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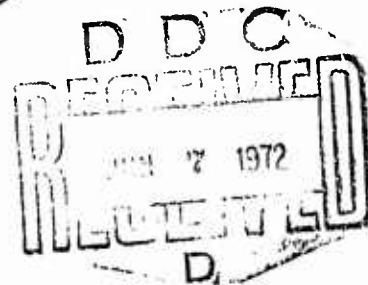
# FOREIGN TECHNOLOGY DIVISION



THE VISCOSITY OF METHANE-NITROGEN AND METHANE-NITROGEN-HYDROGEN MIXTURES AT TEMPERATURES FROM 273 TO 473°K AND PRESSURES TO  $490.3 \cdot 10^5$  N/m<sup>2</sup>

by

N. Ye. Gnezdilov and I. F. Golubev

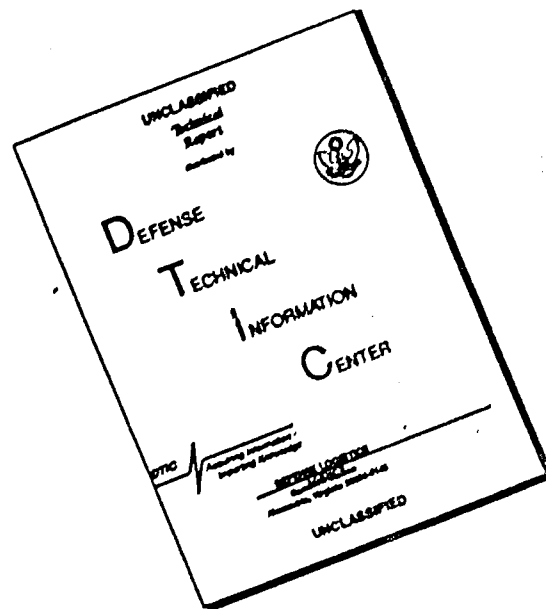


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THE VISCOSITY OF METHANE-NITROGEN AND METHANE-NITROGEN-HYDROGEN MIXTURES AT TEMPERATURES FROM 273 TO 473°K AND PRESSURES TO  $490.3 \cdot 10^5$  N/m<sup>2</sup>

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13. ABSTRACT  Mixtures containing methane, nitrogen, and hydrogen are frequently encountered in the industrial practice of the gas and economical industry, for example in the processes of conversion of methane, synthesis of ammonia, and others. For the hydrodynamic and thermal calculations of these processes it is required to know the viscosity coefficients of mixtures containing the indicated components at various temperatures and pressures. At the present time data are available on the viscosity of mixtures containing methane, nitrogen, and hydrogen which were obtained earlier for one binary mixture with given composition, percentages, temperatures and pressures.			

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KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Viscosity High Pressure Methane Nitrogen Hydrogen						

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

\* ye initially, after vowels, and after ъ, ь; e elsewhere.  
 When written as ѣ in Russian, transliterate as yě or ě.  
 The use of diacritical marks is preferred, but such marks  
 may be omitted when expediency dictates.

THE VISCOSITY OF METHANE-NITROGEN AND METHANE-NITROGEN-  
HYDROGEN MIXTURES AT TEMPERATURES FROM 273 TO 473°K  
AND PRESSURES TO  $490.3 \cdot 10^5$  N/m<sup>2</sup>

N. Ye. Gnezdilov and I. F. Golubev

Mixtures containing methane, nitrogen, and hydrogen are frequently encountered in the industrial practice of the gas and chemical industry, for example in the processes of conversion of methane, synthesis of ammonia, and others.

