

PROPERTIES AND COMPOSITION OF ABSOLUTIZED ETHANOL  
AND ITS EFFECT ON THE GASOLINE OCTANE NUMBER*Volodymyr Starchevskyy<sup>1,\*</sup>, Viktoriia Ribun<sup>2</sup>, Sergii Kurta<sup>2</sup>, Olga Khatsevich<sup>2</sup>*<https://doi.org/10.23939/chcht12.03.346>

**Abstract.** The article describes the types, properties and efficiency of reagents (CaO, tetraethoxytitanium), which chemically bind water and dehydrate ethanol. The composition and properties of the absolutized ethanol were studied using the infrared spectroscopy, mass spectroscopy and gas-liquid chromatography. The octane number of gasoline with the addition of absolutized ethanol together with the combustion activator (diethyl ether) was measured as well. It has been shown that the content of even very small amounts (up to 2 %) of the combustion activator in absolutized ethanol results in the increase of the octane number and improves running abilities of gasoline.

**Keywords:** absolutized ethanol, calcium oxide, tetraethoxytitanium, diethyl ether, octane number.

## 1. Introduction

In connection with the stabilization of oil production and the ban on the use of leaded gasoline in recent years, many countries of the world tend to increase the usage of oxygen-containing compounds as the additions in commercial high-octane gasoline. Methyl (MA), ethyl (EA) and *tert*-butyl (TBA) alcohols, methyl *tert*-butyl ether (MTBE), having high octane numbers and low boiling points are quite widely used among the oxygen-containing compounds. The usage of these additions results in an increase of the octane number and the improvement of the oxygen coefficient and the efficiency of the fuel combustion. All types of the fuel with oxygen-generating additives reduce the release of carbon monoxide (CO) and unburnt fuel parts (C) into the atmosphere. Thus, the addition of 10–15 % MTBE reduces CO content in exhaust gases by 20 %. The use of alcohol-gasoline mixtures as a motor fuel is also promising.

The world ethanol production has recently reached 90 million m<sup>3</sup> per year [1]. The main producers are the USA, Brazil and India. It should be noted that more than 80 % of produced ethanol is used as a component of motor fuels (fuel ethanol). The rest is used for manufacture of the strong drinks, solvents, the ethyl ethers and esters synthesis and as a raw material for organic synthesis [2].

In many countries of the world, gasoline with 10–15 % of various fuel additives is already used. In particular, a mixture of gasoline and ethanol (10–12 %) is successfully used in the USA, Canada and Brazil, where its production is based on a national program. In the United States, 80 % of produced ethanol is used as a fuel. In France, fuel containing ethanol (5 %) is used too. Ukraine consumes around 200 million tons of fuel and energy resources annually and has a deficit of energy resources because the needs for energy consumption are covered only up to 53 % by its own resources. The rest is covered by import: 75 % of the required volume of natural gas and 85 % of crude oil and petroleum products. Such a structure of the energy economy creates Ukraine's dependence on oil and gas exporters and is threatening its energy and national security. Motor transport occupies a leading place in the transportation of goods. The prognosis of the development of Ukraine's motor car park proves the tendency towards a steady increasing of the number of cars and fuel consumption. In 2016, the total motor car park and the park of light commercial vehicles in Ukraine consist of, according to AUTO-Consulting, 9,121 thousand cars, which consume 32.7 million tons of motor fuel. The alcohol industry of Ukraine fully provides internal needs of alcohol for the manufacture of alcoholic drinks, working only up to 30 % of its total capacity [3].

Recently, ethanol production of Ukraine has decreased almost twice from 310 million litres in 1996 to 140 million litres in 2017. Today, 25 % of the 80 distilleries with a total capacity of 480 million litres per year operate. To date, in Ukraine there are more than 40 licensed distilleries that can process 900 thousand tons of grain per year and obtain 320 million litres of grain ethanol. The annual need of beet molasses is 1.1 million

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tons, from which you can get other 300 million litres of ethanol. In the structure of realization of rectified ethanol the largest part is occupied by vodka and ethanol from 81 to 94.5 % in 2015. In January 2016, the manufacturer “Ukrspir” produced more than 860 thousand litres of ethyl alcohol, 85 thousand litres of strong drinks and 756 thousand litres of car washers. At the same time, the company work is provided by 16 factories [4].

In recent years, the production of bioethanol has been steadily increasing. From 2000 to 2014 the amount of produced ethanol has increased by 5 times. The market leaders are: USA (corn), Brazil (sugar cane), Germany and France (sugar beet and grain). Governments of these countries intend to increase the bioethanol production by 70 %. If 10 % of bioethanol is added to gasoline, emissions of aerosol particles are reduced by 50 % and carbon monoxide emissions – by 30 %. Therefore, there is a Directive 2009/28/EC, which requires up to 10 % bioethanol in a motor fuel by 2020. Ukraine signed the Association Agreement with the European Union, so it should undertake the similar obligations. While in the EU this index is gradually approaching 5 % in Ukraine, it does not exceed 1 % [5].

Macroeconomic analysis has shown that adding 20 % of bioethanol to gasoline leads to an annual decrease in gasoline import by \$ 400 million, which will result in \$ 640 million increase in Ukraine’s gross domestic product (GPD). Replacing 20 % of heavy distillates with biodiesel will reduce imports by \$ 1 billion, which can increase Ukraine’s GDP by \$ 1.4 billion.

