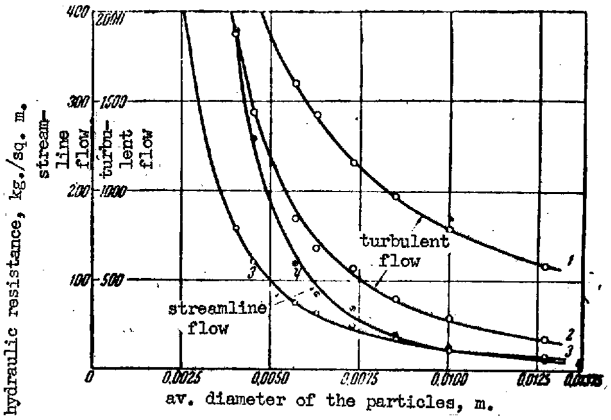

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*Catalyst [illegible] this [illegible]

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								According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	
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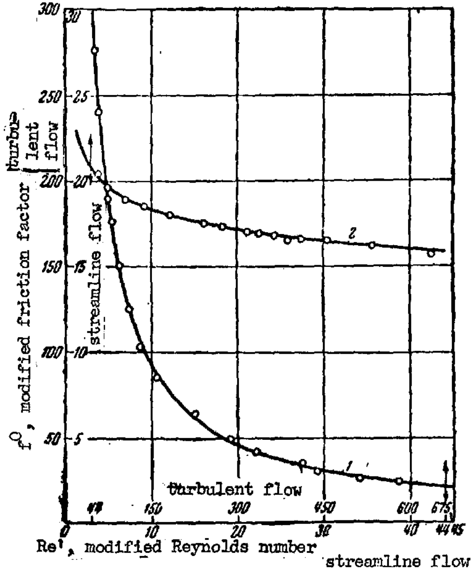

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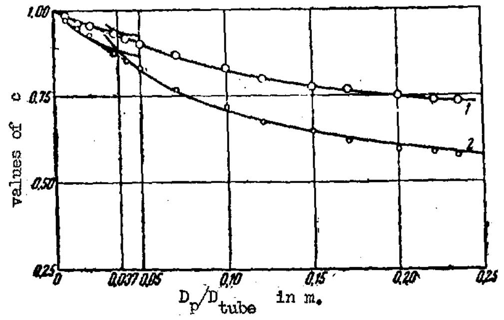

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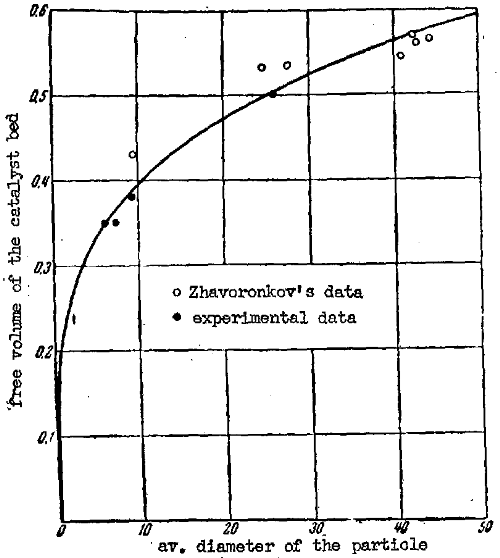

FIG. 3. DEPENDENCE OF THE FREE VOLUME OF THE CATALYST BED UPON THE AVERAGE DIAMETER OF THE PARTICLES.

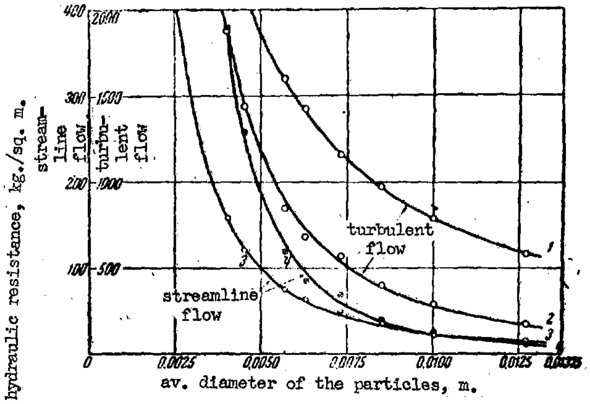

FIG. 4. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYST BED Δp UPON THE AVERAGE DIAMETER OF THE CATALYST GRAINS. For turbulent flow: 1 - according to Chilton and Colburn; 2 - according to Zhavoronkov. For streamline flow: 3 - according to Zhavoronkov; 4 - according to Chilton and Colburn.

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1946, 421 ff.

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2*	Aluminosilicate catalyst	Cylindrical tablets	9 × 9 × 4	7,3	0,35
3	Catalyst for conversion of CO	Tablets	11 × 11 × 6	9,3	0,38
4	Vanadium catalyst	"	11 × 11 × 6.5	9,5	0,43
5	Coke	Irregular	29,6 × 25,8 × 18	24,5	0,532
6*	Glass granules	Pear-shaped	20 × 20 × 37,5	25,8	0,500
7	Coke	Irregular	35,6 × 28,8 × 18	27,5	0,535
8	"	"	47,6 × 41,5 × 33,4	40,8	0,545
9	Gravel	Spherical	56,8 × 40,8 × 29	42,2	0,570
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* Catalyst tested in this work

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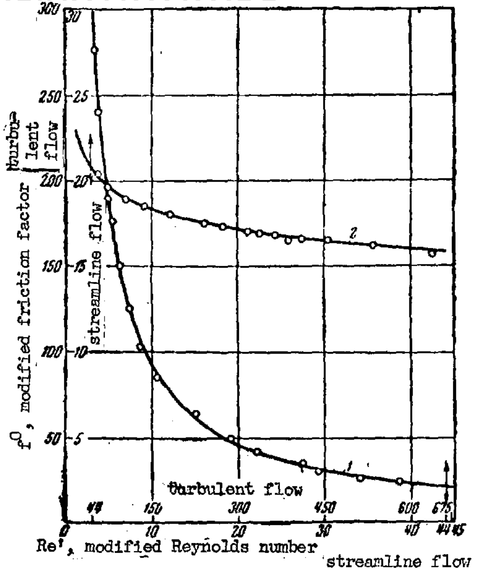
No.	Temp., °C.	Dimensions of the tube m.		Rate of flow of the air		Number of tubes in the tower	Character of the flow	Δp, pressure drop		
								In the empty column		
		Diameter D_{tube}	Altitude Δl (H)	φ, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
1	15	0,1	1	2,28	0,068	1	streamline	$4{,}03\cdot10^{-4}$	0,054	53,2
2	15	0,1	1	33,5	1	1	turbulent	0,019	35,2	219,2
3	500	0,2	2,544	3,46	0,068	1	streamline	$1{,}09\cdot10^{-5}$	0,07	67,6
4	500	0,2	2,544	3,46	0,0004 (0,000378)	180	»	$6{,}07\cdot10^{-8}$	0,07	67,6
5	500	0,2	2,544	50,9	1	1	turbulent	0,013	7,93	492,8
6	500	0,2	2,544	50,9	0,0055	180	streamline	0,004	0,01	985
7	500	0,2	2,544	18304	360	1	turbulent	446,4	$3{,}09\cdot10^{5}$	$1{,}96\cdot10^{7}$
8	500	0,2	2,544	18304	2	180	»	0,044	$4{,}85\cdot10^{3}$	$3{,}07\cdot10^{7}$



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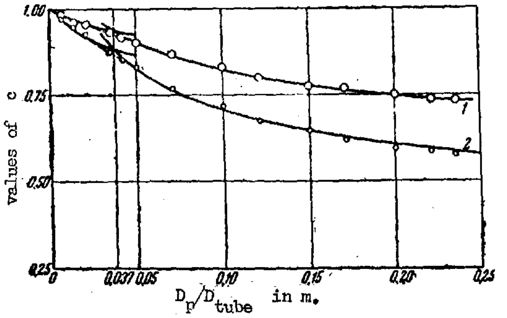

