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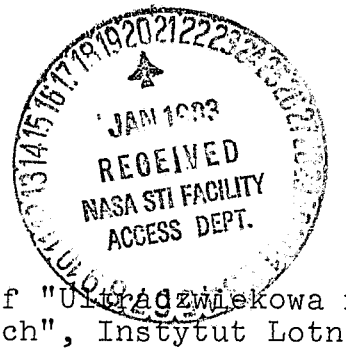
AN ULTRASONIC METHOD FOR CLASSIFYING STANDARD PETROLEUM FUELS

Dr. Wieslaw Szachnowski and Dr. Bogdan Wislicki



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16. Abstract

Some measurements of ultrasonic speed in petroleum fuels were performed. It is shown that there is a correlation between the velocity of ultrasound and a number of standardized physical and chemical properties. It is possible to determine temperature intervals of ultrasonic speeds, charac teristic for a fuel or a group of fuels. Statistical analysis shows that measurement results of ultrasonic velocity can be used for identification of the type or grade of a fuel and a preliminary assessment of quality. By analyzing two-component fuel mixtures on the basis of additive properties, it was found that it is possible to determine quantitatively heavier or lighter impurities in a fuel with an accuracy to within plus or minus 0.5%.

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SUMMARY

Some measurements of ultrasonic speed in petroleum fuels were performed. It is shown that there is a correlation between the velocity of ultrasound and a number of standardized physical and chemical properties. It is possible to determine temperature intervals of ultrasonic speeds, characteristic for a fuel or a group of fuels. Statistical analysis shows that measurement results of ultrasonic velocity can be used for identification of the type or grade of a fuel and a preliminary assessment of quality. By analyzing two-component fuel mixtures on the basis of additive properties, it was found that it is possible to determine quantitatively heavier or lighter impurities in a fuel with an accuracy to within plus or minus 0.5%.

1. INTRODUCTION

The results of studies described in [1,2,3,4 and 5] indicated the possibility of segregation of fuels on the basis of measurements of ultrasound speed. Independently, it appeared possible to estimate the contamination of a given fuel with another "lighter" or "heavier" naphtha product, e.g., fuel or oil. Assuming the maximum simplification of measurement, there was also a possibility of performing a fast evaluation of these products, thus enabling their continuous control.

Statistical analysis of standard fuels was performed in order to examine:

- possibility of determining characteristic intervals of ultrasonic speed for particular types providing their identification with respect to fractional composition,

*Numbers in margin indicate pagination of foreign text.

- possibility of estimating the degree of contamination with other products

Two-component mixtures, imitating contamination of products, were analyzed in sets:

I benzenes and jet fuels
II jet fuels and motor oils
III benzenes and motor oils

The following ranges of concentrations were analyzed more thoroughly: 0-10 volume % and 90-100 volume %.

Measurements of the ultrasound velocity, as a function of temperature, were carried out using an interferometric ultrasonic method, developed in the Aviation Institute [1] with an accuracy no less than 0.1%. Density was determined by the pycnometric method with accuracy plus or minus 1.10^{-4} gcm^{-3} following PN-66/C-04004.

2. RELATIONS AND POSSIBILITIES OF THE APPLICATION OF FUELS /158

In order to find out to what degree the velocity of ultrasound c or its connection with density ϱ in the form of the coefficient of isentropic compression β_S defined by

$$\beta_S = -\frac{1}{\varrho c^2} \tag{1}$$

enables one to determine the amount of impurities in mixtures of products I, II, III, we availed ourselves of the following relations [6,7,8,10 and 11]

$$\frac{1}{c^2} = \frac{V_A}{c_A^2} + \frac{1-V_A}{c_B^2} = \frac{\varrho V_A}{\varrho_A c_A^2} + \frac{\varrho(1-m_A)}{\varrho_B c_B^2} \tag{2}$$

$$\beta_S = V_A\beta_A + (1-V_A)\beta_B = \frac{1}{\varrho_A c_A^2} V_A + \frac{1}{\varrho_B c_B^2}(1-V_A) \tag{3}$$

and correspondingly for component B.

By the application of the coefficient of light refraction or other quantities for a similar purpose, we tried to make use of a simpler relation

$$c = V_A c_A + (1-V_A)c_B \tag{4}$$

and correspondingly for component B.

In the given relations, the notation is: m--weight fraction of components, V--volume fraction of components, A , B--individual components of mixtures (impurities).

The possibility of utilizing relations (2), (3) and (4) depends on the condition that there is no effect of association, as a function of the concentration of components, on linearity of these relations. Only in such a case we can assume that c and β_s will obey the law of additivity. In the light of results described in [2,3], in the case of some fuels, one should expect the appearance of association-solvation effects. It was established that, in the case of fuels, at temperatures 20°C and above, these effects were relatively small. It would appear, therefore, that by making measurements at a temperature of 20°C and above, the influence of these effects on the accuracy of determining concentrations of two-component mixtures can be neglected.

Utilization of relations (2), (3) and (4) for determining concentration of one of the components of mixtures I, II, III would reduce to finding: velocity of ultrasound for a mixture and its components A and B--in the case of using relations (2) and (4), and additionally density of the mixture and its components--in the case of using relation (3). The concentration of a component may be found by transformation of the given equations or from the graphs (Figures 1, 2 and 3). Of these graphs, values of c or β_s for pure components are given by straight lines, from which the concentration of components is read for measured c or β_s of the mixture. For mixtures of various concentrations, appropriate values were found theoretically from relations (2), (3) and (4). Next, c and ϱ were measured experimentally in mixtures of various concentrations. As a result, we obtained values determined theoretically and experimentally and information concerning the possibility of calculating contents of mixture components, without the necessity of making measurements as a function of concentration, or verifying the rules of propagation in the mixtures of analyzed fuels.

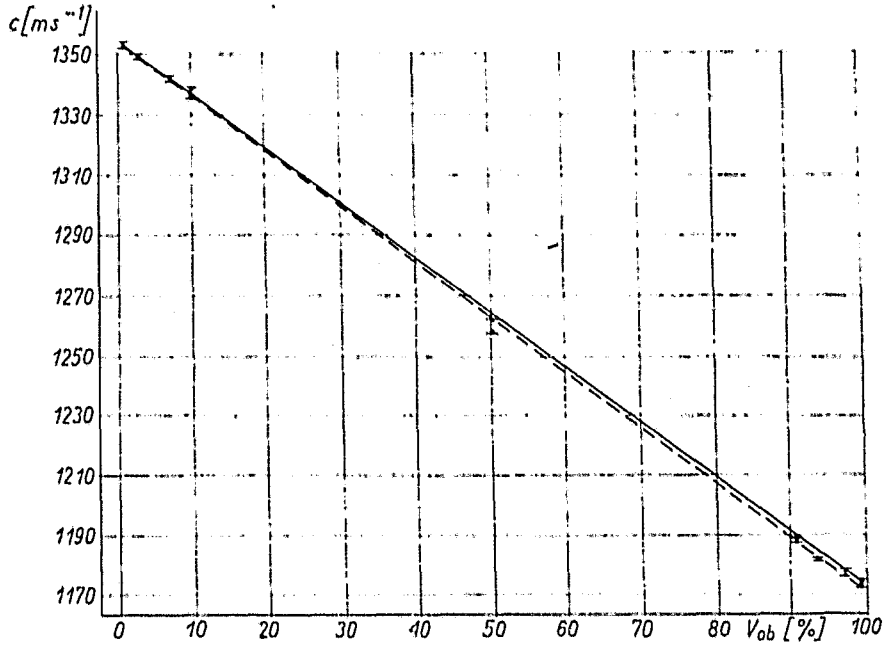

Figure 1a. Dependence $c = f(V)^{20}$ for mixture IZ-20 + B-95/130
calculated - - - -, measured ———