In August 2014, there were 13 enterprises operating in Ukraine that produced alcoholic fuels, 10 of which based on the state alcohol distilleries with a capacity of 23700 tons/month. However, in August 2014 there was introduced 99 EUR tax on alternative gasoline in favour of importers and network monopolists, resulting in the fact that by the beginning of 2015 only two plants (“Haysinsky” and “Ekoeenergy”) with a total capacity of 2,700 tons/month worked [5]. The cost of growing rape grain in recent years ranged from 800 to 1200 UAH/t. At the same time, when the seed market price is 3000 UAH/t, the cost of production of biodiesel from the fossil is 11–12 thousand UAH/t. (about 10 UAH/l), which is 2.5 times lower than the existing prices for diesel oil from oil [6]. The dynamics of growth of bioethanol and biodiesel part in the world represented by the author [2] speaks for itself, so the production of bioethanol has exceeded 100 billion litres, and biodiesel amount reaches 30 billion litres.

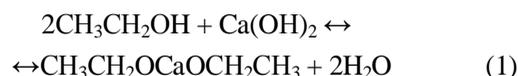
It is known that for homogenization of gasoline ethanol mixtures the third component is used. This component is aromatic hydrocarbons [7], which are added to ordinary gasoline to increase the octane number. In addition, it is not profitable, because the cost of toluene is

by many times higher than the cost of absolute ethanol. As for the preparation of perfect mixtures of bioethanol and biodiesel with gasoline and diesel, only absolute ethanol (99.95 %) must be used, therefore the research of new methods and reagents of ethanol absolutization is an actual problem and purpose of our work, which has a practical and economic value.

## 2. Experimental

The properties of known oxygen-generating additives which activate the motor fuel combustion are presented in Table 1 [3]. The table shows reagents which do not contain water, including ethyl alcohol and ethers, but in this work it is not described how the ethyl alcohol was absolutized, therefore in different sources it has a different octane number. Consequently, we propose our own method of ethanol absolutization with calcium oxide or tetraethoxytitanium (TET).

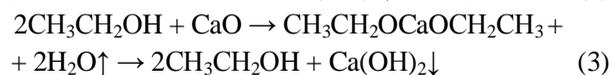
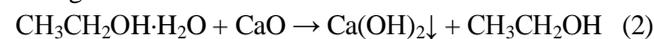
Researches of the method of ethanol absolutization by chemically binding water reagents such as calcium oxide and TET are conducted. Alcohols practically do not interact with alkalis, because among the reaction products there is water that decomposes formed alcoholate and a reverse reaction takes place:



Therefore, fresh prepared (1123 K, 2 h) mineral calcium carbonate, which has the following characteristics, presented in Table 2, was used for ethanol absolutization.

After calcination, samples of CaO were cooled in a vacuum desiccator, to reduce air access and to re-carbonize calcium oxide. Only 1 grade with minimum content of impurities was taken for work (Table 2).

It was suggested that if you take freshly calcined calcium oxide, then absolutized ethyl alcohol and alcoholates of the corresponding metals can be obtained during an irreversible reaction:



The insoluble calcium hydroxide in the alcohol was filtered off, and the absolute ethyl alcohol by reaction (4) and (3) was discharged through a direct refrigerator, and the calcium hydroxide remained in the flask in the precipitate form. Tetraethoxytitanium ( $(\text{CH}_3\text{CH}_2\text{O})_4\text{Ti}$ ) as a dehydrator acts in different way.

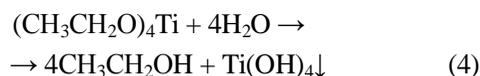


Table 1

## Octane number of oxygen generating gasoline additives, which is measured by different methods

Indices	MTBE	ETBE	MTAE	DIPE	Methanol	Ethanol	tert-Butanol
Research octane number (RON)	112–130	120	105–115	111.6	12	106	108
Motor octane number (MON)	75–115	102	95–105	98.4	90	95	98
Octane number index (RON+MON)/2	110	111	105	105	101	100.5	103
Saturated vapour pressure, MPa (at 293 K)	0.06	0.03	0.02	0.03	0.42	0.13	0.07

Table 2

## Properties of calcium oxide

The component content of calcium oxide	Types of CaO obtained from mineral calcium carbonate, CaCO <sub>3</sub>		
	1	2	3
Active CaO	≤ 90	≤ 80	≤ 70
Active MgO	≥ 5	≥ 5	≥ 5
CaCO <sub>3</sub> and MgCO <sub>3</sub> carbons	≥ 3	≥ 5	≥ 15
Impurities SiO <sub>2</sub> and Al <sub>2</sub> O <sub>3</sub>	≥ 1	≥ 10	≥ 15

Table 3

## Comparative physico-chemical characteristics of oxygen generating additives – gasoline combustion activators [8]

Parameter	Units	Methanol	Ethanol	Butanol	Gasoline
Molecular formula		CH <sub>3</sub> OH	C <sub>2</sub> H <sub>5</sub> OH	C <sub>4</sub> H <sub>9</sub> OH	C <sub>6</sub> H <sub>6</sub>
Molecular weight	g/mol	32.04	46.07	74.12	78.11
Melting point	K	175	159	183	278
Boiling point	K	338	351	390	353
Density	g/cm <sup>3</sup>	0.791	0.789	0.81	0.879
Saturated vapour pressure	kPa, 298 K	16.2	6.5–7.5	0.8	12.7
Vapour density	g/l, 298 K	1.3	1.9	2.4	3.2
Water solubility	g/100 ml	unlimited	unlimited	7.9 g/100ml	1800 mg/l
Viscosity	s·Pa, 298 K	0.544	1.074	–	0.649
Henry's constant	C <sub>air</sub> /C <sub>H<sub>2</sub>O</sub> , 298 K	1.087E-4	2.097E-4 to 2.571E-4	–	2.219E-1
Energy density	MJ/l	16	19.6	29.2	–
Octane number (RON)	–	156	132	104	82.5–98.0
Cetane number (MON)	–	92	89	78	95

During the hydrolysis of TET the titanium tetrahydroxide, which is insoluble in alcohol, precipitates and can be filtered out; the absolutized alcohol is distilled at a special installation under vacuum, or with air dehydrators under normal conditions.