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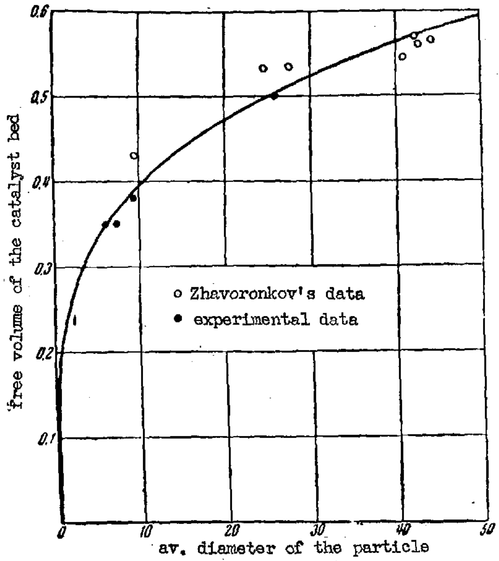

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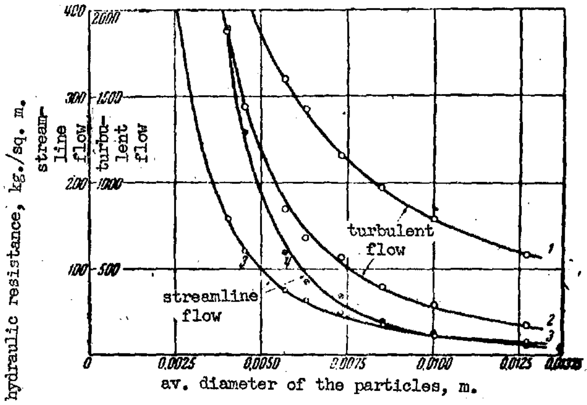

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								In the empty column		
		Diameter D_{tube}	Altitude Δl (H)	Q, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
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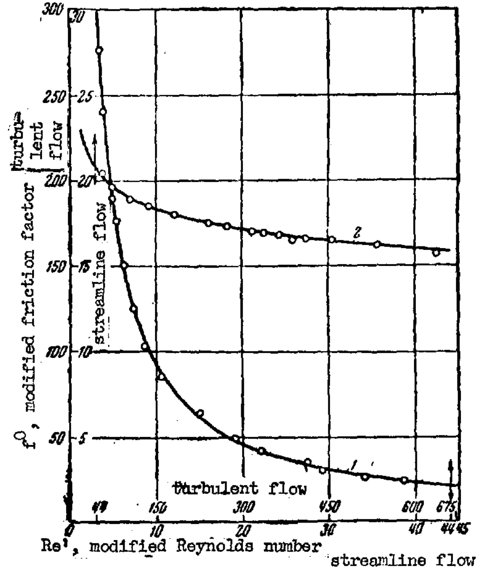

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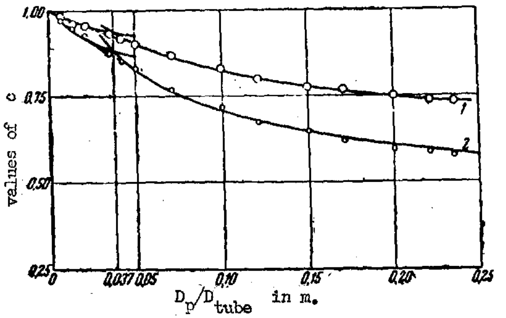

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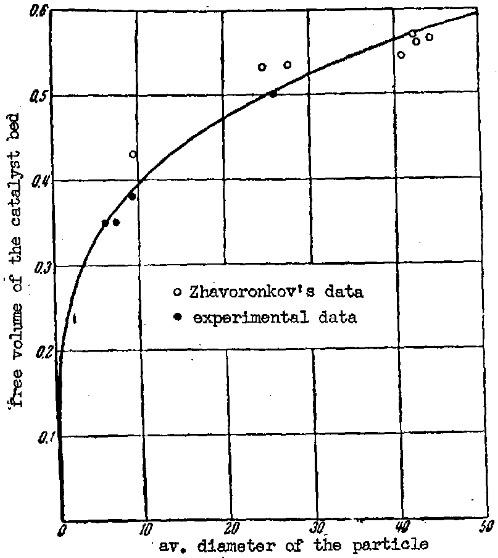

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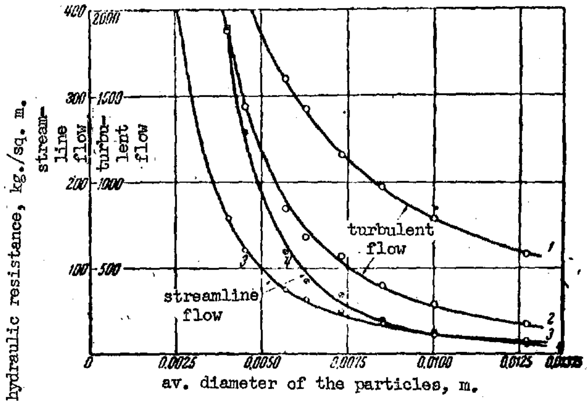

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Izv. (tekh.)
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No.	Temp., °C.	Dimensions of the tube, m.		Rate of flow of the air		Number of tubes in the tower	Character of the flow	Δp, pressure drop		
								In the empty column		According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
		Diameter D_{tube}	Altitude Δl (H)	G, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	
1	15	0,1	1	2,28	0,068	1	streamline	$4{,}03\cdot10^{-4}$	0,054	53,2
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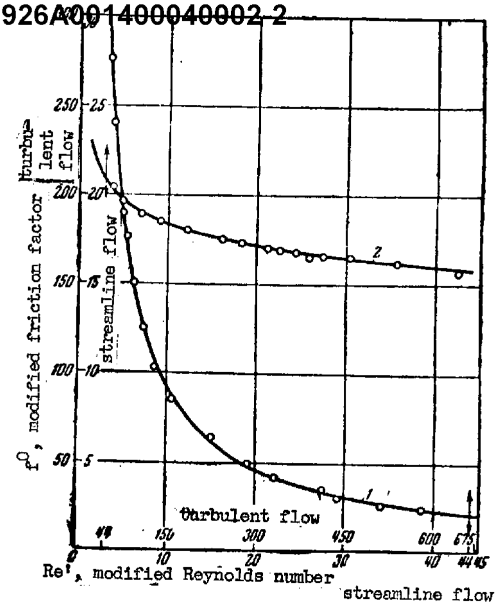

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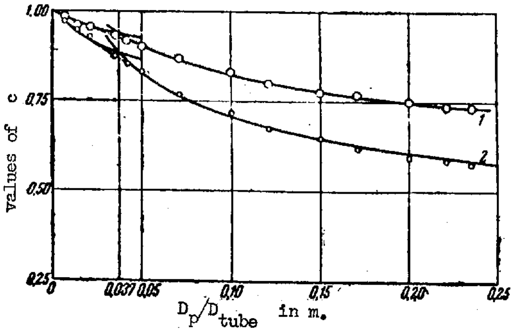

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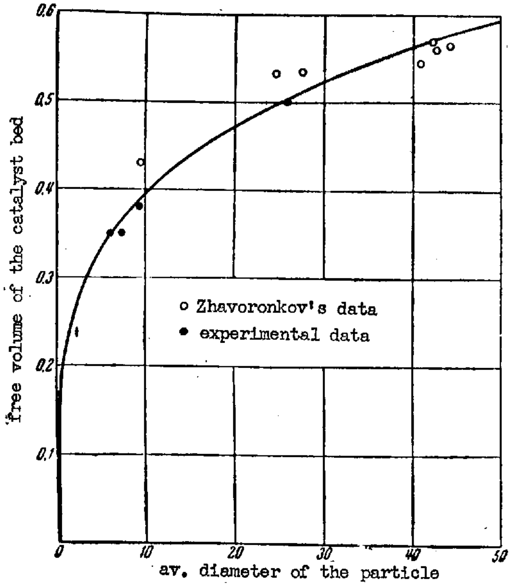