For the hydrodynamic and thermal calculations of these processes it is required to know the viscosity coefficients of mixtures containing the indicated components at various temperatures and pressures. At the present time data are available on the viscosity of mixtures containing methane, nitrogen, and hydrogen which were obtained earlier [1] for one binary mixture with the composition 80% CH<sub>4</sub> + 20% N<sub>2</sub> at temperatures of 293, 323.6, and 373.2°K and pressures from 0.1013 to 30.39 mN/m<sup>2</sup> and for three ternary mixtures with the composition 37.85% CH<sub>4</sub> + 16.80% H<sub>2</sub> + 45.34% N<sub>2</sub> at temperatures from 294.4 to 373.5°K and pressures from 0.1013 to 30.39 mN/m<sup>2</sup>; the composition 19.8% CH<sub>4</sub> + 24.7% H<sub>2</sub> + 55.5% N<sub>2</sub> at temperatures from 285.7 to 373.9°K and pressures from 0.1013 to 30.39 mN/m<sup>2</sup>; and the composition 17% CH<sub>4</sub> + 62.5% H<sub>2</sub> + 20.5% N<sub>2</sub> at temperatures from 298 to 473°K and pressures from 0.1013 to 81.04 mN/m<sup>2</sup>.

Using the capillary method on the previously described installation [1] we continued and expanded the measurements of the viscosity of mixtures containing these components. We determined the viscosity of

two binary mixtures with the composition 27.8% CH<sub>4</sub> + 72.2% N<sub>2</sub> and 55.1% CH<sub>4</sub> + 44.9% N<sub>2</sub> at temperatures from 273 to 473°K and pressures to 49.03 mN/m<sup>2</sup> and two ternary mixtures with the composition 21.8% CH<sub>4</sub> + 57.7% H<sub>2</sub> + 20.5% N<sub>2</sub> and 18.9% CH<sub>4</sub> + 49.8% H<sub>2</sub> + 31.4% N<sub>2</sub> at temperatures from 273 to 473°K and pressures to 49.03 mN/m<sup>2</sup>. The results of the measurements are given in Tables 1-4.

Table 1. Viscosity ( $10^{-5}$  N·s·m<sup>-2</sup>) for the mixture: 27.8% CH<sub>4</sub> + 72.2% N<sub>2</sub>.

P, N/m <sup>2</sup> · 10 <sup>5</sup> по манометру	(2) Температура, °K					
	273.15	298.15	323.15	373.15	423.15	473.15
0	1474	1575	1671	1851	2034	2200
9.807	1489	1590	—	1668	—	—
19.60	1504	1607	1699	1878	2054	2213
19.60	1510	—	—	—	—	—
49.03	1587	1654	1742	1914	2056	2229
49.03	1573	—	—	1925	—	—
98.07	1709	1779	1848	2006	2149	2292
148.0	1893	1934	2000	2092	2221	2362
196.0	1962	—	2018	—	2239	—
196.0	2197	2104	2168	2211	2310	2426
196.0	2129	—	—	—	—	2436
245.2	2318	2280	2312	2324	2405	2512
245.2	2360	—	—	—	—	—
294.2	2532	2469	2450	2442	2504	2604
294.2	—	2498	—	—	—	—
343.2	2781	2699	2693	2562	2666	2682
343.2	2766	—	—	—	—	—
392.3	3000	2851	2741	2697	2716	2774
392.3	3008	—	2769	—	—	—
441.3	3125	3007	2926	2816	2818	2833
441.3	—	3038	—	—	—	—
490.3	3356	3180	3091	2955	2930	2941
490.3	3368	3207	3081	—	2976	—

Table 2. Viscosity ( $10^{-5}$  N·s·m<sup>-2</sup>) for the mixture: 55.1% CH<sub>4</sub> + 44.9% N<sub>2</sub>.