As can be seen from Table 3 [8], ethanol has the most similar properties with gasoline according to the main indicators (boiling point and octane number). In addition, it is the cheapest and most affordable as a bioethanol – a product of natural raw materials processing, therefore, it was selected for absolutization. The ethanol concentrations were measured by the weight pycnometer method and determined by theoretical data [9]. The volume concentration of alcohol is determined by the areometers (ASP-1, ASP-2) using tabular data. Chromatography of ethanol and gasoline is carried out on by a gas-liquid

chromatography, a method for determining oxygen-containing compounds in gasoline (HPCHEM\SEQUENCE\D161124A.S\METHOD\ D4815N.M) by internal standard (ISTD) based on 15 known calibrated substances, including ethanol (Figs. 2–4). Infrared spectroscopy of ethanol samples is carried out by IR spectroscope (IS 50 FT-IR "NICOLET" Slovensko). Mass spectroscopy of the samples is carried by a mass spectroscope (MX-7304A, AO.SELMI, Sumy, Ukraine, 1 to 210 mass range). Determination of the cetane number of diesel fuel L-0.2-40 and the octane number of petrol A-80, as well as the freezing point of diesel fuel was carried out using the laboratory analyzer "Octane meter" of Shatox sx-100k type [15]. Also, an assessment of the petrol gasoline by a motor method was carried out at the "OKKO" quality control laboratory in Galich, Ivano-Frankivsk region of Ukraine.

### 3. Results and Discussion

Table 4 shows the results of the ethanol absolutization using tetraethoxytitanium. As can be seen from the Table, absolutized ethanol can be obtained with the ethanol concentration, which increases from 92.5 to 93–96 wt % (or 95.41–99.50 vol %), but does not reach 100 wt %.

Therefore, at the second stage of our research, we used a more reactive dehydrator – calcium oxide which was calcined at 1123 K; its characteristics are presented in Table 2. We selected a sample No.1 with a minimum content of magnesium oxide (MgO – 5 %), carbonates (CaCO<sub>3</sub>+MgCO<sub>3</sub> – 3 %) and other impurities (SiO<sub>2</sub>+Al<sub>2</sub>O<sub>3</sub> – 1 %). As can be seen from the results presented in Table 4, the CaO consumption decreases to 20 wt %, compared with 25 wt % of (C<sub>2</sub>H<sub>5</sub>O)<sub>4</sub>Ti, and

the concentration of absolutized ethanol increases to 99.5–100.0 wt %, or 99.7–100.0 vol %. In addition, the loss of alcohol decreases. After absolutization with (C<sub>2</sub>H<sub>5</sub>O)<sub>4</sub>Ti these losses reaches 15–25 % C<sub>2</sub>H<sub>5</sub>OH (Table 3), while for CaO they decrease to 8–13 % relative to the initial C<sub>2</sub>H<sub>5</sub>OH (Table 4). So we can say that calcium oxide as a chemically binding water reagent is much more effective dehydrator. As can be seen from Fig. 1, the ethanol concentration after treatment with calcined calcium oxide (21 % CaO) reaches 99.95 wt %, while the absolutization with tetraethoxytitanium increases the concentration of ethanol only to 96.5 wt %.

At the same time, the non-absolutized 95 % ethanol contains an admixture of MTBE (0.09531 wt %). In this case, the low-boiling impurity in the non-absolute ethanol is absent (Fig. 2).

Table 4

Properties of ethanol after absolutization with tetraethoxytitanium

Initial ethanol amount, SSU 4221:200 95 vol %, 92.5 wt %		The amount of ethanol obtained after absolutization		Ethanol yield after absolutization	The amount of Ti(OC <sub>2</sub> H <sub>5</sub> ) <sub>4</sub>		Ethanol density after absolutization	Ethanol concentration after absolutization	
V, ml	m, g	V, ml	m, g	wt %	m, g	%	g/cm <sup>3</sup>	vol %	wt %
100	82.15	85	69.07	84.08	26.65	25	0.8126	95.41	93.0
100	82.16	85.1	70.72	86.08	27.55	25.11	0.8065	95.85	93.5
100	82.10	77.59	62.1	75.14	29.15	26.20	0.8014	97.49	96.0
100	82.10	77.59	62.1	75.14	29.15	26.20	0.8014	99.50	96.0

Table 5

Properties of ethanol after absolutization by CaO (90 %)