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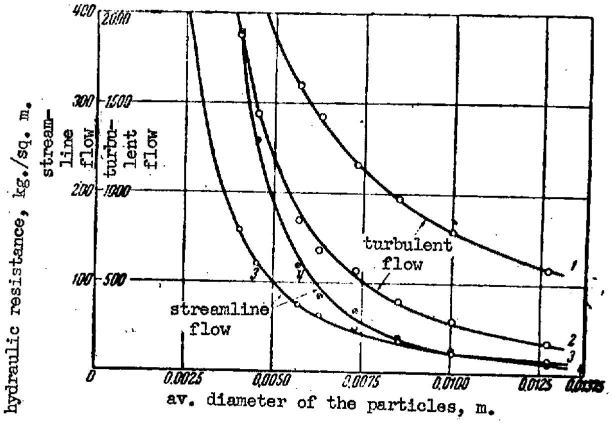

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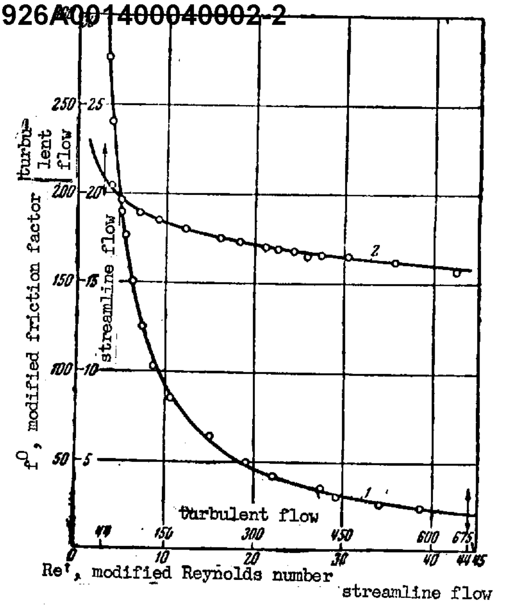

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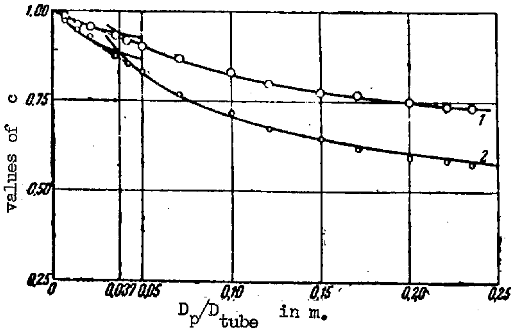

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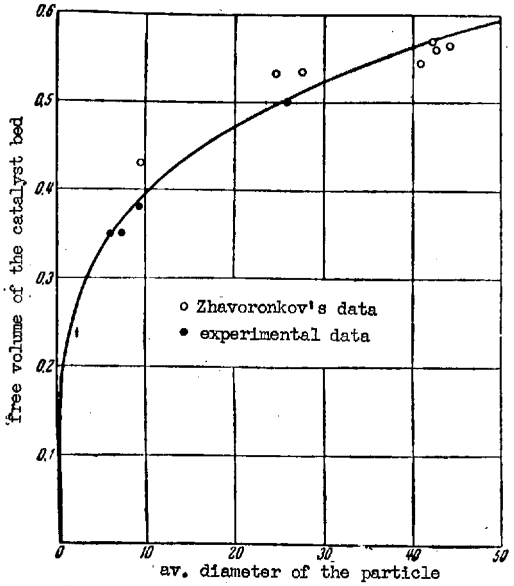

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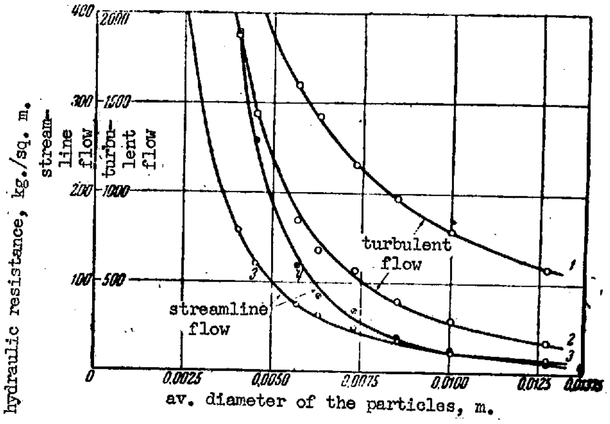

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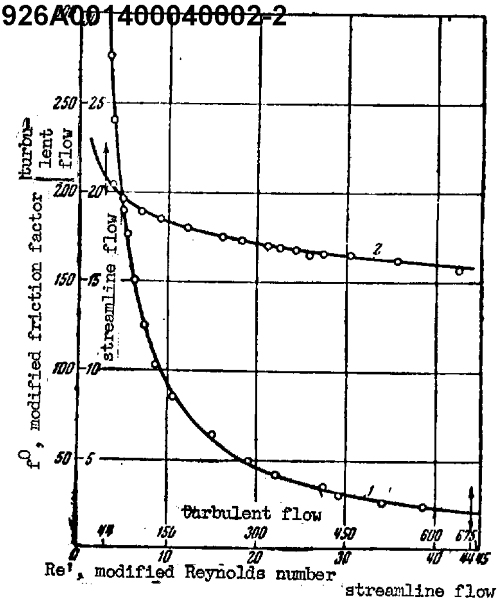
8	500	0,2	2,544	18304	2	180	»	0,044	$4{,}85 \cdot 10^3$	$3{,}07 \cdot 10^7$



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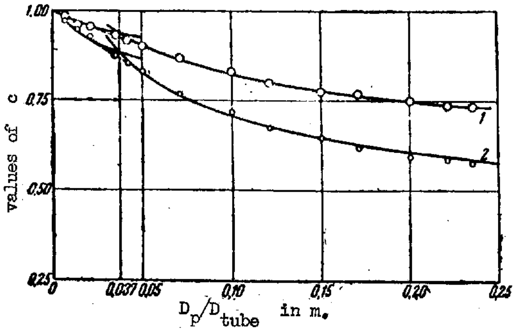

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1 - for streamline flow; 2 - for turbulent flow

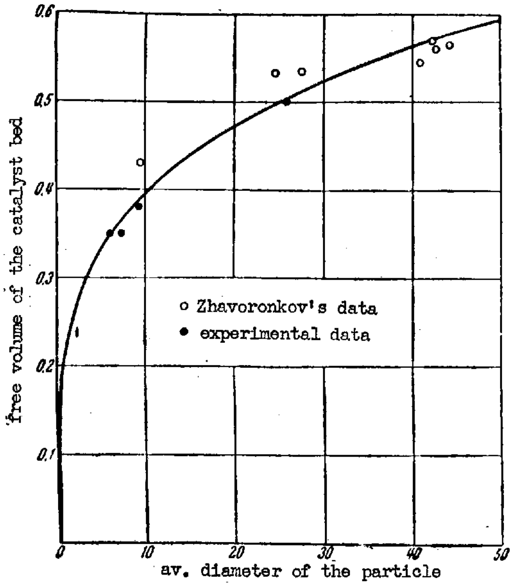

FIG. 3. DEPENDENCE OF THE FREE VOLUME OF THE CATALYST BED UPON THE AVERAGE DIAMETER OF THE PARTICLES.

