

Dielectric Control of Motor Fuel Compounding Plants

Nabil Abdel Sater¹, Andrey Grigorov¹, Gelena Neustroieva¹, Oleksandr Bondarenko², Vasyl Matukhno², Sergii Vavreniuk²

¹ National Technical University «Kharkov Polytechnic Institute», 61002, 2 Kirpichova str., Kharkov, Ukraine

² National University of Civil Defense of Ukraine, 61023, 94 Chernyshevskaya str., Kharkov, Ukraine

Received November 29, 2021; Accepted March 29, 2022

Abstract

The article proposes the use of operational dielectric control system to increase the efficiency of operation of automatic compounding of motor fuels. These plants are used at oil refining enterprises in Ukraine and are an integral part of the technological chain of the commercial fuels production.

It is established that all the main components and additives used for the production of commercial gasoline brands A-92, A-95 and A-98 have higher values (ϵ_{mix}) than straight run base gasoline. And this, in turn, can be used for operational control of the gasoline compounding process. This control can be carried out on the basis of the information received from capacitive sensors which are located in pipelines of the main material streams. Moreover, the control is carried out on the content of components (X, %) or on the value of the octane number (ON, point) of the mixture on the basis of experimentally obtained dependences $\epsilon_{\text{mix}} = f(X)$ and $\text{ON} = f(\epsilon_{\text{mix}})$.

Keywords: Motor fuel; Compounding; Operational control; Additives; Dielectric constant; Octane number; Properties; Gasoline.

1. Introduction

Modern motor fuels are produced in accordance with the developed recipes and are a mixture of components obtained by technologies of primary refining of crude oil, secondary thermo-catalytic processes and additives for various functional purposes. They usually contain more than 200 individual hydrocarbons of different structure, the content of which as well as their interaction with each other determines the properties of the fuel. In the conditions of oil refineries motor fuels are obtained using an automatic compounding system, which is the final technological stage of production of commercial fuels. During compounding, the ratio of the components (their concentration) to be mixed and the quality of the commercial fuel obtained as a result of this operation are strictly controlled.

Today, control over the technological process of compounding is carried out on the basis of the results of laboratory analysis in the central factory laboratory of samples taken at the appropriate installation places. Note that laboratory control includes the definition of a number (from 3 to 5) of standardized quality indicators that characterize the properties of the fuel obtained. On our opinion, such a system is outdated and does not correspond to modern trends in improving the efficiency of operation of installations and technological equipment of Ukrainian refining enterprises.

2. Research objective

Radical changes in this area should be made in the direction of development and implementation of modern systems of operative control of the technological process, which is based on obtaining the operational information. Such information is obtained when using in the system of quality the analyzers (sensors), which are located on the main material flows [1]. And on the basis of this information, adjustments to the process of fuel compounding are immediately made.

When using the system of automatic control of motor fuels compounding the positive factors include:

- 1) improving the quality of marketable products;
- 2) preventing the release of substandard product;
- 3) reducing the costs for laboratory analytical control;
- 4) the ability to correct quickly the dosed input of components and additives.

It is clear that these factors can be met only by using for product quality assessment a single integrated indicator, instead of a set of standardized indicators (density, resistance to detonation, saturated vapor pressure, fractional composition, etc.), which adequately characterizes the composition and properties of motor fuel. Given the electrical properties of petroleum products (they are not polar dielectrics), such indicator is their relative dielectric constant (ϵ). Today, based on this indicator, a number of methods allowing to quickly obtain the information about the composition, properties of oil and petroleum products have been developed [2-4].

3. Results and discussions

For the production of standard motor fuel, for example, motor gasoline brands A-92, A-95 and A-98, usually equal proportions of straight-run gasoline fraction (b.p.-180 °C), catalytic cracking and reforming gasoline, supplemented with additives - substances that have high resistance to detonation are used [5].

The effect of any component of gasoline on the value (ϵ_{mix}) of the resulting mixture in general can be represented as

$$\epsilon_{\text{mix}} = \epsilon_{\text{b.f.}} + \epsilon_{\text{comp.}} \quad (1)$$

where $\epsilon_{\text{b.f.}}$ - the value of the base (straight-run) gasoline fraction; $\epsilon_{\text{comp.}}$ - component value.

In this case, from the sources [6-7] it is known that there is a certain ratio between the main groups of hydrocarbons (paraffins, olefins, naphthenes, cycloolefins, aromatic hydrocarbons) which all petroleum products consist of

$$\epsilon_{\text{p.}} < \epsilon_{\text{ol.}} < \epsilon_{\text{nap.}} < \epsilon_{\text{c.ol.}} < \epsilon_{\text{ar.}} \quad (2)$$

The chemical composition of straight-run gasolines is mainly represented by paraffinic and naphthenic hydrocarbons. Also, they contain a small, up to 5 % part of aromatic compounds [8]. In view of this, their value (ϵ_{mix}) does not exceed 1.9 units.

Catalytic cracking gasolines are represented by 52-55 % olefinic hydrocarbons, 39-43 % by paraffinic hydrocarbons and 5-6 % by aromatic compounds [9]. Due to this, their value (ϵ_{mix}) will be slightly higher than that of straight-run gasolines.

Catalytic reforming gasolines are 70-75 % represented by aromatic hydrocarbons, 25-30 % by a mixture of paraffinic and naphthenic hydrocarbons [10]. As a result, their value (ϵ_{mix}) will be higher than that of straight-run gasolines and catalytic cracking gasolines.