The initial ethanol amount, 95% vol., 92,5% mas.		The amount of ethanol obtained after absolutization		Ethanol yield after absolutization	The amount of CaO		Ethanol density after absolutization	Ethanol concentration after absolutization	
V, ml	m, g	V, ml	m, g	wt %	m, g	%	g/cm <sup>3</sup>	vol %	wt %
100	82.15	96	75.77	92.23	18	1.91	0.7893	100.0	100.0
100	82.16	93	73.42	89.36	17.8	1.66	0.7894	99.97	99.95
100	82.10	93	73.42	89.43	17.5	1.32	0.7895	99.93	99.89
100	82.10	90	71.69	87.32	17	0.71	0.7899	99.72	99.51

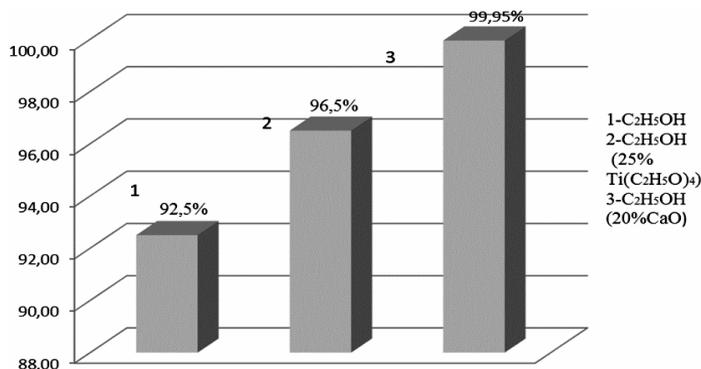


Fig. 1. Dependence of the ethyl alcohol concentration after absolutization with tetraethoxytitanium (25 % (C<sub>2</sub>H<sub>5</sub>O)<sub>4</sub>Ti) and calcium oxide (20 % CaO)

According to the chromatogram (Fig. 2), the concentration of non-absolutized ethanol reaches 97.8499 vol % against 95.0 %, as it was measured by the weight pycnometer method (Tables 4 and 5). At the same time, the concentration of ethanol absolutized with calcium oxide (Fig. 3) is 97.5724 vol %. Taking into account 2.3432 % of unidentified low-boiling impurity ( $T_b = 308\text{--}310\text{ K}$ ) and 0.03433 % of MTBE (according to the chromatogram in Fig. 3), the total concentration of absolutized ethanol is 99.95 vol %, as it was determined by the pycnometric method (Tables 4 and 5).

Taking into account the chromatogram data in Fig. 3 and its interpretation, we determine the qualitative composition of one of the unknown components ( $X = 2.3432\%$ ), which appears in the chromatogram of ethyl alcohol (99.95%), absolutized with CaO for 2.8 min. At the same time, the chromatographic analysis of 99.99% ethyl alcohol absolutized by industrial method [9] (Fig. 4), shows 100.03 vol % of ethanol. The difference of 0.03 % might be a mistake of the device or an alcohol supplier analysis method.

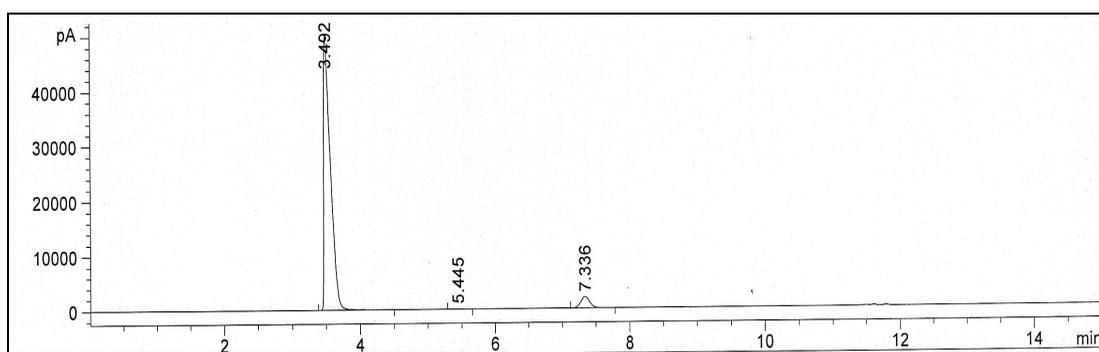


Fig. 2. Chromatogram of the initial, non-absolutized ethanol (95.0 vol %) with corresponding interpretation

Retention time, min	Signal	Square, pA·s	Content/square ratio	Content, %	Name
3.111	1	–	–	–	Methanol
3.492	1	3.42147e5	8.22788e-1	104.88462	Ethanol (97.8499 %)
3.968	1	–	–	–	<i>i</i> -Propanol
4.381	1	–	–	–	<i>tert</i> -Butanol
4.798	1	–	–	–	<i>n</i> -Propanol
5.445	1	328.77359	7.78020e-1	9.53013e-2	MTBE(0.09531%)
5.719	1	–	–	–	<i>sec</i> -Butanol
6.133	1	–	–	–	DIPE
6.380	1	–	–	–	<i>i</i> -Butanol
6.668	1	–	–	–	ETBE
6.933	1	–	–	–	<i>tert</i> -Amyl alcohol
7.336	1	1.88688e4	1.00000	7.03000	DME (ISTD)
7.505	1	–	–	–	<i>n</i> -Butanol
All with ISTD:				104.97992	All without DME (ISTD) 97.94531 %