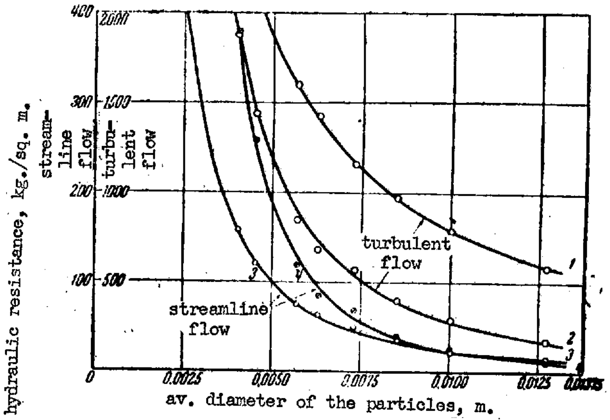

FIG. 4. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYST BED Δp UPON THE AVERAGE DIAMETER OF THE CATALYST GRAINS. For turbulent flow: 1 - according to Chilton and Colburn; 2 - according to Zhavoronkov. For streamline flow: 3 - according to Zhavoronkov; 4 - according to Chilton and Colburn.

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4	Vanadium catalyst	"	11 × 11 × 6,5	9,5	0,43
5	Coke	Irregular	29,6 × 25,8 × 18	24,5	0,532
6*	Glass granules	Pear-shaped	20 × 20 × 37,5	25,8	0,500
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9	Gravel	Spherical	56,8 × 40,8 × 29	42,2	0,570
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* Catalyst tested in this work

Izv. (tekh.)
1946, 421 ff.

TABLE 1. HYDRAULIC RESISTANCE OF CATALYTIC TOWERS WITHOUT THE CATALYST AND WITH IT

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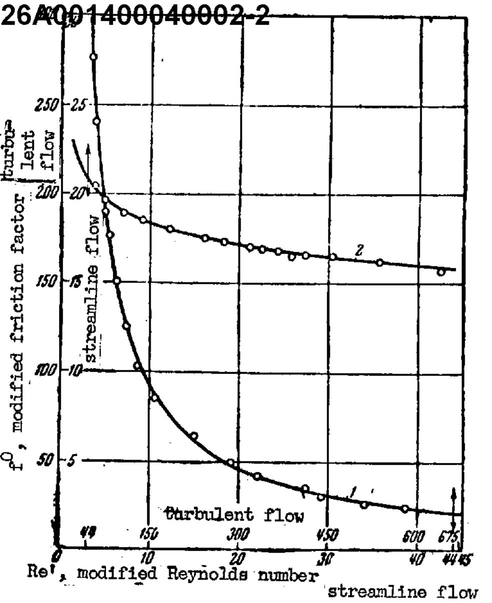
								In the empty column		
		Diameter D_{tube}	Altitude Δl (H)	$\mathcal{G}$, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
1	15	0,1	1	2,28	0,068	1	streamline	$4{,}03\cdot10^{-4}$	0,054	53,2
2	15	0,1	1	33,5	1	1	turbulent	0,019	35,2	219,2
3	500	0,2	2,544	3,46	0,068	1	streamline	$1{,}09\cdot10^{-5}$	0,07	67,6
4	500	0,2	2,544	3,46	0,0004 (0,000378)	180	»	$6{,}07\cdot10^{-8}$	0,07	67,6
5	500	0,2	2,544	50,9	1	1	turbulent	0,013	7,93	492,8
6	500	0,2	2,544	50,9	0,0055	180	streamline	0,004	0,01	985
7	500	0,2	2,544	18304	360	1	turbulent	446,4	$3{,}09\cdot10^{5}$	$1{,}96\cdot10^{7}$
8	500	0,2	2,544	18304	2	180	»	0,044	$4{,}85\cdot10^{3}$	$3{,}07\cdot10^{7}$



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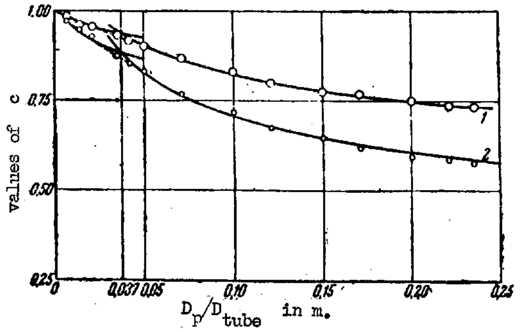

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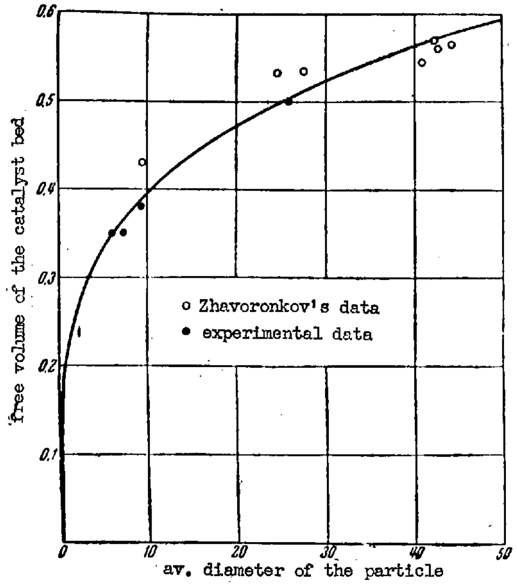

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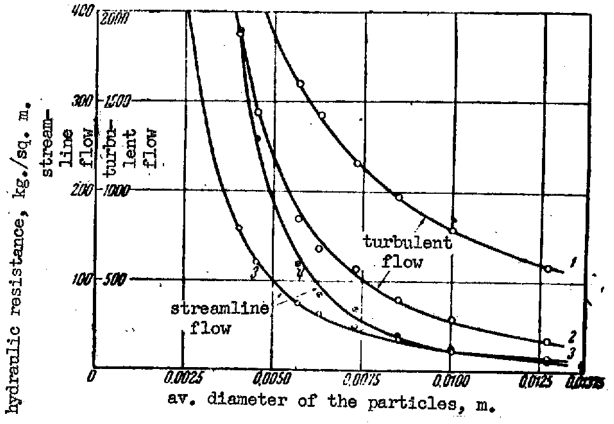

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Izv. (tekh.)
1946, 421 ff.

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								In the empty column		According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
		Diameter D_{tube}	Altitude Δl (H)	Q, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	
1	15	0,1	1	2,28	0,068	1	streamline	$4,03 \cdot 10^{-4}$	0,054	53,2
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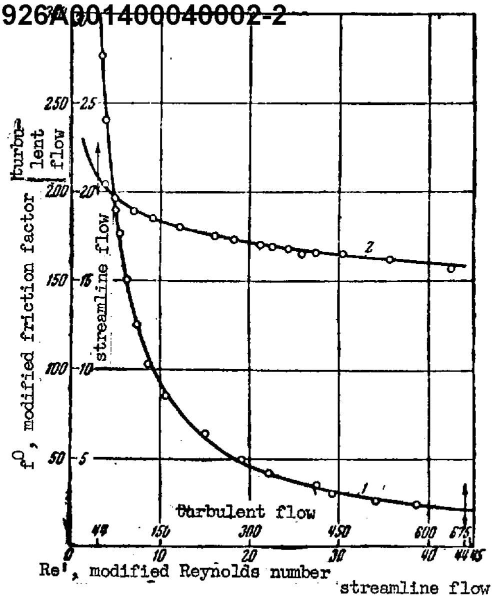

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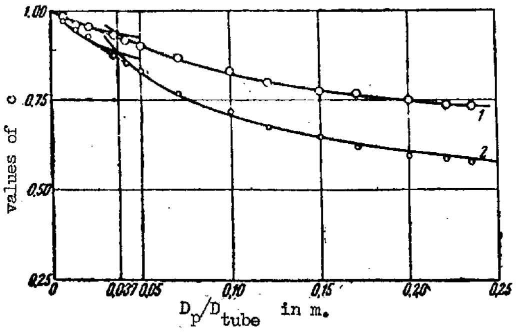
1 - streamline flow; 2 - turbulent flow