P, N/m <sup>2</sup> · 10 <sup>5</sup> по манометру	(2) Температура, °K					
	273.15	298.15	323.15	373.15	423.15	473.15
0	1311	1405	1493	1693	1831	1989
9.807	—	1419	1509	1676	—	—
19.60	1344	1436	—	1687	1850	2007
49.03	1417	1493	1567	1723	1882	2039
49.03	1394	—	—	—	—	—
98.07	1561	1600	1665	1801	1945	2086
98.07	—	1621	1680	—	—	—
148.0	1784	1778	1808	1901	2028	2140
196.0	2042	1994	1968	2021	2114	2224
196.0	2051	—	—	—	—	—
245.2	2268	2190	2136	2155	2216	2312
245.2	2282	—	2149	—	—	—
294.2	2532	2387	2319	2391	2390	2396
343.2	2769	2595	2492	2414	2444	2486
343.2	2750	—	—	2426	—	—
392.3	2953	2786	2660	2562	2546	2579
441.3	3167	2956	2819	2685	2619	2663
441.3	3173	2974	2830	2700	—	—
490.3	3327	3146	2962	2814	2751	2765
490.3	3332	3150	2974	2821	2764	—

KEY: (1) p, N/m<sup>2</sup> · 10<sup>5</sup> on a manometer; (2) Temperature, °K.

KEY: (1) p, N/m<sup>2</sup> · 10<sup>5</sup> on a manometer; (2) Temperature °K.

The data obtained on the methane-nitrogen binary mixtures were processed in coordinates "excess viscosity ( $\eta_{PT} - \eta_{TP}$ ) - density  $\rho$ " (Fig. 1, curves II and III). The same processing was conducted for the data of work [1] (curve I).

The experimental points for all temperatures are arranged well on one general curve for every mixture. The values of density for the given methane-nitrogen mixtures were taken from work [2].



Table 3. Viscosity ( $10^{-8} \text{ N}\cdot\text{s}\cdot\text{m}^{-2}$ ) for a mixture: 21.8%  $\text{CH}_4$  + 57.7%  $\text{H}_2$  + 20.5%  $\text{N}_2$ .

(1) $\rho, \text{N/m}^2 \cdot 10^5$ по манометру	(2) Температура, °K					
	273,15	298,15	323,15	373,15	423,15	473,15
0	1256	1310	1421	1575	1724	1874
9.807	1261	1344	1430	1579	1726	—
9.807	1264	—	1125	—	—	2026
19.60	1264	1347	—	—	—	2027
19.60	—	1354	—	—	—	—
49.03	1300	1331	1463	1602	1744	1881
49.03	1296	—	—	—	—	2035
98.07	1360	1442	1511	1633	1772	1916
98.07	1369	—	—	1631	—	2061
148.0	1441	—	1570	1689	1811	1945
148.0	1453	1508	1561	1631	—	2092
196.0	1533	1580	1624	1743	1856	1984
196.0	1541	1592	—	—	1848	2124
245.2	1627	1666	1701	1803	1905	2021
245.2	—	1670	1708	1794	—	2154
294.2	1722	1748	1774	1855	1949	2063
294.2	—	1754	—	—	1941	2186
343.2	1818	1830	1847	1904	1995	2094
343.2	1823	—	—	1915	—	2217
392.3	1916	1911	1919	1966	2032	2139
392.3	—	—	—	1957	—	2248
441.3	2011	1991	1990	2021	2084	2175
441.3	—	—	—	—	2091	2281
490.3	2116	2071	2061	2073	2132	2212
490.3	2106	2080	—	—	—	2311

KEY: (1)  $\rho, \text{N/m}^2 \cdot 10^5$  on a manometer. (2) Temperature, °K.

Table 4. Viscosity ( $10^{-8} \text{ N}\cdot\text{s}\cdot\text{m}^{-2}$ ) for a mixture: 18.8%  $\text{CH}_4$  + 49.8%  $\text{H}_2$  + 31.4%  $\text{N}_2$ .