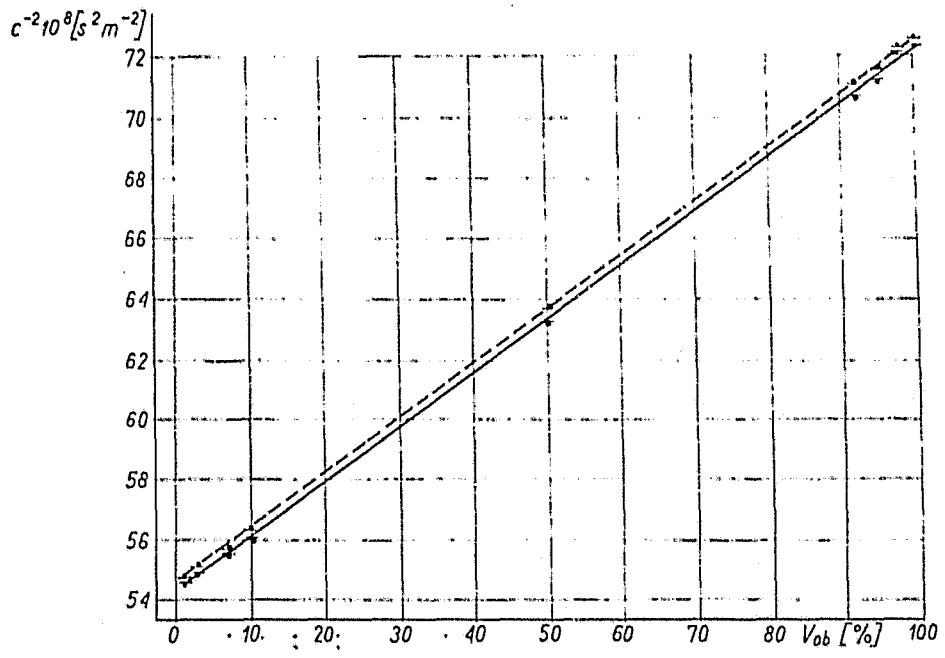

Figure 1b. Relation $c^{-2} = f(V)^{20}$ for mixture IZ-20 + B-95/130
calculated: - - - -, measured ———

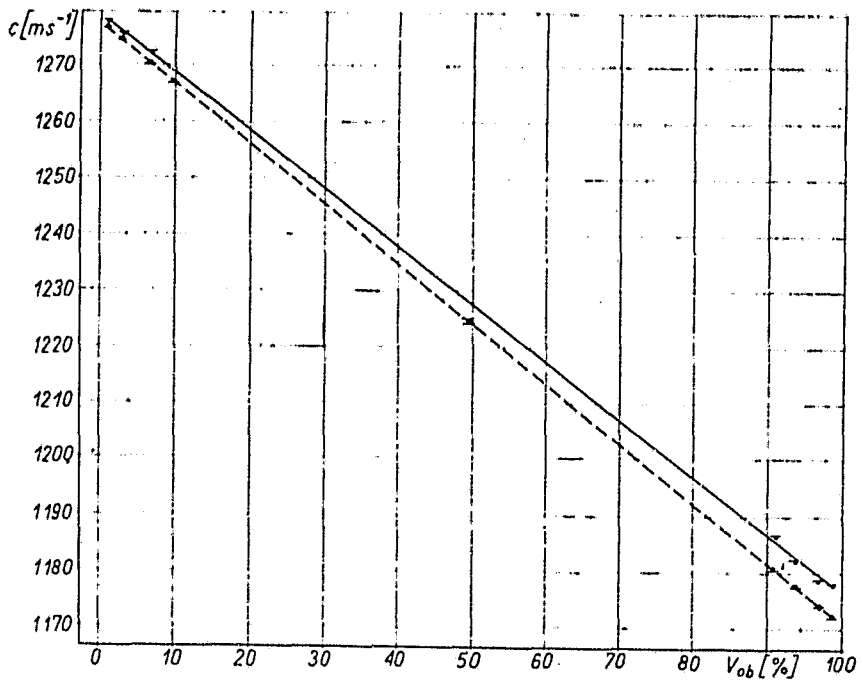

Figure 2a. Relation $c = f(V)^{20}$ for mixture TS-1 + B-95/130 calculated - - - -, measured ———

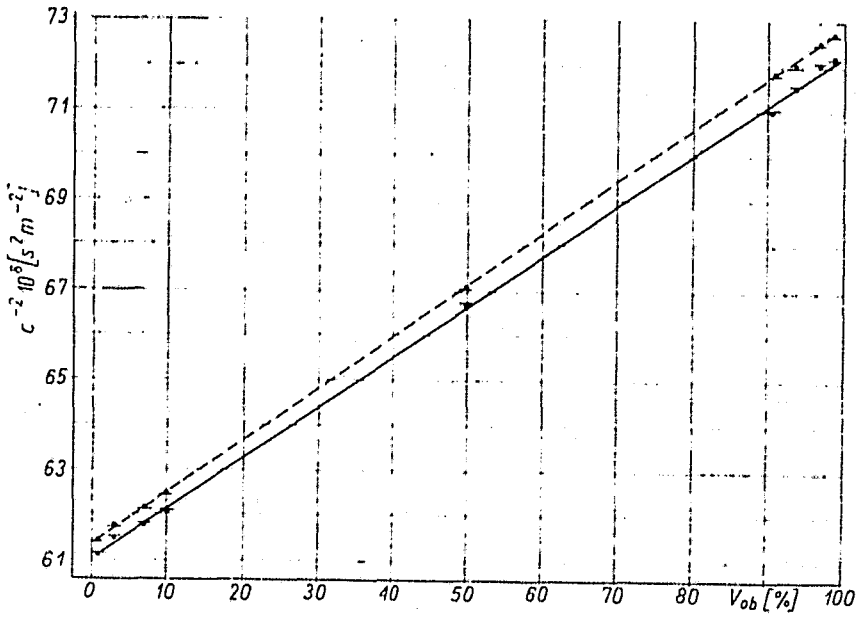

Figure 2b. Relation $c^{-2} = f(V)^{20}$ for mixtures TS-1 + B-95/130 calculated - - - -, measured ———

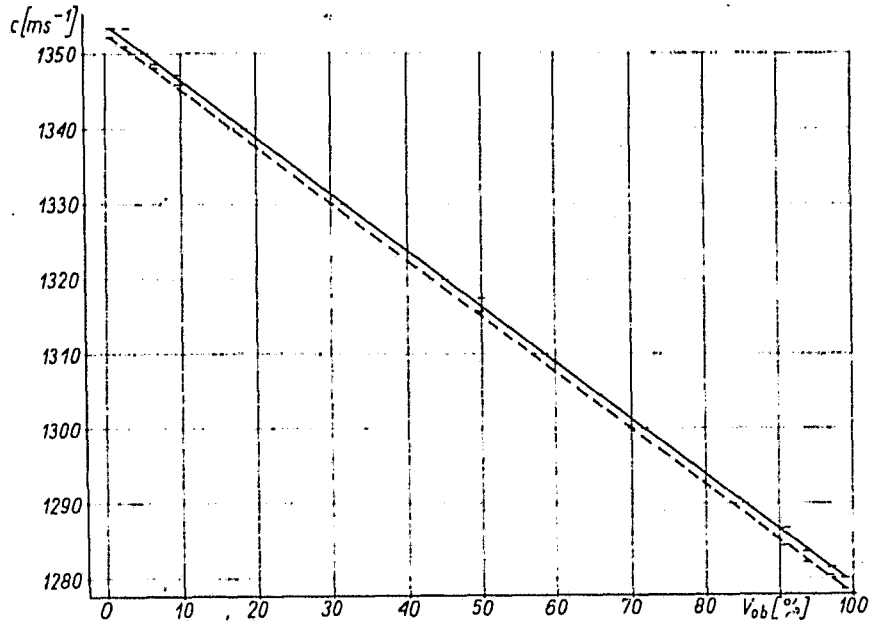

Figure 3a. Relation $c = f(V)^{20}$ for mixture IZ-20 + TS-1
calculated - - - -, measured ———

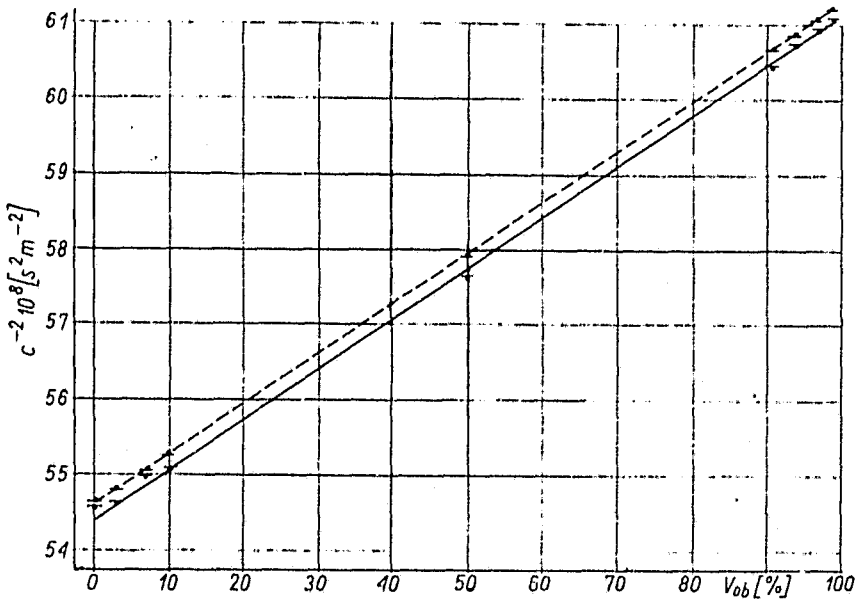

Figure 3b. Relation $c^{-2} = f(V)^{20}$ for mixture IZ-20 + TS-1
calculated - - - -, measured ———