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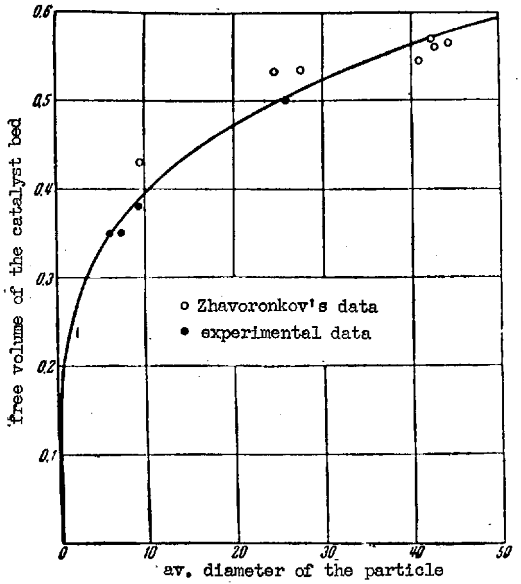

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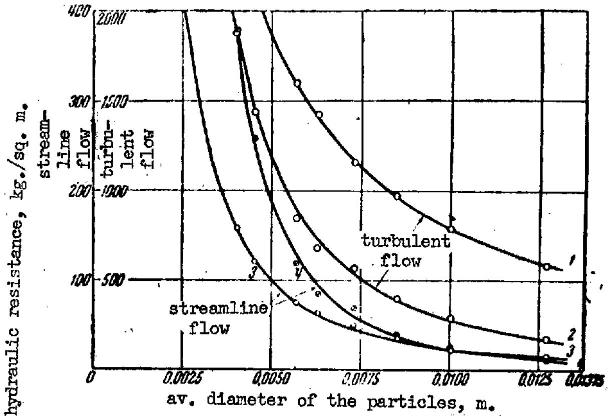

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Izv. (tekh.)
1946, 421 ff.

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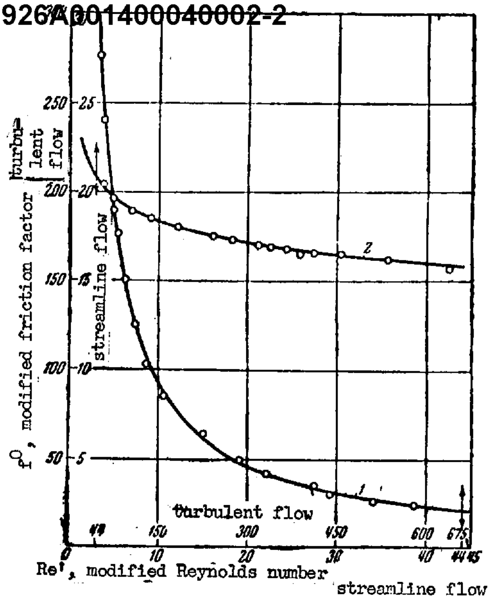

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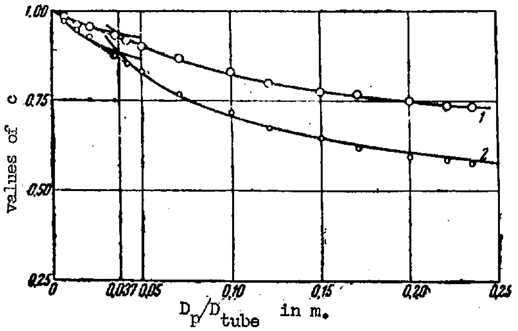

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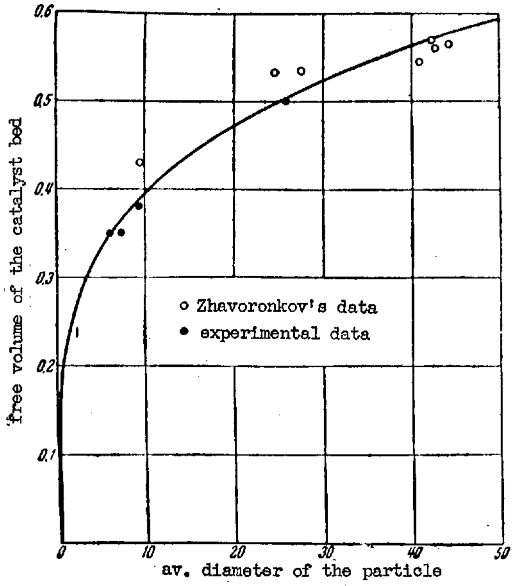

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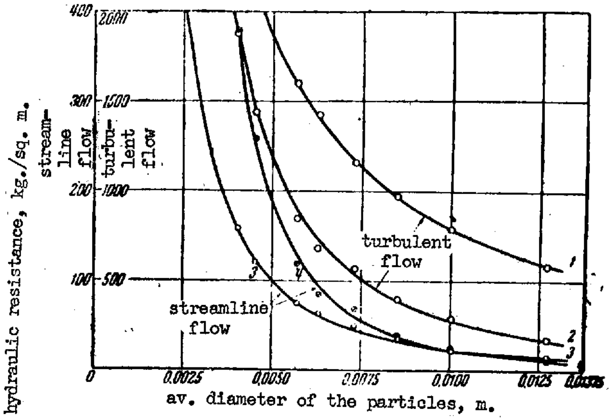

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Izv. (tekh.)
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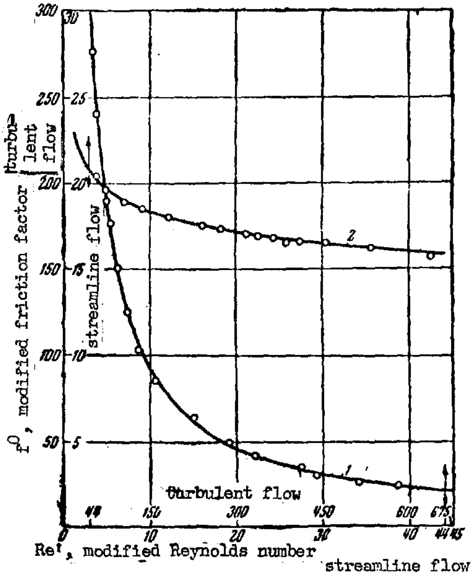

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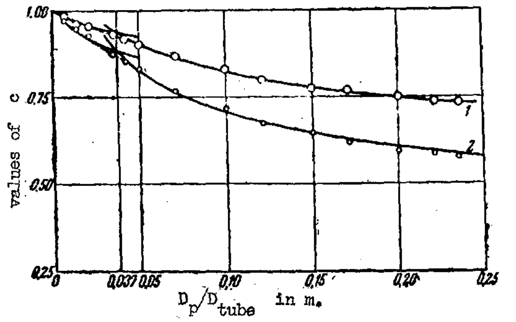

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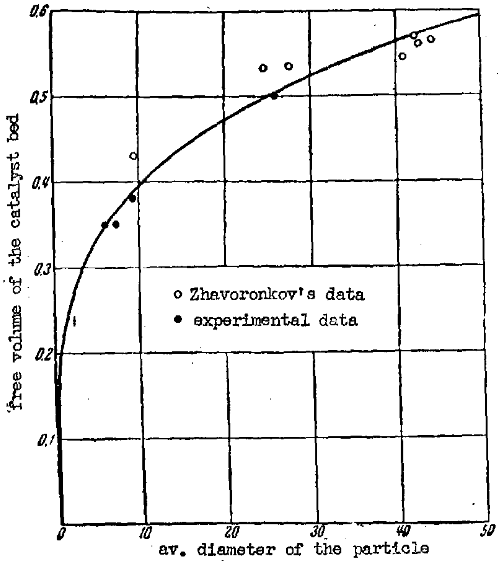