(1) $\rho, \text{N/m}^2 \cdot 10^5$ по манометру	(2) Температура, °K					
	273,15	298,15	323,15	373,15	423,15	473,15
0	1408	1501	1588	1756	1913	2065
9.807	1412	—	1593	1760	—	2069
9.807	—	—	1596	1764	—	—
19.60	1428	1514	1605	1769	1922	—
19.60	—	—	1600	1764	—	—
49.03	1466	1551	1633	1794	1943	2089
49.03	1460	1548	—	—	—	—
98.07	1549	1620	1692	1841	1984	2116
98.07	—	1625	—	—	1831	—
148.0	1652	1702	1760	1893	2024	2150
148.0	—	1713	—	1888	2043	—
196.0	1761	1800	1835	1953	2075	2191
196.0	1764	—	1843	—	—	—
245.2	1872	1890	1920	2014	2132	2225
245.2	—	—	1925	—	2124	—
294.2	1985	1985	2008	2084	2186	2263
294.2	—	1986	—	—	2191	—
343.2	2094	2077	—	2150	2233	2299
343.2	—	2073	2085	—	—	—
392.2	2193	2173	—	2213	2285	2334
392.2	—	2175	2165	—	—	—
441.3	2301	2266	2246	2276	2334	2374
441.3	—	—	2250	—	2340	—
490.3	2402	2363	2330	2340	2392	2441
490.3	2409	2356	2336	—	—	—

KEY: (1)  $\rho, \text{N/m}^2 \cdot 10^5$  on a manometer. (2) Temperature, °K.

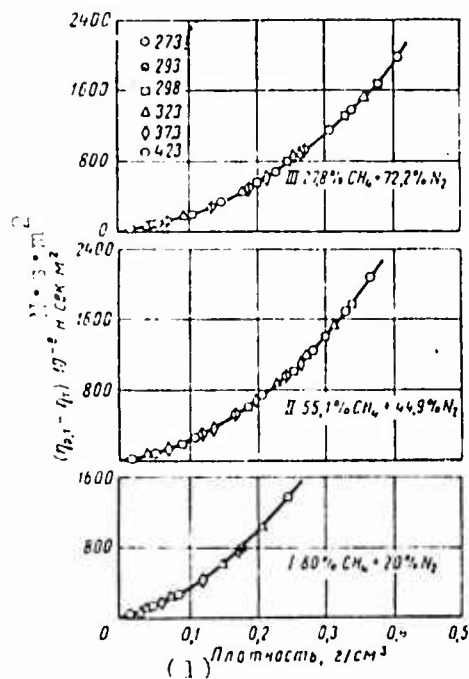


Fig. 1. Dependence of  $(\eta_{p,T} \cdot T^{-n_T})$  on density for a  $\text{CH}_4\text{-N}_2$  mixture.

KEY: (1) Density,  $\text{g/cm}^3$ .

As an example Figure 2 shows the dependence of the viscosity of the methane-nitrogen mixture on composition at a temperature of 323°K and various pressures. It should be noted that the graphic processing of the experimental data on the dependence of the viscosity of methane-nitrogen mixtures on composition and other temperatures showed a picture analogous to that depicted in Fig. 2. Here the data of work [1] are arranged well on the curves of dependence on composition at all the investigated temperatures (an exception are the data obtained at atmospheric pressure).

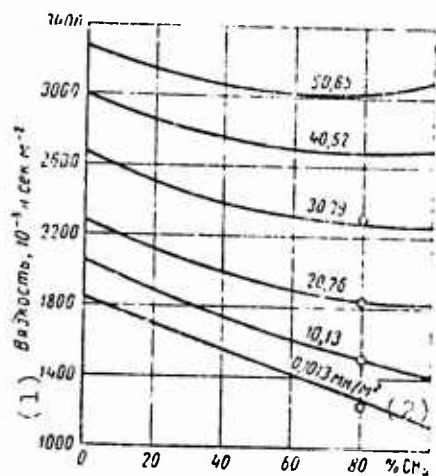


Fig. 2. The viscosity of a  $\text{CH}_4\text{-N}_2$  mixture at 323°K and various pressures — according to the authors, O — according to work [1]. KEY: (1) Viscosity,  $10^{-6} \text{ N}\cdot\text{s}\cdot\text{m}^{-2}$ ; (2)  $\text{mN}/\text{M}^2$

Figure 3 depicts the results of experimental measurements for one of the ternary mixtures of methane-hydrogen-nitrogen. Such a picture is also observed for the second investigated mixture.