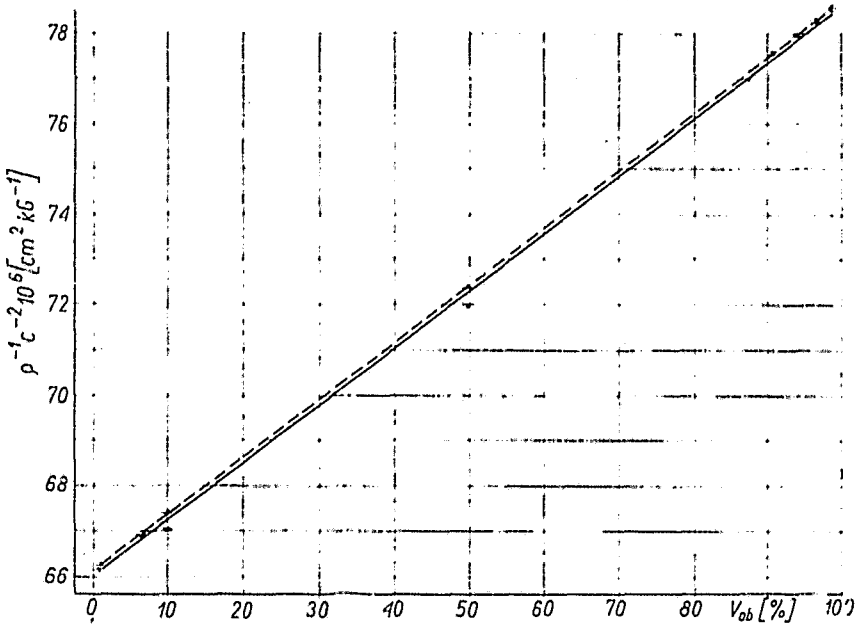

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Figure 3c. Relation $\varrho^{-1}c^{-2} = f(V)^{20}$ for mixture IZ-20 + TS-1 calculated - - - -, measured ———

3. RESULTS OF STUDIES

3.1 General characteristics c(T)

Measurements of C(T) correlated with other typical properties of fuels enabled us to establish sufficiently large intervals of c(T) (Figure 4), minimum 10-30 ms^{-1} [1,4 and 5]. At the available accuracy of measurements, the obtained differences of velocity made possible identification of the product. For benzenes and motor oils, the c(T) characteristics made it possible to distinguish between kinds in a given type of product (Figure 4). For jet fuels, these possibilities were limited (Figure 7). This applied particularly to fuels ATK, PS-2, PS-3 whose c(T) values did not differ much. Their differentiation would be possible if we had at our disposal a measurement with an accuracy higher by one order. A statistical comparative evaluation of c(T) with a number of normalized physicochemical properties considered first of all these properties which were connected directly with the properties of fuels.

The analysis of samples of one kind of motor oil IZ-20 revealed a correlation between c(T) and a parameter describing rheological properties at lowered temperatures--the temperature of blockage of cold filter (Tables 1, 4 5, Figures 9, 11). A relation was observed also of an increase of ultrasound speed with a change of other parameters: an increase of the characteristic temperatures corresponding to 50% and end of distillation, density, coefficient of light refraction, average amount of carbon in ring structures, and decrease of the amount of carbon in paraffin structures. These results confirmed the earlier data, obtained for fractions of hydrocarbons representing definite types of structures [2]. These data indicated the possibility of anticipating the change of c(T) in the case of contamination of a sample of the tested product with added lighter or heavier products. /165

Tests carried out on a sample of motor oil, complying with requirements of the standards, confirmed this suggestion (Figure 5). Introduction into samples 5 and 6 of 10% transformer oil, and of the same amount of benzene B-70, resulted correspondingly in raising and lowering the value of c(T) outside the standard limits for motor oils.

3.2 Statistical c(T) characteristic of fuels in narrow temperature range

In the group of benzene fuels, the intervals of c values were as follows (Table 2, Figures 6 and 7):

etylina I 1190,6 ÷ 1150,6 ms^{-1}, $\Delta c_{20} = 40,0\ ms^{-1}$, $\Delta c_{25} = 41,2\ ms^{-1}$

benzyna I (nonethylized) 1183,0÷1174,4 ms^{-1}, $\Delta c_{20} = 8,6\ ms^{-1}$, $\Delta c_{25} = 7,6\ ms^{-1}$

benzyna II (qualified as etylina I) 1174,9÷1171,9 ms^{-1}, $\Delta c_{20} = 3\ ms^{-1}$, $\Delta c_{25} = 2,3\ ms^{-1}$

etylina II 1205,0÷1192,6 ms^{-1}, $\Delta c_{20} = 12,4\ ms^{-1}$, $\Delta c_{25} = 8,2\ ms^{-1}$

for all kinds of benzenes 1205,0÷1150,6 ms^{-1}, $\Delta c_{20} = 84,4\ ms^{-1}$, $\Delta c_{25} = 54,9\ ms^{-1}$.

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Etyline II should be distinguished from the remaining fuels of this kind. It shows a correlation of the c(T) value with density and distillation temperatures. Both in the group of samples and for various kinds, there were relatively large differences in the properties referred to c(T), e.g., sample no. 6 of etylina I, sample no. 11 of