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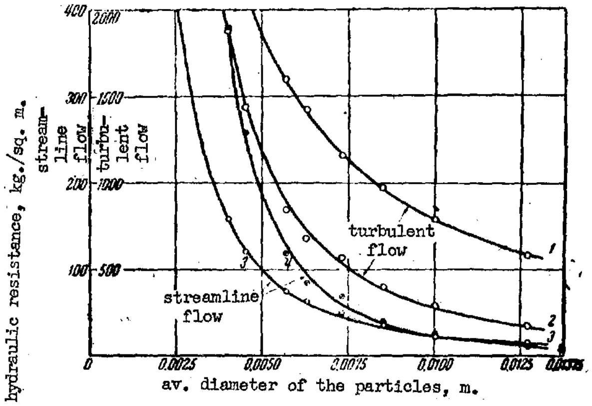

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8	500	0,2	2,544	18304	2	180	»	0,044	$4{,}85\cdot10^{3}$	$3{,}07\cdot10^{7}$

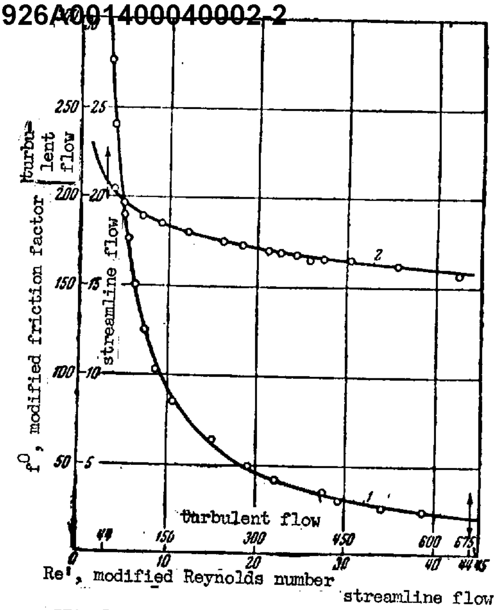

FIG. 1. DEPENDENCE OF THE MODIFIED FRICTION FACTOR f^0 UPON THE MODIFIED REYNOLDS NUMBER Re' BY THE FORMULA OF CHILTON AND COLBURN. 1 - streamline flow; 2 - turbulent flow

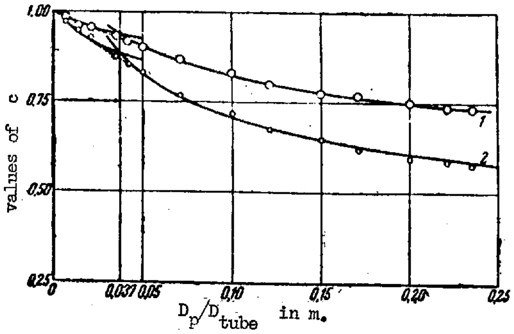

FIG. 2. DEPENDENCE OF THE COEFFICIENT OF THE EFFECT OF THE WALLS c UPON THE RATIO OF THE AVERAGE DIAMETER OF THE PARTICLES TO THE DIAMETER OF THE TUBE D_p/D_{tube} BY THE FORMULA OF CHILTON AND COLBURN. 1 - for streamline flow; 2 - for turbulent flow

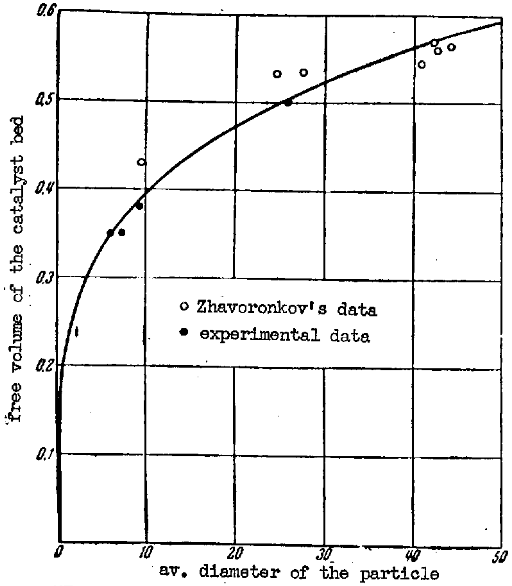

FIG. 3. DEPENDENCE OF THE FREE VOLUME OF THE CATALYST BED UPON THE AVERAGE DIAMETER OF THE PARTICLES.

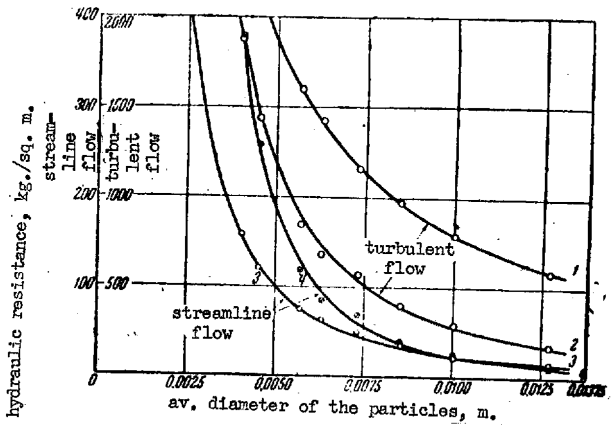

FIG. 4. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYST BED Δp UPON THE AVERAGE DIAMETER OF THE CATALYST GRAINS. For turbulent flow: 1 - according to Chilton and Colburn; 2 - according to Zhavoronkov. For streamline flow: 3 - according to Zhavoronkov; 4 - according to Chilton and Colburn.

TABLE 2. INTERDEPENDENCE BETWEEN THE FREE SPACE OF THE PACKING AND THE AVERAGE DIAMETER OF THE GRAIN

No.	Type of packing	Shape	Dimensions of the grains, mm.	Av. diameter of the grain, mm.	Free space
1*	Glass rods	Cylinders	5 × 5 × 8	6,0	0,35
2*	Aluminosilicate catalyst	Cylindrical tablets	9 × 9 × 4	7,3	0,35
3	Catalyst for conversion of CO	Tablets	11 × 11 × 6	9,3	0,38
4	Vanadium catalyst	"	11 × 11 × 6,5	9,5	0,43
5	Coke	Irregular	29,6 × 25,8 × 18	24,5	0,532
6*	Glass granules	Pear-shaped	20 × 20 × 37,5	25,8	0,500
7	Coke	Irregular	35,6 × 28,8 × 18	27,5	0,535
8	"	"	47,6 × 41,5 × 33,4	40,8	0,545
9	Gravel	Spherical	56,8 × 40,8 × 29	42,2	0,570
10	Coke	Irregular	52 × 40,3 × 35,5	42,6	0,560
11	Andesite	"	56 × 43,7 × 32,6	44,1	0,565

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* Catalyst tested [illegible]

Izv. (tekh.)
1946, 421 ff.