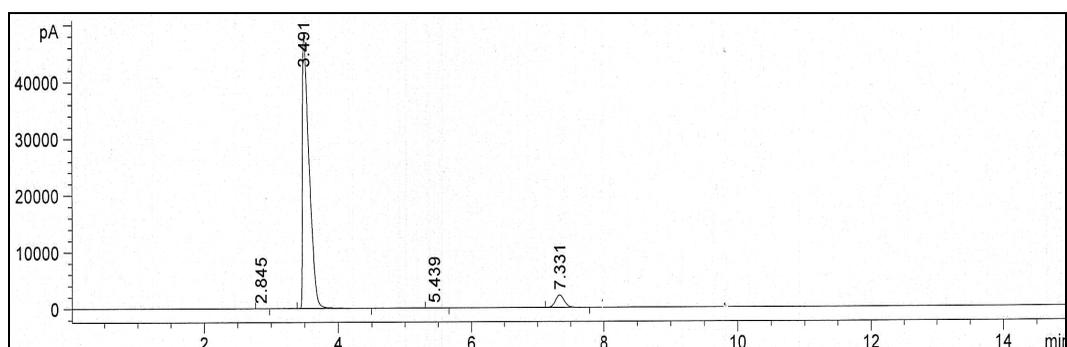


Fig. 3. Chromatogram of the ethanol (99.95 vol %), absolutized with calcium oxide with corresponding interpretation

Retention time, min	Signal	Square, pA·s	Content/square ratio	Content	Name
3.111	1	–	–	–	Methanol
3.491	1	3.31410e5	8.22875e-1	103.06328	Ethanol (97.5724 %)
3.968	1	–	–	–	<i>i</i> -Propanol
4.381	1	–	–	–	<i>tert</i> -Butanol
4.798	1	–	–	–	<i>n</i> -Propanol
5.439	1	36.47682	2.49050	3.43328e-2	MTBE (0.03433 %)
5.719	1	–	–	–	<i>sec</i> -Butanol
6.133	1	–	–	–	DIPE
6.380	1	–	–	–	<i>i</i> -Butanol
6.668	1	–	–	–	ETBE
6.933	1	–	–	–	<i>tert</i> -Amyl alcohol
7.331	1	2.01892e4	1.00000	7.63000	DME (ISTD)
7.505	1	–	–	–	<i>n</i> -Butanol
All with ISTD:				103.09761	All without DME (ISTD) 99.95 %

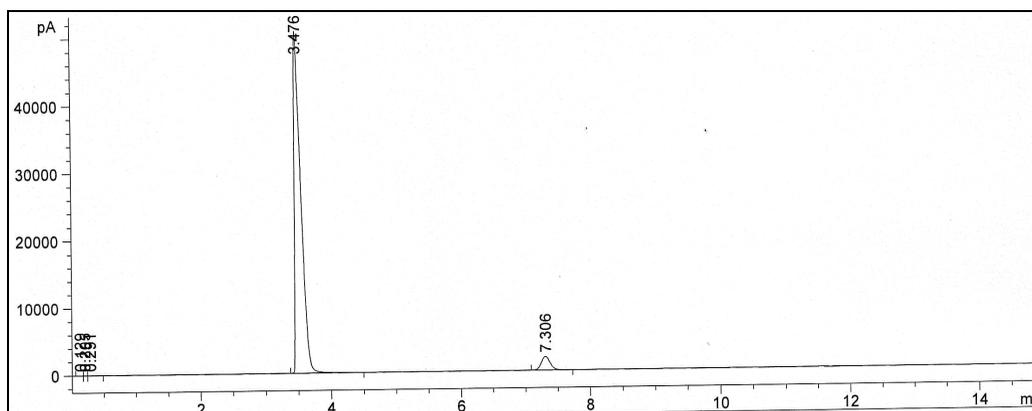
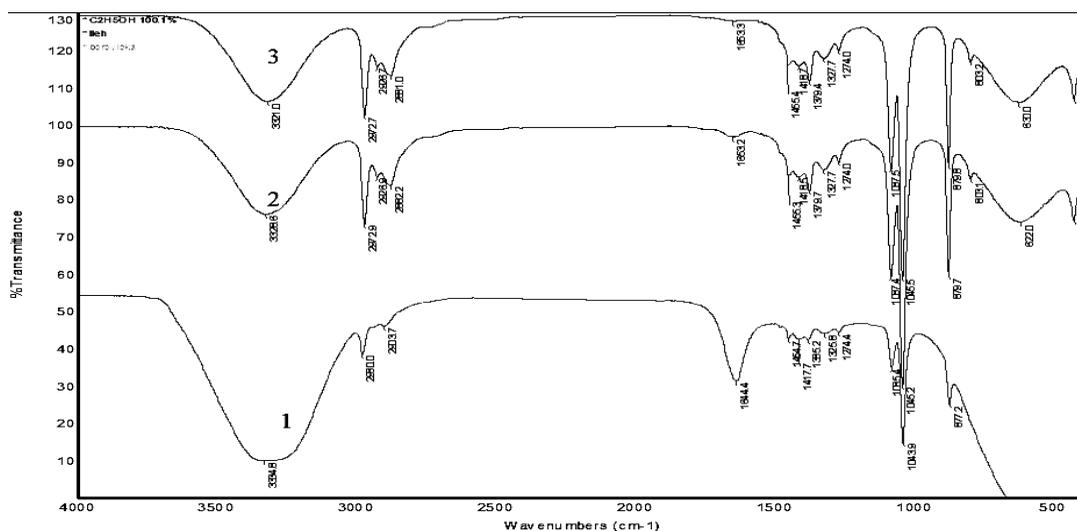


Fig. 4. Chromatogram of the ethanol (99.99 vol %), absolutized by industrial method [9] with corresponding interpretation