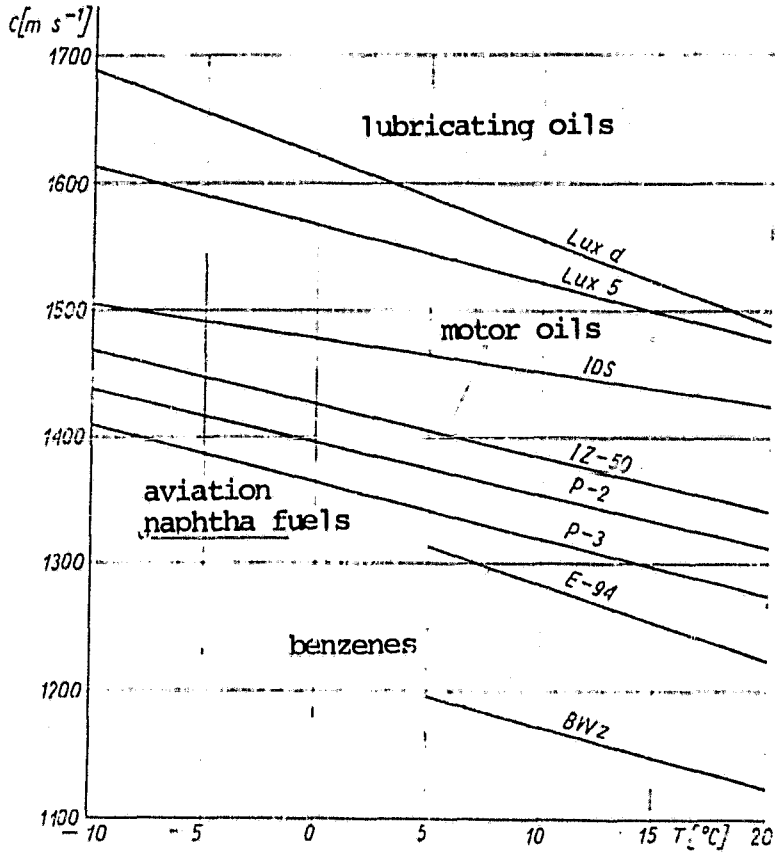

Figure 4. Relation c = f(T). Intervals for various types of fuels and oils

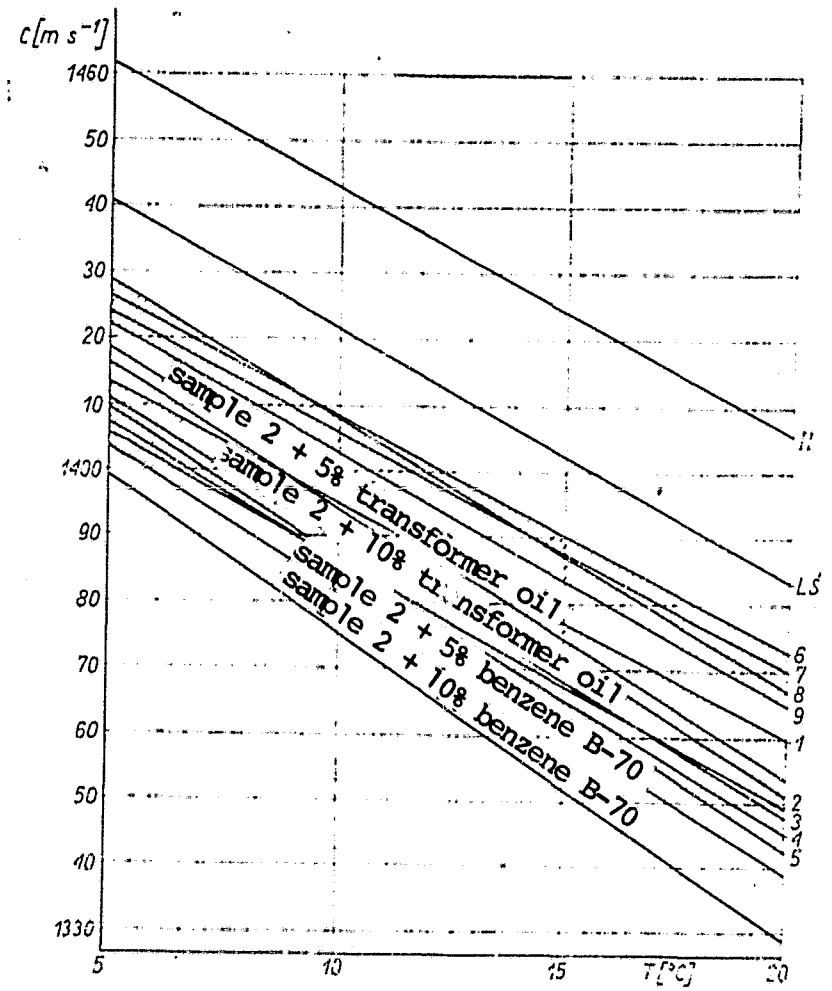

Figure 5. c(T) characteristic for contaminated motor oils. 1-5 complying with standard; 6-9 not complying with standard

TABLE 1. Physiocochemical properties of motor oils [9]

product	remarks	specific gravity ϱ^{20}	molecular weight M	coefficient of light refraction n_D^{20}	normal distillation 10%	50%	90%	95%	amount of carbon in % paraffinic	in rings
VII	complies with standard, pos. 1,2,3,4 and 5	0,818–0,826	192–198	1,4572–1,4622	185–193	240–247	306,314	327–328	58,8–63,1	36,9–41,2
	does not comply with standard, pos. 6,7,8 and 9	0,836–0,838	200–209	1,4663–1,4682	203–213	253–265	330–344	350–360	54,4–57,8	42,2–45,6
II		0,852	–	–	290	290	350	–	–	–
II		0,863	254	1,4809	260	320	385	395	44,1	55,9

*see Tables 4 and 5

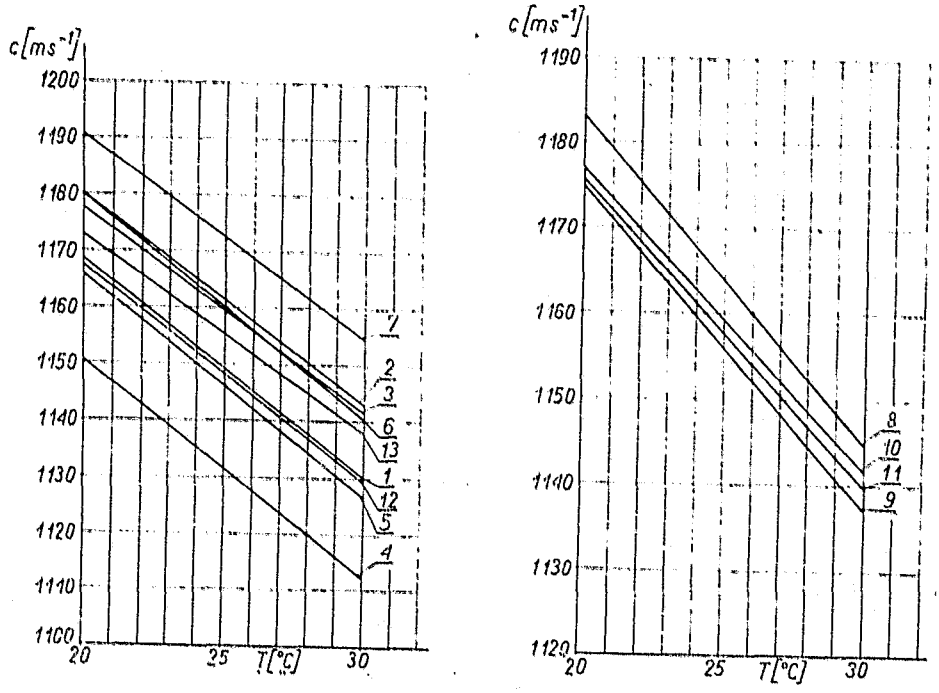

Figure 6. Characteristic c(T) for samples:
a--etylina I; b--benzyna I

benzyna I, or between kinds of etylina I--benzyna I. These differences, finding confirmation in other properties, indicate a different structural-fractional composition. Samples nos. 8, 10 and 11 of benzyna I had an induction period outside of the norm. These facts were reflected in values of c(T) (Figure 6).

The group of jet fuels (Table 3, Figure 7) was not statistically representative. The values of Δc were 2.1 ms^{-1} at the maximum. A confirmation of such a small dispersion of c(T) values for larger amount of samples creates the possibility of qualifying the kind by means of the c(T) characteristic.

Group I of motor oils was characterized by intervals $\Delta c_{20} = 16{,}7\ ms^{-1}$, $\Delta c_{30} = 16{,}0\ ms^{-1}$ (Table 4, Figure 8). Correlations were the same as in the case of benzenes, regular.

In group II of motor oils (Table 4, Figure 9), the intervals were $\Delta c_{20} = 12{,}8\ ms^{-1}$, $\Delta c_{30} = 2.6\ ms^{-1}$. Samples nos. 47 and 48 did not differ

TABLE 2. Typical physicochemical properties and velocities of ultrasounds for benzene fuels

consecutive number	product	no. of sample	density 20°C	normal distillation °C				
				start	10%	50%	90%	end %
1	2	3	4	5	6	7	8	9
1	Etylina I	1	0,716	35	52	90	160	182/97
2	„	4	0,717	39	58	88	140	178/98
3	„	2	0,722	37	50	106	164	186/98
4	„	3	0,723	37	51	96	169	187/98
5	„	5	0,723	39	59	88	145	177/98
6	„	6	0,723	40	54	86	153	190/98
7	„	12	0,724	40	61	101	142	170
8	„	13	0,730	41	64	104	151	180
9	„	7	0,743	39	60	110	174	199/97
10	Benzyna I	8	0,732	42	63	108	154	185
11	„	10	0,732	42	62	109	164	190
12	„	11	0,733	42	63	108	166	193
13	„	9	0,733	43	64	108	164	188
14	Benzyna II	14	0,735	37	54	101	155	191
15	„	15	0,734	30	54	103	162	189
16	Etylina II	16	0,747	37	58	113	169	195
17	„	17	0,748	37	58	108	167	198

TABLE 2 (continued)

contents of 4-ethyl lead g/kg	compressibility of vapors kg/cm²	contents of resin mg/100 ml	induction period min	octane number	velocity of sound ms⁻¹ 20 C	25 C	30°C
10	11	12	13	14	15	16	17
0,175	0,73			79,5	1168,6	1150,0	1130,1
0,160	0,55			80,0	1150,6	1131,5	
1,050	0,61			78,0	1180,1	1161,7	1142,9
1,005	0,54			79,0	1177,7	1159,7	
0,500	0,50			82,0	1165,7	1146,1	
0,330	0,56			82,0	1179,7	1160,0	
0,950	0,50	3,2	500	84,2	1167,4	1148,4	
0,570	0,46	1,6		84,0	1172,8	1155,4	
	0,58			83,4	1190,6	1172,7	
	0,49	3,2	330	77,6	1183,0	1165,2	1144,7
	0,48	2,8	400	76,3	1176,7	1159,3	
	0,48	4,4	445	76,1	1175,6	1157,6	
	0,47	1,2	480	76,2	1174,4	1156,0	
0,310	0,62	2,4		91,3	1171,9	1155,9	
0,310	0,61	12,8	620	91,0	1174,9	1158,2	
0,400	0,57	2,0	480	94,7	1205,0	1186,4	1169,2
0,350	0,52	4,0	480	94,9	1192,6	1173,0	1159,3

Footnote: Samples nos. 8, 10 and 11 do not comply with requirements of GOST 2084-67 with regard to induction period; sample no. 15 satisfies requirements of PN-66/C-56025 with regard to contents of resins.