TABLE 1. HYDRAULIC RESIS[illegible] CATALYTIC TOWERS WITHOUT THE CATALYST AND WITH IT

No.	Temp., °C.	Dimensions of the tube, m.		Rate of flow of the air		Number of tubes in the tower	Character of the flow	Δp, pressure drop		
								In the empty column		
		Diameter D_{tube}	Altitude Δl (H)	Q, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
1	15	0,1	1	2,28	0,068	1	streamline	$4{,}03 \cdot 10^{-4}$	0,054	53,2
2	15	0,1	1	33,5	1	1	turbulent	0,019	35,2	219,2
3	500	0,2	2,544	3,46	0,068	1	streamline	$1{,}09 \cdot 10^{-5}$	0,07	67,6
4	500	0,2	2,544	3,46	0,0004 (0,000378)	180	»	$6{,}07 \cdot 10^{-8}$	0,07	67,6
5	500	0,2	2,544	50,9	1	1	turbulent	0,013	7,93	492,8
6	500	0,2	2,544	50,9	0,0055	180	streamline	0,004	0,01	985
7	500	0,2	2,544	18304	360	1	turbulent	446,4	$3{,}09 \cdot 10^{5}$	$1{,}96 \cdot 10^{7}$
8	500	0,2	2,544	18304	2	180	»	0,044	$4{,}85 \cdot 10^{3}$	$3{,}07 \cdot 10^{7}$

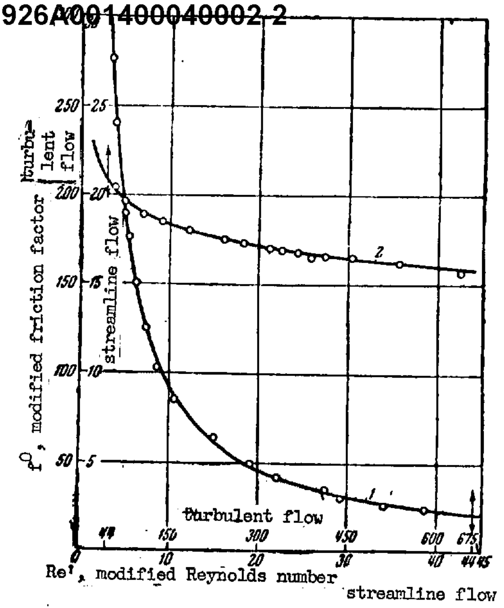

FIG. 1. DEPENDENCE OF THE MODIFIED FRICTION FACTOR f^0 UPON THE MODIFIED REYNOLDS NUMBER Re' BY THE FORMULA OF CHILTON AND COLBURN.
1 - streamline flow; 2 - turbulent flow

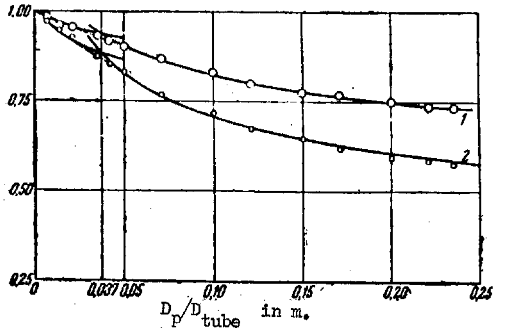

FIG. 2. DEPENDENCE OF THE COEFFICIENT OF THE EFFECT OF THE WALLS c UPON THE RATIO OF THE AVERAGE DIAMETER OF THE PARTICLES TO THE DIAMETER OF THE TUBE D_p/D_{tube} BY THE FORMULA OF CHILTON AND COLBURN.
1 - for streamline flow; 2 - for turbulent flow

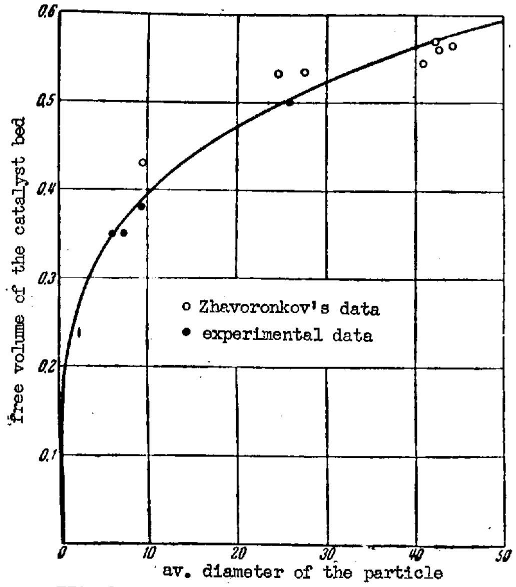

FIG. 3. DEPENDENCE OF THE FREE VOLUME OF THE CATALYST BED UPON THE AVERAGE DIAMETER OF THE PARTICLES.

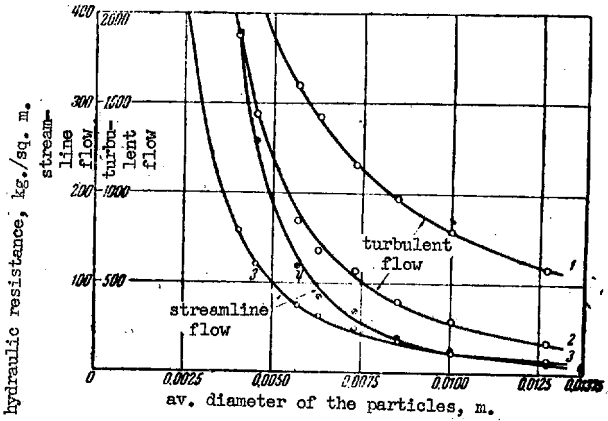

FIG. 4. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYST BED Δp UPON THE AVERAGE DIAMETER OF THE CATALYST GRAINS. For turbulent flow: 1 - according to Chilton and Colburn; 2 - according to Zhavoronkov. For streamline flow: 3 - according to Zhavoronkov; 4 - according to Chilton and Colburn.

TABLE 2. INTERDEPENDENCE BETWEEN THE FREE SPACE OF THE PACKING AND THE AVERAGE DIAMETER OF THE GRAIN

No.	Type of packing	Shape	Dimensions of the grains, mm.	Av. diameter of the grain, mm.	Free space
1*	Glass rods	Cylinders	5 × 5 × 8	6,0	0,35
2*	Aluminosilicate catalyst	Cylindrical tablets	9 × 9 × 4	7,3	0,35
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*Catalyst tested [illegible]

Izv. (tekh.)
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TABLE 1. HYDRAULIC RESIS[illegible] TOWERS WITHOUT THE CATALYST AND WITH IT

No.	Temp., °C.	Dimensions of the tube m.		Rate of flow of the air		Number of tubes in the tower	Character of the flow	Δp, pressure drop		
								In the empty column		
		Diameter D_{tube}	Altitude Δl (H)	Q, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
1	15	0,1	1	2,28	0,068	1	streamline	$4{,}03\cdot10^{-4}$	0,054	53,2
2	15	0,1	1	33,5	1	1	turbulent	0,019	35,2	219,2
3	500	0,2	2,544	3,46	0,068	1	streamline	$1{,}09\cdot10^{-5}$	0,07	67,6
4	500	0,2	2,544	3,46	0,0004 (0,000378)	180	»	$6{,}07\cdot10^{-8}$	0,07	67,6
5	500	0,2	2,544	50,9	1	1	turbulent	0,013	7,93	492,8
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7	500	0,2	2,544	18304	360	1	turbulent	446,4	$3{,}09\cdot10^{5}$	$1{,}96\cdot10^{7}$
8	500	0,2	2,544	18304	2	180	»	0,044	$4{,}85\cdot10^{7}$	$3{,}07\cdot10^{7}$

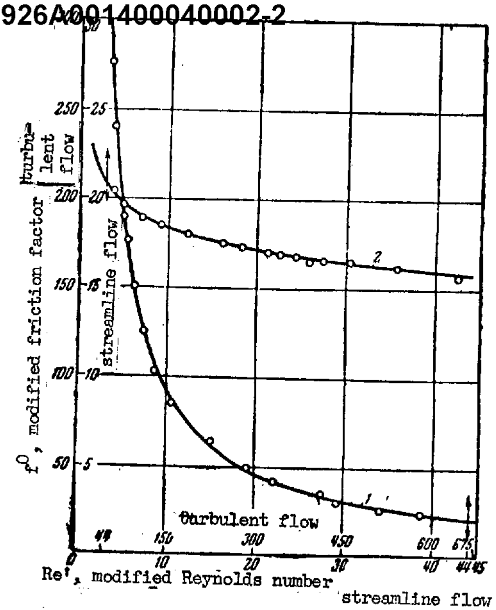

FIG. 1. DEPENDENCE OF THE MODIFIED FRICTION FACTOR f^0 UPON THE MODIFIED REYNOLDS NUMBER Re' BY THE FORMULA OF CHILTON AND COLBURN. 1 - streamline flow; 2 - turbulent flow