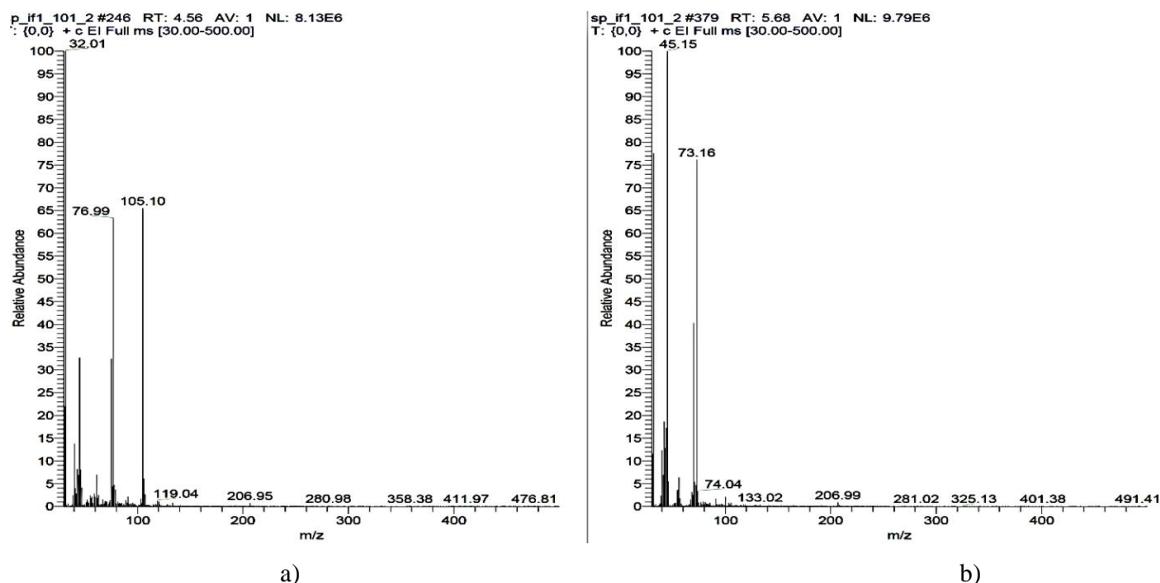
Retention time, min	Signal	Square, pA·s	Content/square ratio	Content, %	Name
3.111	1	–	–	–	Methanol
3.491	1	3.49655e5	8.22748e-1	106.84766	Ethanol
3.968	1	–	–	–	<i>i</i> -Propanol
4.381	1	–	–	–	<i>tert</i> -Butanol
4.798	1	–	–	–	<i>n</i> -Propanol
5.439	1	–	–	–	MTBE
5.719	1	–	–	–	<i>sec</i> -Butanol
6.133	1	–	–	–	DIPE
6.380	1	–	–	–	<i>i</i> -Butanol
6.668	1	–	–	–	ETBE
6.933	1	–	–	–	<i>tert</i> -Amyl alcohol
7.331	1	1.83622e4	1.00000	6.82000	DME (ISTD)
7.505	1	–	–	–	<i>n</i> -Butanol
8.129	1	–	–	–	Benzene
All with ISTD:				106.84766	All without DME (ISTD) 100.03%

Unfortunately, this impurity is not identified by graded chromatograms of alcohols and ethers, therefore, an IR spectral analysis of this alcohol is performed, which is compared with the IR spectra of the original (95 %) and pure absolute (100 %) ethyl alcohol (Fig. 5). As can be seen from Fig. 5, the IR spectra of all three samples do not differ significantly from each other. Only in two

absorption regions 3320–3330 and 1630–1640 cm<sup>-1</sup>, there is a noticeable difference in the absorption intensity of the fluctuations of the corresponding groups, which significantly decrease from the maximum in the original non-absolutized 95 % C<sub>2</sub>H<sub>5</sub>OH (curve 1, Fig. 5) to a minimum in absolute 100 % C<sub>2</sub>H<sub>5</sub>OH (curve 3, Fig. 5).



**Fig. 5.** Infrared spectra of different ethyl alcohols: 95.0 vol % non-absolutized  $C_2H_5OH$  (1); 99.95 vol %  $C_2H_5OH$  absolutized with CaO (2) and 100 %  $C_2H_5OH$  of industrial production (3)



**Fig. 6.** Mass spectra of initial 95 % ethanol (a) and absolutized with CaO 99.95 % ethanol (b)

First of all, the amount of water in samples of ethanol decreases from 4–5 % in the initial non-absolutized alcohol (*curve 1*, Fig. 5) to 0.1–0.05 % in the absolutized with CaO ethanol (*curve 2*, Fig. 5) and up to 0 % in the absolutized 100 %  $C_2H_5OH$  (*curve 3*, Fig. 5). Therefore, the absorption intensity in the region of 3320–3330  $cm^{-1}$ , which corresponds to the valence fluctuations of the hydroxyl groups of the  $H_2O$  molecules, decreases by 20 % (according to the spectrograms in Fig. 5). This is noticed in the transition from the non-absolutized 95 %  $C_2H_5OH$  (*curve 1*, Fig. 5) to the absolutized with CaO ethanol (*curve 2*, Fig. 5) and to the absolute 100 % ethanol (*curve 3*, Fig. 5). In addition, in the spectrograms of the absolutized with CaO 99.95 %  $C_2H_5OH$  (*curve 1*, Fig. 5)