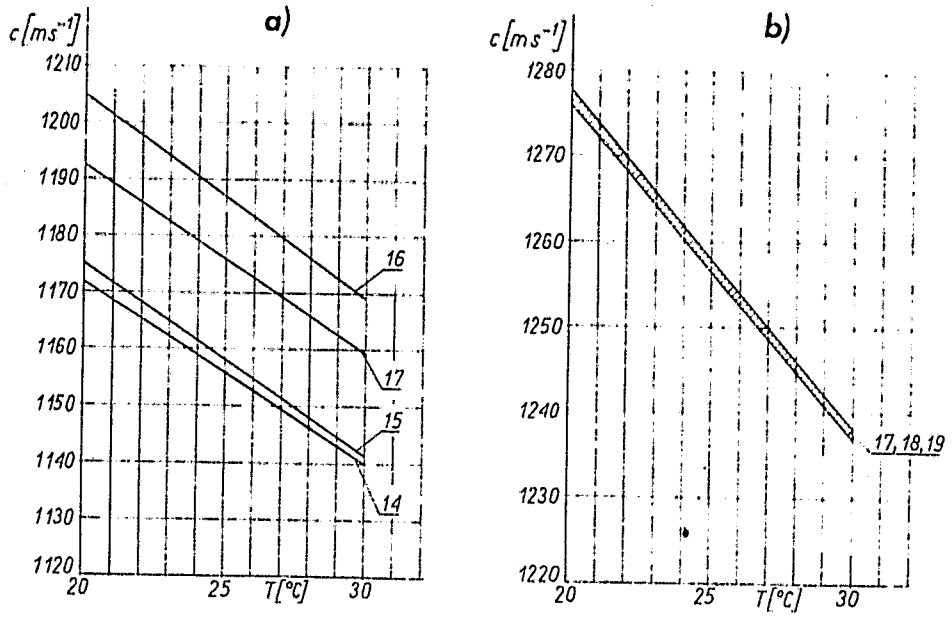

Figure 7. Characteristic c(T) for samples:
a--etylina II
b--benzyna II and fuel I

TABLE 3. Typical physicochemical properties and velocities of ultrasounds for jet fuels.

consecutive number	product	no. of sample	density 20°C	normal distillation °C					freezing temperature °C
				start	10%	50%	90%	end %	
1	2	3	4	5	6	7	8	9	10
1	Paliwo I	18	0,776	138	153	175	209	234/98	−60
2	„	19	0,777	139	153	175	211	230/98	−60
3	„	20	0,777	139	152	173	214	234/98	−60

contents of resin mg/100 ml	contents of sulfur %	contents of aromatic hydrocarbons %	iodine number $gJ_2/100\ g$	acidity mgKOH/100 ml	velocity of sound ms^{-1}		
					20°C	25°C	30°C
11	12	13	14	15	16	17	18
1,5	0,109	17,45	0,37	0,21	1277,6	1257,0	1238,1
1,4	0,081	17,61	0,37	0,14	1276,7	1254,9	1237,2
1,8	0,136	18,23	0,45	0,20	1276,1	1256,9	1237,1

TABLE 4. Typical physicochemical properties and velocities of ultrasounds for motor oils

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consecutive number	product		no. of sample	density 20°C	normal distillation 50%	normal distillation end %	acidity mgKOH/100 ml	Temperature °C ignition	Temperature °C clouding	Temperature °C freezing
1	2		3	4	5	6	7	8	9	10
1	motor oil	I	22	0,815	249	348/98	1,5	43	−5	−10
2		„	24	0,817	251	350/98	1,5	54	−5	−10
3		„	23	0,818	253	346/98	1,5	50	−5	−10
4		„	25	0,818	251	348/98	1,6	55	−5	−10
5		„	29	0,818	258	354/98	1,6	59	−5	−10
6		„	36	0,818	248	352/98	1,6	55	−5	−10
7		„	30	0,819	261	360/98	1,6	55	−5	−10
8		„	35	0,819	257	357/98	1,6	55	−5	−10
9		„	37	0,819	253	358/98	1,5	52	−5	−10
10		„	39	0,819	258	356/98	1,6	52	−5	−10
11		„	21	0,820	254	350/98	1,4	59	−5	−10
12		„	26	0,820	251	347/98	1,6	50	−5	−10
13		„	34	0,820	259	360/98	1,4	55	−5	−10
14		„	38	0,820	254	360/98	1,5	48	−5	−10
15		„	40	0,820	259	360/98	1,6	54	−5	−10
16		„	31	0,822	261	358/98	1,5	54	−5	−10
17		„	33	0,822	255	354/98	1,5	53	−5	−10
18		„	32	0,823	257	358/98	1,5	61	−5	−10
19		„	28	0,825	262	360/98	1,6	57	−5	−10
20		„	27	0,826	266	360/98	1,7	59	−5	−10
21										
		II	47	0,814	248	350/96	1,5	48	−5	−10
22		„	48	0,815	247	350/96	1,5	47	−5	−10
23		„	46	0,816	261	350/95	0,26	69		−12
24		„	42	0,823	249	338/97	4,49	46		
25		„	44	0,824	248	343/98	4,7	57		
26		„	43	0,824	251	350/98	6,7	49		
27		„	45	0,825	243	333/97	6,1	58		
28		„	41	0,825	245	350/98	4,8	43		−27
29										
		III	49	0,831	274	338/96	2,9	91	−10	−15
30		„	50	0,834	267	332/96	2,5	91	−10	−15
31										
		IV	51	0,858	244	291/90	2,9	72	−35	−45
32										
		V	55	0,799	202	288/98	0,49	50	−25	−35
33		„	56	0,806	206	285/98	0,90	46	−25	−35
34		„	53	0,815	230	318/98	3,36	48		−36
35		„	54	0,818	241	335/98	4,20	42		−37
36										
		VI	58	0,816	241	345/96	0,40	59		−30
37		„	59	0,816	242	345/96	0,48	61	−17	−30
38		„	57	0,817	244	350/96	0,60	61		−30

FOOT NOTE: Samples nos. 57, 58 and 59 have the temperature of blockage of cold filter -180°C; the standard blockage temperature for oil V is -20°C.

TABLE 4 (continued)

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coke %	contents of sulfur %	contents of resin mg/100 ml	cetane no.	velocity of sound ms^{-1} 20°C	25°C	30°C
11	12	13	14	15	16	17
	0,14	22,0	45,0	1347,7	1329,2	1309,5
	0,18	23,0	45,0	1349,5		1312,1
	0,16		45,0	1352,8	1334,2	1314,5
	0,18		45,0	1349,7		1311,6
	0,24		45,0	1356,8		1319,1
	0,34	22,0	45,0	1357,3		1318,2
	0,20	23,0	45,0	1358,1		1319,7
	0,18	23,0	45,0	1355,4		1316,7
	0,32	22,0	45,0	1354,4		1316,2
	0,21	23,0	45,0	1356,3		1317,8
	0,16	22,0	45,0	1353,5	1334,9	1315,4
	0,20	24,0	45,0	1354,0		1316,2
	0,19	22,0	45,0	1355,5		1317,3
	0,30		45,0	1355,1		1316,7
	0,19	22,0	45,0	1355,8		1317,7
	0,22	23,0	45,0	1359,6		1321,2
	0,19		45,0	1359,2		1321,0
	0,30	22,0	45,0	1359,1		1320,7
	0,48		45,0	1363,2		1324,8
	0,43	22,0	45,0	1364,4		1325,5
	0,18	23,0	45,0	1346,8	1328,2	1307,9
	0,22	23,0	45,0	1345,9	1326,1	1309,4
0,020	0,52	23,0	60,0	1355,3	1337,2	1317,5
0,012			53,5	1353,5		1315,7
0,0026			51,5	1354,4	1336,2	1316,7
0,0185			53,0	1358,7		1320,5
0,0224			50,0	1356,8	1337,6	1318,8
0,0290			50,5	1355,9		1318,1
0,0180	0,14	10,0	53,0	1371,6	1351,8	1334,5
0,0170	0,13	15,0	54,0	1373,9	1354,9	1337,4
0,1400	0,12		40,0	1374,9	1356,6	1338,0
	0,24	10,0	48,0	1313,6	1295,3	1275,5
	0,39		45,0	1321,6	1302,3	1273,5
0,0120	0,38		50,5	1341,1		1302,3
0,0130	0,48		53,0	1345,9		1307,4
0,0400				1342,7		1304,4
0,0150	0,25			1343,4		1304,5
0,0290	0,20			1344,7	1325,3	1305,5

TABLE 5. Typical physicochemical properties and velocities of ultrasounds for motor oils