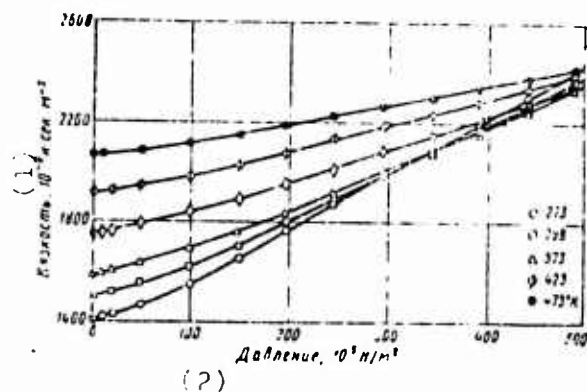


Fig. 3. The viscosity of the mixture 18.8%  $\text{CH}_4$  + 49.8%  $\text{H}_2$  + 31.4%  $\text{N}_2$  depending on pressure and temperature KEY: (1) Viscosity,  $10^{-8} \text{ N}\cdot\text{s}\cdot\text{m}^{-2}$ ; (2) Pressure,  $10^5 \text{ N}/\text{m}^2$ .

Figure 4 depicts the processing of the laboratory findings on the viscosity of ternary mixtures in the coordinates "excess viscosity-density", showing also that for triple (multicomponent) mixtures there is a uniform dependence of excess viscosity on density at various temperatures.

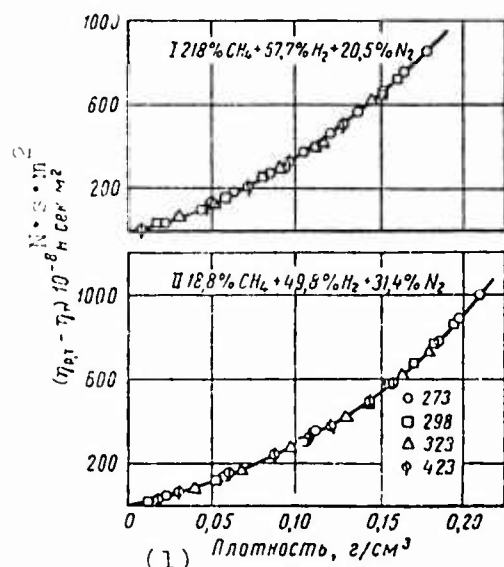


Fig. 4. Dependence of  $(\eta_{p,T} - \eta_{p,T}^0)$  on density for a  $\text{CH}_4\text{-H}_2\text{-N}_2$  mixture. KEY: (1) Density,  $\text{g/cm}^3$ .

The values of density for ternary mixtures used in this processing were calculated according to the Krichevskiy-Kazarnovskiy equation [3] with the constants given in work [2].

#### CONCLUSIONS

The laboratory findings, measured by the capillary method, are given for mixtures with the composition: 27.8%  $\text{CH}_4$  + 72.2%  $\text{N}_2$ ; 55.1%  $\text{CH}_4$  + 44.9%  $\text{N}_2$ ; 21.8%  $\text{CH}_4$  + 57.7%  $\text{H}_2$  + 20.5%  $\text{N}_2$ ; and 18.8%  $\text{CH}_4$  + 49.5%  $\text{H}_2$  + 31.4%  $\text{N}_2$  at temperatures from 273 to 473°K and pressures to 49.03  $\text{atm}/\text{cm}^2$ .

The processing of the experimental results showed the unique dependence of excess viscosity on density at all temperatures.

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(ГИАЭ)

(GIAP [State Scientific Research and Planning  
Institute of the Nitrogen Industry and Products  
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