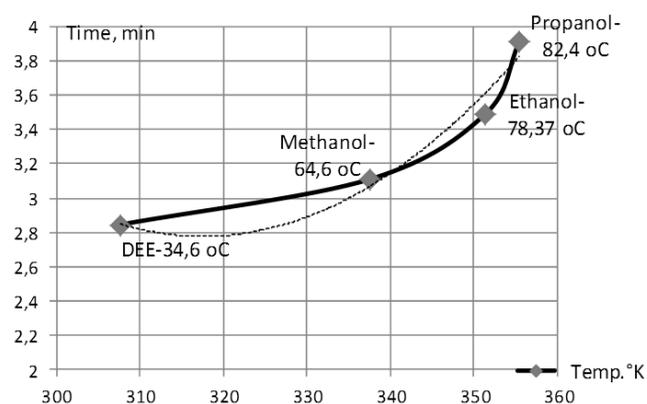
and absolute 100 % ethanol (*curve 3*, Fig. 5) absorption disappears in the region of deformation oscillations 1630–1640  $cm^{-1}$  of double bonds  $C=C$  or  $C=O$  [10] compared with non-absolutized 95 % alcohol (*curve 1*, Fig. 5), which can be identified as the presence of ketones, aldehydes, complex esters and ethers, and corresponds to the presence of MTBE in ethyl alcohol, which is identified in chromatograms of non-absolutized 95 % and absolutized with CaO 99.95 % ethyl alcohol (Figs. 2 and 3) in the range of 0.034–0.095 %.

For identification and more proper determination of the composition and structure of the impurity ( $X = 2.3432\%$ ) in ethanol, which is identified in the chromatogram of the absolutized with CaO ethanol at

2.845 min (Fig. 5), we carried out a mass spectrometric analysis of our samples of non-absolutized 95 % and absolutized with CaO 99.95 % ethanol by the mass spectroscopy MX-7304A, AO.SELMI shown in Fig. 6.

As can be seen in the mass spectrogram of non-absolutized 95 % ethyl alcohol (Fig. 6a), radical composition of the impurity is formed by the electron action of the mass spectrometer, there can be three types of free radicals with molecular weights such as 32.01 m.u.  $-\text{C}_2\text{H}_5\bullet = 29$  m.u.; 76.99 m.u.  $-(\text{CH}_3)_3\text{O}\bullet = 73$  m.u.; 105.1 m.u.  $-\text{C}(\text{CH}_3)_3\text{OOCH}_2\bullet = 103$  m.u. They may be formed by the action of electrons of the mass spectrometer on ethyl alcohol  $\text{C}_2\text{H}_5\text{OH}$  and methyl *tert*-butyl ether  $\text{C}(\text{CH}_3)_3\text{OOCH}_2$ , which are identified in the chromatograms of the initial non-absolutized 95 % alcohol (Fig. 2). At the same time, for absolutized with calcium oxide 99.95 % ethanol (Fig. 6b) in the composition of the impurity radicals formed by the action of electrons of the mass spectrometer, there can be only two types of free radicals with molecular weights such as 45.15 m.u.  $-\text{C}_2\text{H}_5\text{O}\bullet = 44$  m.u. and 73.16 m.u.  $-(\text{C}_2\text{H}_5)_2\text{O}\bullet = 74$  m.u. They can be formed by the electron influence of the mass spectrometer on ethyl alcohol  $\text{C}_2\text{H}_5\text{OH}$  and diethyl ether  $(\text{C}_2\text{H}_5)_2\text{O}$ , which are identified in a chromatogram of the 99.95 % ethanol absolutized with CaO (Fig. 3).

Taking into account that we know the retention time of the impurity ( $X = 2.3432$  % at 2.845 min), which is not identified in the chromatogram of 99.95 % ethanol, absolutized with CaO (Fig. 3), therefore, we have constructed dependence of the retention time of three kinds of alcohol (*i*-propanol, ethanol, methanol) and diethyl ether (DEE) on the boiling points of these substances at the chromatogram (Fig. 7).



**Fig. 7.** Dependence of retention time of *i*-propanol, ethanol, methanol and DEE on the boiling points of these substances from the chromatogram (Fig. 3)

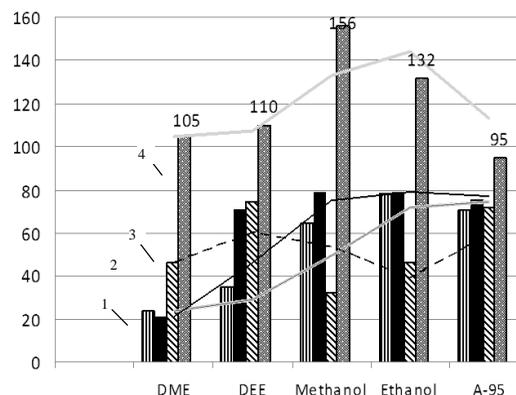
The analysis of the curves shows that the diethyl ether retention time at the boiling point of 307.6 K is 2.85 min, which coincides with the chromatogram data (2.845 min). In this way, we confirm the assumption that during the absolutization of 95 % ethanol with calcium oxide, ethyl alcohol containing 2.3432 % of diethyl ether and 97.5724 %  $\text{C}_2\text{H}_5\text{OH}$  can be obtained.