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consecutive number	product	no. of sample	normal distillation, °C: density 20°C	start	50%	end %	viscosity cSt: 0 °C	20 °C	acidity mgKOH/100 ml
1	2	3	4	5	6	7	8	9	10
1	motor oil VII	71	0,818	148	240	355	5,25	3,15	2,25
2	„	77	0,819	170	236	336	4,84	2,91	0,74
3	„	73	0,819	163	247	348	5,03	3,06	0,24
4	„	74	0,821	157	247	352	5,78	3,28	0,38
5	„	75	0,821	156	247	350	5,03	3,17	0,39
6	„	72	0,822	160	245	346	5,27	3,19	0,64
7	„	52	0,822		246	340/92		3,27	0,26
8	„	82	0,823	152	235	346	5,03	2,96	1,02
9	„	70	0,823	165	235	364	5,74	3,28	1,96
10	„	64	0,823	163	244	344	5,31	3,12	0,47
11	„	76	0,824	157	237	346	5,16	3,03	0,78
12	„	79	0,826	155	236	342	5,05	2,95	0,76
13	„	62	0,826	150	240	335	5,62	3,23	0,54
14	„	63	0,826	157	241	308/90	5,18	3,14	0,57
15	„	78	0,827	168	244	346	5,71	3,26	0,69
16	„	65	0,828	158	240	346	5,01	3,04	0,59
17	„	81	0,831	179	247	314/90	5,72	3,33	0,46
18	„	60	0,832	169	262	327/90	7,58	4,21	0,85
19	„	80	0,835	156	258	324/90	7,23	4,02	0,48
20	„	69	0,836	165	254	365	8,16	4,32	1,76
21	„	67	0,836	171	259	333/90	7,76	4,23	1,46
22	„	61	0,836	180	265	357/95	8,70	4,62	0,64
23	„	68	0,837	171	261	336/90	7,98	4,39	1,37
24	„	66	0,838	175	263	360/95	8,35	4,53	1,38

TABLE 5 (continued)

contents of sulfur %	contents of resin mg/100 ml	coke %	molecular wt.	coefficient of light refraction	blockage temp. of cold filter	contents of carbon % in rings	aromatic	naphthenic	paraffinic	velocity of sound ms^{-1} 20 C	30°C
11	12	13	14	15	16	17	18	19	20	21	22
0,28			194	1,4575	−13	37,5	9,0	26,5	62,5	1349,0	1311,1
0,44			190	1,4586	−15	36,1	11,0	25,1	63,9	1346,4	1307,9
0,32			199	1,4582	−12	34,5	9,0	25,5	65,5	1345,4	1307,5
0,39	16,0	0,026	195	1,4598	−10	37,0	11,0	26,0	63,0	1350,0	1313,0
0,38	5,0	0,027	198	1,4588	−14	36,9	10,0	26,9	63,1	1348,3	1310,0
0,38			187	1,4592	−12	42,8	10,0	32,8	57,2	1348,6	1310,9
					−13					1350,8	1312,9
0,37	28,0	0,057	187	1,4605	−12	39,0	12,0	27,0	61,0	1346,6	1308,0
0,59			187	1,4590	−14	42,0	10,0	32,0	58,0	1350,8	1312,8
0,38			193	1,4612	−14	38,9	12,5	26,4	61,1	1351,0	1312,9
0,49			189	1,4608	−10	41,5	12,0	29,5	58,5	1347,9	1310,2
0,45			185	1,4640	−12	39,4	16,0	23,4	60,6	1350,7	1313,5
0,48	18,0	0,030	192	1,4622	−12	41,2	12,5	28,7	58,8	1353,6	1315,8
0,48			193	1,4622	−15	41,1	12,5	28,6	58,9	1351,7	1313,6
0,47			195	1,4631	−9	38,8	12,5	26,3	61,2	1355,1	1317,4
0,43			192	1,4620	−15	38,7	12,5	26,2	61,3	1351,0	1312,5
0,54	4.0	0,028	196	1,4648	−10	42,1	13,5	28,6	57,9	1356,4	1318,5
0,41			210	1,4650	−11	40,0	11,0	29,0	60,0	1365,4	1327,9
0,54			205	1,4680	−5	39,7	13,5	26,2	60,3	1366,4	1328,9
0,97	33,0	0,066	202	1,4670	−3	42,2	13,6	29,2	57,8	1368,3	1330,8
1,02			206	1,4665	−4	42,0	12,0	30,0	58,0	1365,4	1328,8
0,31			209	1,4663	−4	44,1	11,0	33,1	55,9	1371,3	1333,9
1,01			207	1,4668	−4	42,5	11,5	31,0	57,5	1366,9	1330,1
0,98	45,0	0,046	200	1,4682	−2	45,6	13,5	32,1	54,4	1369,6	1332,1

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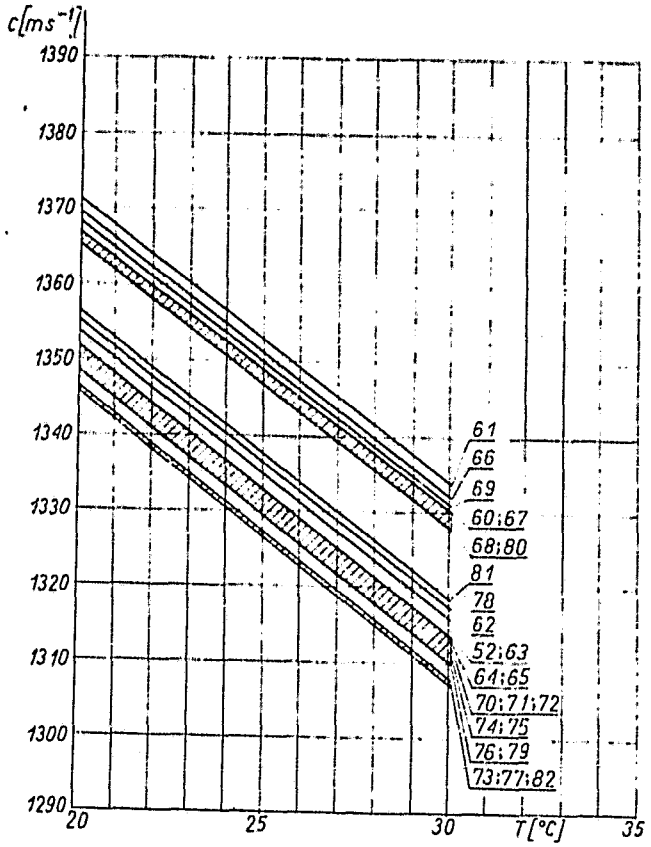

Figure 8. Characteristic c(T) of samples; motor oil I

in their c(T) values, and the remaining samples were quite similar. The directional coefficient of sample 48 was smaller than others. No clear correlation, as in the case of benzenes, was observed. Narrow intervals of c(T) values contained in intervals corresponding to oils group I merit special attention (the same producer).

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In the oil groups III to VII, the same regularities were observed as in groups discussed previously (Tables 4 and 5, Figures 10 and 11). For samples of oils V, which had different directional coefficients c(T) from other oils, a connection was seen between fractional composition and values of directional coefficients c(T). It is probable that the presence of lower-boiling fractions in oils V reduced the value of these coefficients. The broad range of c(T) values enabled us to draw conclusions about various amounts of properties of fractions which composed the oils.

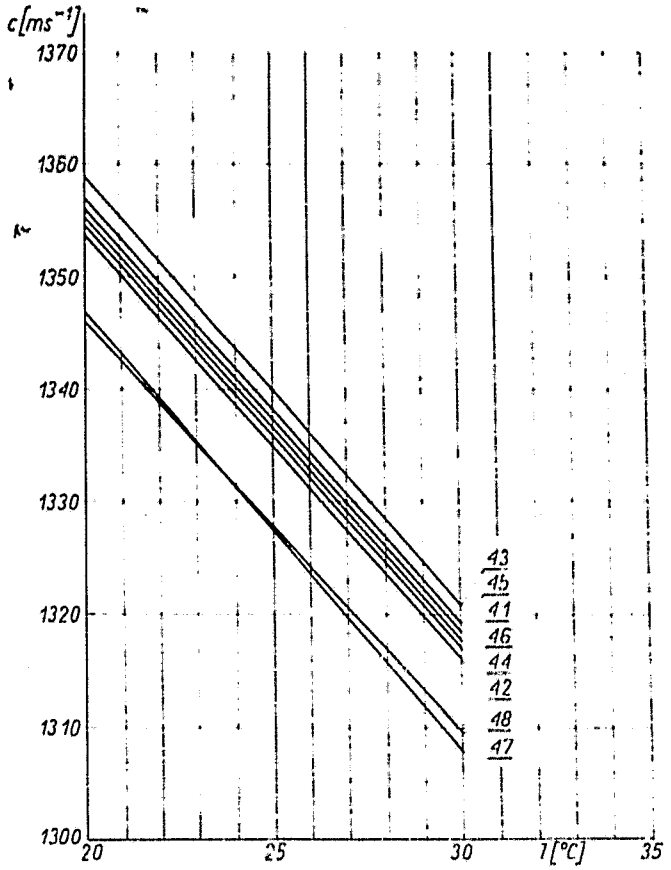

Figure 9. Characteristic c(T) of samples; motor oil II

Motor oils III and IV were characterized by larger c(T) values than the rest, thus enabling us to distinguish them according to kind. Samples of oils VI failed to satisfy the requirements of Polish norms with respect to the temperature of blockage of the cold filter (Table 4, Figure 10). Similarly, samples of oils VII (Tabl 1, /173 Figure 5) did not satisfy these requirements [9]. In both these cases, one could observe relatively higher values of c(T) or lower values of directional coefficients for samples which failed the tests. Also, the temperatures of 50% and the end of distillation of these samples were relatively higher. This correlation can be described, in the region of the given kind, as follows: an increase of distillation temperatures corresponds to increasing c(T) value or decreasing values of the directional coefficient c(T) and increase of the blockage temperature of the exchangeable filter.