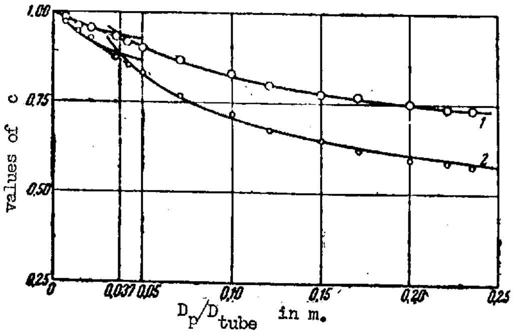

FIG. 2. DEPENDENCE OF THE COEFFICIENT OF THE EFFECT OF THE WALLS c UPON THE RATIO OF THE AVERAGE DIAMETER OF THE PARTICLES TO THE DIAMETER OF THE TUBE D_p/D_{tube} BY THE FORMULA OF CHILTON AND COLBURN. 1 - for streamline flow; 2 - for turbulent flow

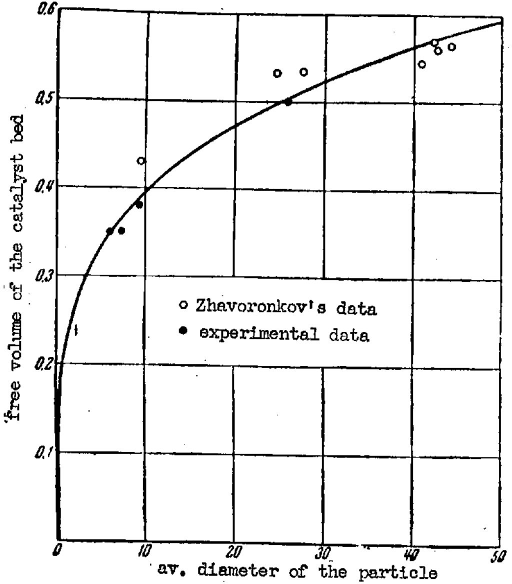

FIG. 3. DEPENDENCE OF THE FREE VOLUME OF THE CATALYST BED UPON THE AVERAGE DIAMETER OF THE PARTICLES.

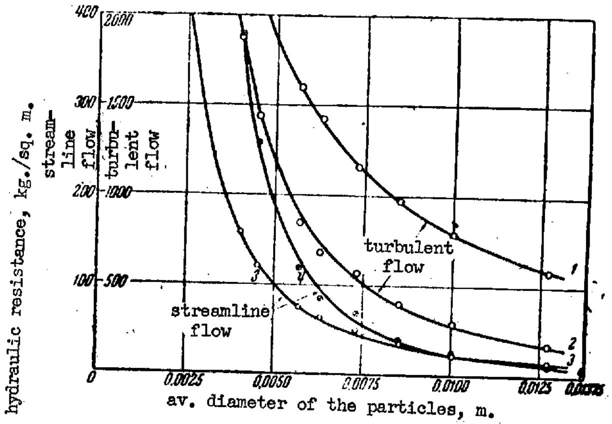

FIG. 4. DEPENDENCE OF THE HYDRAULIC RESISTANCE IN THE CATALYST BED Δp UPON THE AVERAGE DIAMETER OF THE CATALYST GRAINS. For turbulent flow: 1 - according to Chilton and Colburn; 2 - according to Zhavoronkov. For streamline flow: 3 - according to Zhavoronkov; 4 - according to Chilton and Colburn.

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* Catalyst tested in this work

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TABLE 1. HYDRAULIC RESISTANCE OF [illegible] CATALYST AND WITH IT

No.	Temp., °C.	Dimensions of the tube, m.		Rate of flow of the air		Number of tubes in the tower	Character of the flow	Δp, pressure drop		
								In the empty column		
		Diameter D_{tube}	Altitude Δl (H)	Q, kg./hr.	$w(v_0)$, m./sec.			According to d'Arcy, Blasius, Nikuradze	According to Zhavoronkov	According to Zhavoronkov, packed with the catalyst (cylinders 9 x 9 x 4 mm.)
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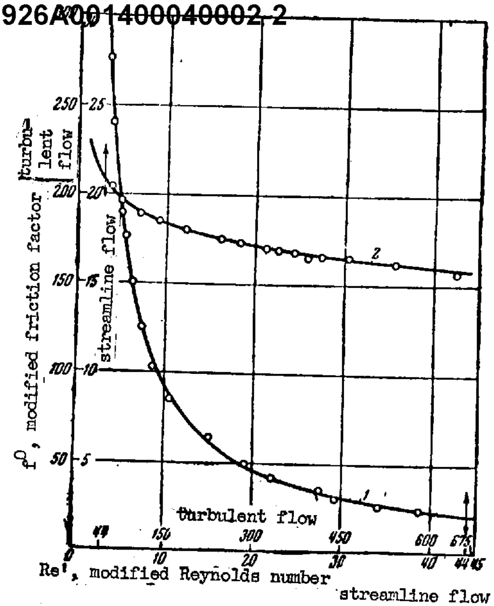

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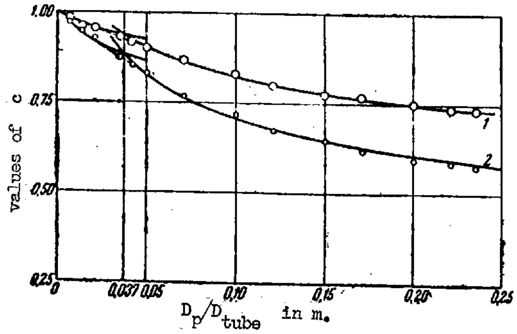

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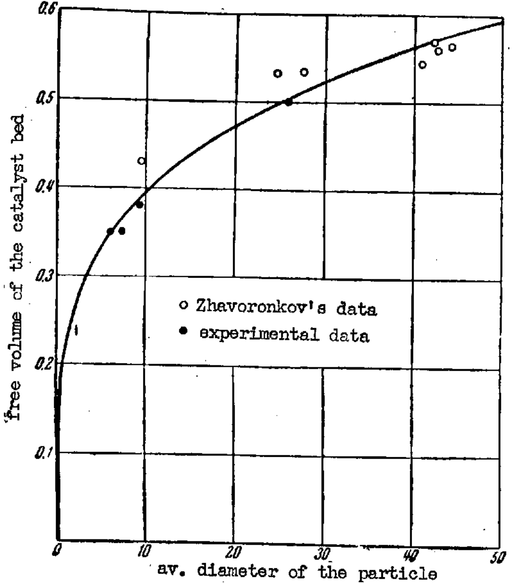
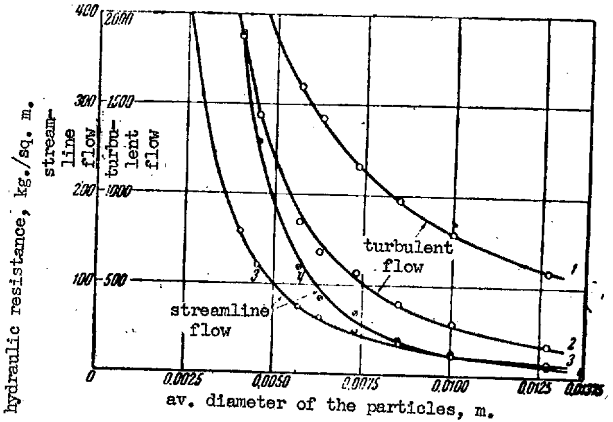


FIG. 3. DEPENDENCE OF THE FREE VOLUME OF THE CATALYST BED UPON THE AVERAGE DIAMETER OF THE PARTICLES.



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