We checked how 2.3432 % of diethyl ether influences the ethanol octane number and the gasoline octane number. Previously, the physico-chemical characteristics of some oxygen-generating additives for gasoline, shown in Fig. 8, were analyzed. As can be seen from Fig. 8, the density and molecular mass of diethyl ether are close to those of gasoline A-95. The boiling point of the diethyl ether 307.6 K is lower than that of gasoline. It is approaching the boiling point of the first fraction of gasoline, which is 307.6 K. These properties are especially useful for accelerated engines of gasoline cars in winter, when ignition is hampered by a lowered ambient temperature (below 263 K). Thus, the diethyl ether presence improves the gasoline combustion efficiency, which we have checked by adding 10–95 % absolutized (97.5 %) alcohol containing 2.34 % of diethyl ether, which is presented in Fig. 9.

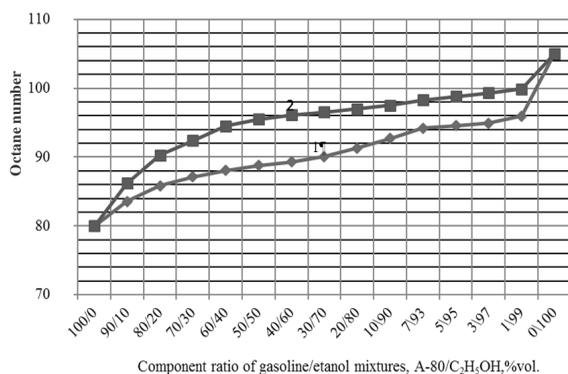
Octane numbers of A-80 gasoline with absolute ethanol additives (gasoline-ethanol mixture) are counted according to the authorship formula [11], which is derived from experimental data [12]. These octane numbers are compared with the octane numbers of gasoline, in which ethanol with diethyl ether is added.

$$\text{ONGE} = [26.44 - 0.29(\text{ON0})]\ln\text{Ce} + [1.32(\text{ON0}) - 29.49]$$

where ONGE – octane number of gasoline-ethanol mixture; ON0 – octane number of initial gasoline; Ce – ethanol content.



**Fig. 8.** Physico-chemical characteristics of oxygen-generating additives (DME – dimethyl ether, DEE – diethyl ether, methanol, ethanol) in comparison with the characteristics of gasoline A-95: boiling points (1); density (2); molecular weight (3) and octane number (4)



**Fig. 9.** Dependence of the octane number of gasoline A-80 on the amount and kind of added ethanol: theoretically calculated ON (1) of gasoline-ethanol mixtures from the formula [11] and experimentally obtained ON (2) of gasoline-ethanol mixtures with the addition of absolutized ethyl alcohol containing 2.34 % of diethyl ether

Obtained data of the octane number dependence is performed in Fig. 9 (curve 1) and compared with the octane number of gasoline-ethanol mixtures to which ethanol containing 2.34 % of diethyl ether was added (curve 2). Thus, it was shown that ethyl alcohol containing diethyl ether can more effectively increase the octane number of gasoline A-80. The content of 20–40 % of such ethanol in gasoline A-80 increases its octane number to 91–95 units. While conventional 99.95 % ethanol increases the octane number of gasoline A-80 only to 85–88 units. In the case of the maximum possible absolutized ethanol content up to 80–90 % in gasoline A-80, the octane number reaches 91–93 units, and the introduction of the same amount of 99.95 % ethanol containing 2.34 % of diethyl ether in gasoline A-80, the octane number reaches 97–97.5 units [16].

#### 4. Conclusions

The properties and high ability of calcium oxide and tetraethoxytitanium as dehydrators for chemical binding of water and absolutization of 96 % ethyl alcohol to 99.95 % have been investigated. The dependence of the properties and composition of the absolute alcohol on the dehydrator nature was shown. Infrared spectroscopy, mass spectroscopy, and gas-liquid chromatography confirmed the presence of 2–2.34 % of diethyl ether in ethanol, which is absolutized by freshly prepared calcium oxide. It was determined that the octane number of gasoline A-80 with the addition of 20–90 % of the absolutized ethanol containing 2.34 % of the combustion activator – diethyl ether – increases gasoline octane number more significantly than with the addition of the same amount of an ordinary absolute 99.95 % alcohol without diethyl ether and reaches 95–97 units, whereas the octane number of gasoline with ordinary absolute ethanol reaches only 88–95 units. We confirmed literary data that the content of even very small amounts of ethers, as combustion activators, combined with the absolute ethyl alcohol leads to an improvement in the gasoline running abilities.

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#### ВЛАСТИВОСТІ Й СКЛАД АБСОЛЮТИЗОВАНОГО ЕТАНОЛУ ТА ЙОГО ВПЛИВ НА ОКТАНОВЕ ЧИСЛО БЕНЗИНУ

**Анотація.** Описано види, властивості та ефективність реагентів (CaO, тетраетоксититан), які хімічно зв'язують воду та абсолютизують етанол. За допомогою інфрачервоної спектроскопії, мас-спектроскопії та газо-рідинної хроматографії вивчено склад та властивості абсолютизованого етанолу. Оцінено октанове число бензину з додаванням абсолютизованого етанолу з активатором горіння – діетиловим етером. Показано, що вміст навіть дуже невеликих кількостей (до 2 %) активатора горіння в абсолютизованому етанолі приводить до збільшення октанового числа та поліпшення експлуатаційних властивостей бензину.

**Ключові слова:** кальцій оксид, тетраетоксититан, абсолютизований етанол, діетиловий етер, октанове число.