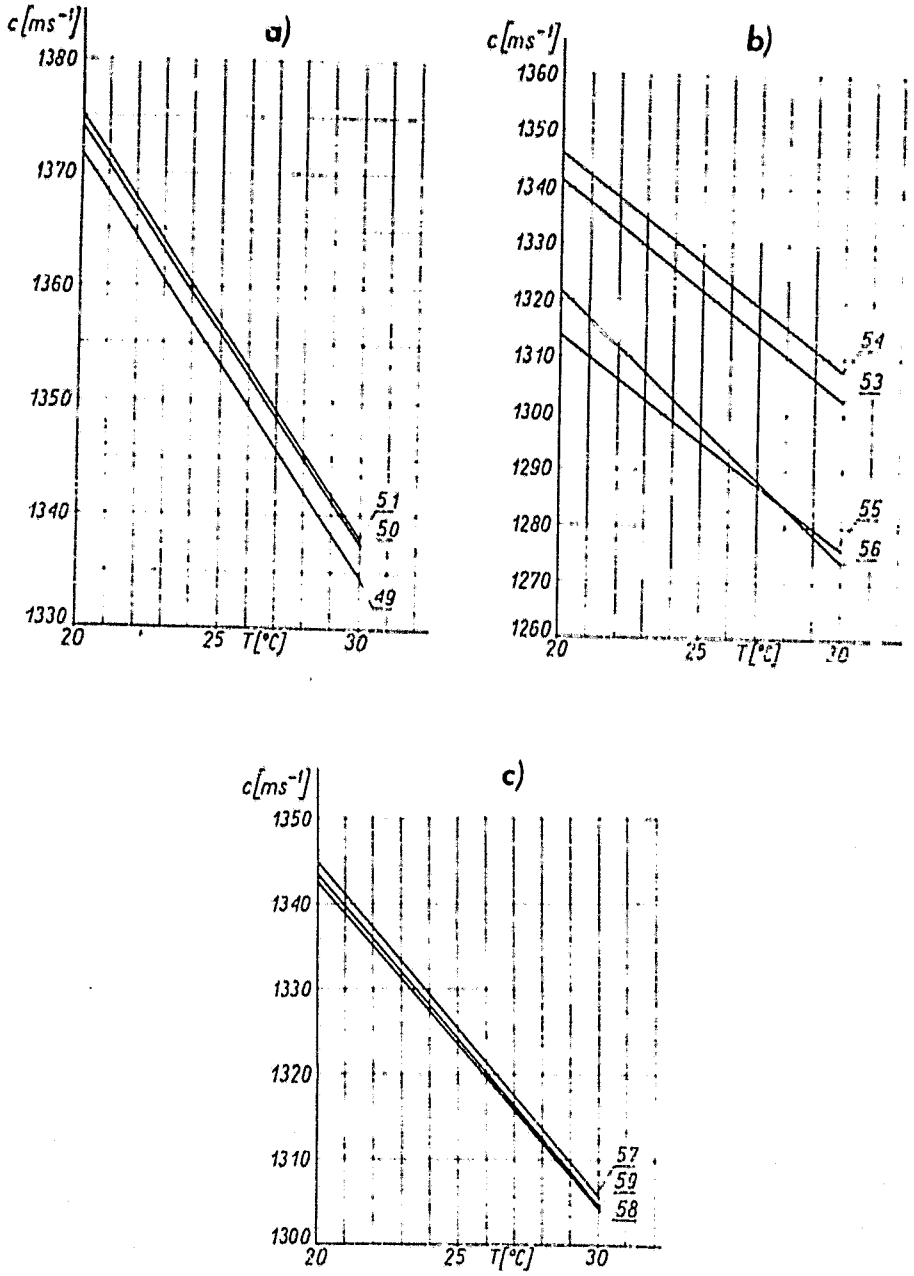

Figure 10. Characteristic c(T) for samples of a--motor oils III and IV; b--motor oil V; c--motor oil IV

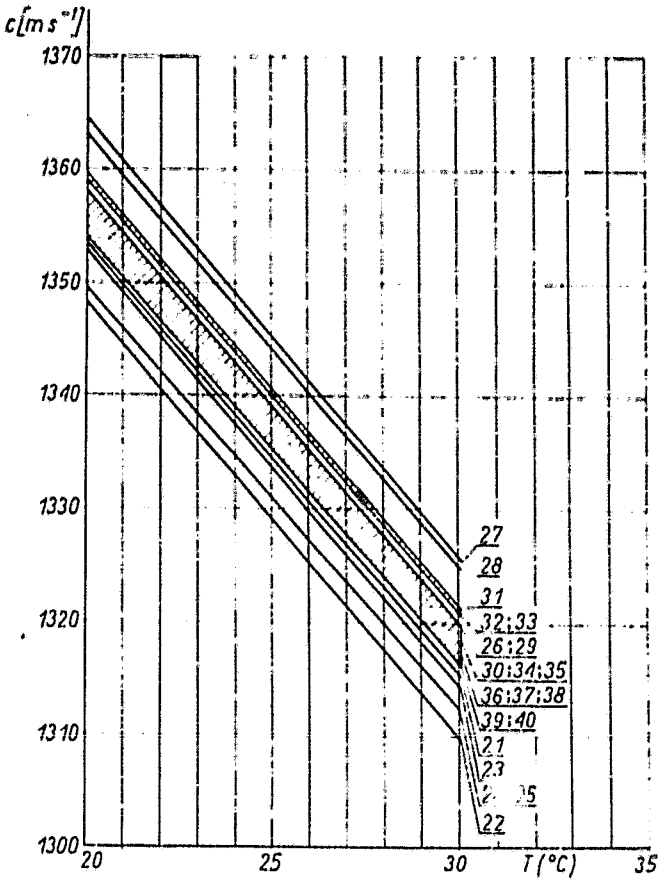

FIGURE 11. Characteristic c(T) for samples of motor oil VII

3.3 Determination of density of fuel mixtures

For results on analyzed compositions (Tables 6, 7 and 8; Figures 1, 2 and 3) obtained with the aid of relations (2), (3) and (4), the relative error did not exceed plus or minus 1%. The results of determining density of composition II (naphtha fuel--motor oil) had the smallest errors. This fact can be explained by the smaller volatility of the components of composition II than in the case of composition I and III which contained benzene. Taking into account the temperature of the measurements (20°C) and the time required for them, the grade of values and distribution of errors seem reasonable. For the same reasons, one should expect that in an analysis of compositions I and III, the errors would be much higher. Having in mind properties of functions $\frac{1}{\varrho c^2}$ and $\frac{1}{c^2}$ expressed in the tendency to "straighten

TABLE 6. Calculated values c_{MO}^{-2} and measured values c_{MP}^{-2} at temperature 20°C, according to realtions (2) for mixtures of fuels. I--jet fuel; VII--motor oil

No.	Product	V_A %	V_B %	c_A ms^{-1}	c_B ms^{-1}	c_{MO}^{-2} s^{2}m^{-2} 10^8	c_{MP}^{-2} s^{2}m^{-2} 10^8	$\frac{c_{MO}^{-2}-c_{MP}^{-2}}{c_{MP}^{-2}}$ 100%
1	2	3	4	5	6	7	8	9
1	I+VII	1	99	1277,6	1353,5	54,65	54,61	0,07
2	„	3	97	1277,6	1353,5	54,78	54,63	0,27
3	„	7	93	1277,6	1353,5	55,05	55,01	0,07
4	„	10	90	1277,6	1353,5	55,25	55,09	0,29
5	„	50	50	1277,6	1353,5	57,92	57,64	0,48
6	„	91	9	1277,6	1353,5	60,66	60,47	0,31
7	„	94	6	1277,6	1353,5	60,86	50,77	0,14
8	„	97	3	1277,6	1353,5	61,06	60,97	0,14
9	„	99	1	1277,6	1353,5	61,19	61,10	0,14
10	B95/110+I	1	99	1171,6	1277,6	61,38	61,25	0,21
11	„	3	97	1171,6	1277,6	61,61	61,46	0,24
12	„	7	93	1171,6	1277,6	62,07	61,77	0,48
13	„	10	90	1171,6	1277,6	62,42	62,06	0,58
14	„	50	50	1171,6	1277,6	67,05	66,66	0,58
15	„	91	9	1171,6	1277,6	71,80	70,99	1,13
16	„	94	6	1171,6	1277,6	72,15	71,55	0,83
17	„	97	3	1171,6	1277,6	72,50	72,11	0,54
18	„	99	1	1171,6	1277,6	72,73	72,15	0,80
19	B95/130+VII	1	99	1171,6	1353,5	54,76	54,68	0,14
20	„	3	97	1171,6	1353,5	55,13	54,93	0,36
21	„	7	93	1171,6	1353,5	55,66	55,63	0,41
22	„	10	90	1171,6	1353,5	56,41	55,98	0,76
23	„	50	50	1171,6	1353,5	63,71	63,25	0,73
24	„	91	9	1171,6	1353,5	71,20	70,82	0,53
25	„	94	6	1171,6	1353,5	71,25	71,66	0,12
26	„	97	3	1171,6	1353,5	72,30	72,29	0,01
27	„	99	1	1171,6	1353,5	71,66	72,39	0,37

Note: MO - calculated; MP - measured

out" the form of their curves as a function of P and T [1,2,3 and 6], and empirical results, one should expect smaller errors when using higher concentrations.

The errors for relation (3) were the highest. The smallest errors were obtained when using relation (4). This relation is the simplest and, by the same token, the most desirable one for this type of application. In this case, one avoids propagation of errors of "c" measurements and the error of determining „ϱ". Undoubtedly, when using the current method of measuring the velocity of ultrasound, one can reduce errors by merely changing the thermostatic conditions of the samples, /176 to avoid loss by evaporation of volatile components. Also, a statistical analysis (Table 6, consecutive nos. 15 and 16) should reduce errors.

TABLE 7. Calculated values $\varrho^{-1}c_{M0}^2$ and measured values $\varrho^{-1}c_{MP}^2$ at temperature 20°C, according to relation (3) for mixtures of fuels.

No.	product	V_A %	c_A ms^{-1}	ϱ_A gcm^{-3}	V_B %	c_B ms^{-1}	ϱ_B gm^{-3}	c_{MP} ms^{-1}	c_{MP} gcm^{-3}	$\varrho^{-1}c_{M0}^2$ cm^{2}kG^{-1}10^6	$\varrho^{-1}c_{MP}^2$ cm^{2}kG^{-1}10^6	$\frac{\varrho^{-1}c_{M0}^2\,\varrho^{-1}c_{MP}^2}{\varrho^{-1}c_{MP}^2}$ 100%
1	I+VII	1	1277,6	0,7781	99	1353,5	0,8251	1353,2	0,8245	66,28	66,23	0,07
2	„	3	1277,6	0,7781	97	1353,5	0,8251	1353,0	0,8234	66,53	66,43	0,15
3	„	7	1277,6	0,7781	93	1353,5	0,8251	1348,3	0,8219	67,03	66,93	0,14
4	„	10	1277,6	0,7781	90	1353,5	0,8251	1347,3	0,8202	67,41	67,02	0,58
5	„	50	1277,6	0,7781	50	1353,5	0,8251	1317,2	0,8021	72,43	71,96	0,65
6	„	91	1277,6	0,7781	9	1353,5	0,8251	1286.0	0,7823	77,59	77,29	0,38
7	„	94	1277,6	0,7781	6	1353,5	0,8251	1282,8	0,7813	77,97	77,97	0,00
8	„	97	1277,6	0,7781	3	1353,5	0,8251	1280,7	0,7794	78,35	78,32	0,03
9	„	99	1277,6	0,7781	1	1353,5	0,8251	1279,3	0,7785	78,60	78,49	0,14

TABLE 8. Calculated values c_{MO} and measured values c_{MP} at temperature 20°C, according to relation (4), for mixtures of fuels. /178

no.	product	V_A %	V_B %	c_A ms^{-1}	c_B ms^{-1}	c_{MO} ms^{-1}	c_{MP} ms^{-1}	$\frac{c_{MO}-c_{MP}}{c_{MP}} 100\%$
1	2	3	4	5	6	7	8	9
1	I+VII	1	99	1277,6	1353,5	1352,7	1353,2	0,03
2	„	3	97	1277,6	1353,5	1351,2	1353,0	0,13
3	„	7	93	1277,6	1353,5	1348,2	1348,3	0,01
4	„	10	90	1277,6	1353,5	1345,9	1347,3	0,09
5	„	50	50	1277,6	1353,5	1315,5	1317,2	0,10
6	„	91	9	1277,6	1353,5	1284,4	1286,0	0,10
7	„	94	6	1277,6	1353,5	1282,1	1282,8	0,05
8	„	97	3	1277,6	1353,5	1279,9	1280,7	0,06
9	„	99	1	1277,6	1353,5	1278,4	1279,3	0,07
10	B-95+I	1	99	1171,6	1277,6	1276,5	1277,8	0,05
11	„	3	97	1171,6	1277,6	1274,4	1275,6	0,09
12	„	7	93	1171,6	1277,6	1270,2	1272,4	0,01
13	„	10	90	1171,6	1277,6	1267,0	1269,4	0,09
14	„	50	50	1171,6	1277,6	1224,6	1224,8	0,02
15	„	91	9	1171,6	1277,6	1181,1	1186,9	0,49
16	„	94	6	1171,6	1277,6	1178,0	1182,2	0,35
17	„	97	3	1171,6	1277,6	1174,8	1177,6	0,24
18	„	99	1	1171,6	1277,6	1172,7	1177,3	0,39
19	B-95+VII	1	99	1171,6	1135,5	1351,7	1352,4	0,05
20	„	3	97	1171,6	1135,5	1348,0	1349,3	0,09
21	„	7	93	1171,6	1135,5	1340,8	1340,7	0,01
22	„	10	90	1171,6	1135,5	1335,3	1336,6	0,09
23	„	50	50	1171,6	1135,5	1262,5	1257,4	0,41
24	„	91	9	1171,6	1135,5	1188,0	1188,3	0,02
25	„	94	6	1171,6	1135,5	1182,5	1181,3	0,10
26	„	97	3	1171,6	1135,5	1177,1	1176,1	0,08
27	„	99	1	1171,6	1135,5	1173,4	1175,3	0,10

The linearity of the applied relations as a function of the concentration of components of the analyzed mixtures, within the limits of given errors, allows one to conclude that at the temperature 20°C no significant association-solvation effects occur (Figures 1, 2 and 3). Such effects would limit the application of these relations for a quantitative determination of the mixtures of fuels or fuels and oils.

4. SUMMATION

a) Measurement of the velocity of ultrasounds as a function of temperature, performed by the method developed at the Aviation Institute, enables a fast qualification of fuels, i.e., allows to distinguish and define the types: benzenes, jet fuels, motor oils and kinds of fuels.

b) A correlation was found between the velocity of ultrasounds and: the density of products, their boiling ranges, freezing temperature,

clouding temperature and the temperature of blockage of cold filter. In this connection:

- there is a possibility of qualitative evaluation of fuel with respect to its compliance with requirements of the norm concerning boiling temperatures in normal distillation;
- there is a possibility of qualitative determination of the compliance of motor oils with norms with respect to freezing temperature, clouding temperature and temperature of the blockage of cold filter.

c) It was found that there is additivity of the velocity of ultrasounds and its relations, as a function of concentration, for mixtures of fuels of various types, particularly in the form of c(V) relation; it enables a fast measurement of the contents of components in two-component mixtures:

benzene - jet fuel
benzene - motor fuel
jet fuel - motor oil

This determination requires only the measurement of the velocity of ultrasounds at one temperature for components and for the sample. For mixtures with known and repeatable qualitative composition, the quantitative analysis reduces to preparing a model curve and then only to determining the velocity of ultrasounds for samples of unknown quantitative composition. The obtained accuracy of ±0.5% could be substantially improved. There is a possibility of developing a continuous method for the control of quality and impurities in standard fuels, lubricating and hydraulic oils, and of their components.

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