Then, when adding any of the components presented above to the straight-run gasoline fraction, there will be a certain increase of value (ϵ_{mix}), which is confirmed by the experimental data presented in Fig. 1.

At the maximum content of components in the mixture at the level of 35 % (see Fig. 1): for catalytic cracking gasoline $\Delta\epsilon = 0.05$ units; for catalytic reforming gasoline $\Delta\epsilon = 0.22$ units.

Today, the alcohols are increasingly used in gasoline compositions: methanol, ethanol, propane and iso-butane. This, in turn, helps to increase the environmental friendliness of gasoline - in the exhaust gases of the internal combustion engine there is a decrease in the amount of CO, NO_x and solid C [11]. In addition, alcohols exhibit high antiknock properties. Usually the amount of alcohol in gasoline does not exceed 15 %, which increases the resistance to detonation by 6-8 points [11-12].

The value (ϵ) of alcohols ranges from 17.7 to 33.1 units [6-7], but when they are added to the straight-run gasoline fraction as well as in the case of catalytic cracking and reforming gasolines, the value (ϵ_{mix}) increases, that is shown on Fig. 2.

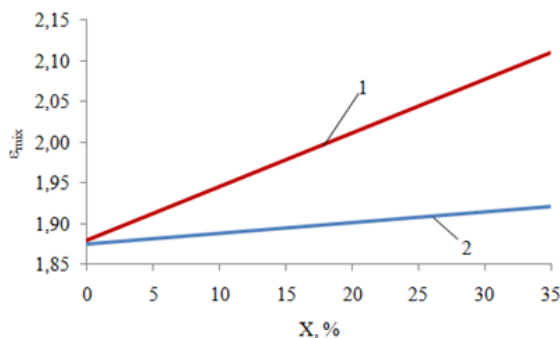


Figure 1. Dependence of (ϵ_{mix}) of the mixture on the content of component X: 1 - catalytic reforming gasoline; 2 - catalytic cracking gasoline

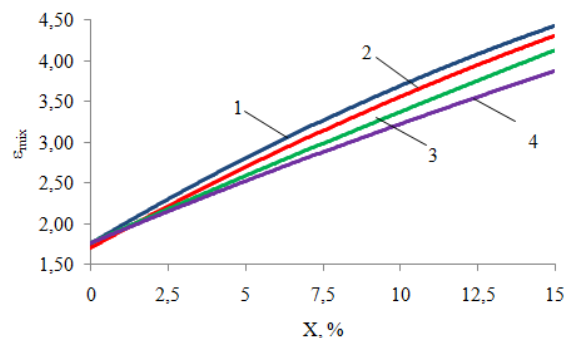


Figure 2. Dependence of (ϵ_{mix}) of the mixture on the alcohol content X: 1-methanol; 2 - ethanol; 3 - propanol; 4- iso-butanol

On value of (ϵ) the alcohols can be arranged in the following order: methanol > ethanol > propanol > iso-butanol. This is the dependence (see Fig. 2) that persists for mixtures of straight-run gasoline fraction with the studied alcohols. Thus, at the maximum alcohol content in the mixture at the level of 15 %: for methanol $\Delta\epsilon = 2.46$ units; for ethanol $\Delta\epsilon = 2.33$ units; for propanol $\Delta\epsilon = 2.27$ units; for iso-butanol $\Delta\epsilon = 1.93$ units.

To increase the detonation resistance of gasolines in addition to alcohols esters (dimethyl ether (DME), methyl tert-butyl ether (MTBE)) and N-methylaniline (MMA) are used.

Ethers, like alcohols, help to improve the environmental properties of gasolines (reducing CO emissions by up to 20 %), their starting properties and increase their resistance to detonation (OC = 98-103 points per motor method). The optimal concentration of esters in gasoline varies between 5-15 % [13-14].

Also, in the composition of some gasolines such an additive as MMA can be found. Usually its optimal amount in gasoline is up to 2 %, which increases the resistance to detonation by 6 points. Although, according to [15], it is forbidden to use it in Euro 5 gasoline.

Considering these additives in view of their influence on the value (ϵ) of the straight-run gasoline fraction, we note that DME and MTBE contain an oxygen atom (O), and MMA is a compound of cyclic structure with a nitrogen atom (N). This, in turn, contributes to a slightly larger (4.0-6.0 units) value (ϵ) than value of straight-run gasoline (up to 1.90 units). Therefore, the increase of the concentration (X, %) of these additives in the composition of the straight-run gasoline fraction will lead to an increase of the value (ϵ_{mix}) in comparison with the original straight-run gasoline fraction, which is illustrated in Fig. 3.

Applying the methods of mathematical statistics to the dependences presented in Fig. 1-3, we obtain regression equations that adequately ($R^2=0.8234\div 0.9982$) characterize the dependence (ϵ_{mix}) on X for the investigated components / additives (see Table 1).

Also of practical interest is the dependence of detonation resistance, expressed in points of octane number (ON) of commercial gasoline, on their (ϵ_{mix}). Based on the data presented in [3, 16], this dependence has the character shown in Fig. 4. This dependence is used in the development of portable express commercial motor fuels quality analyzers [17-18].

Table 1. Regression equations for dependences obtained

Component/Additive	Regression equation ($p = 0,95$)	R^2
Catalytic cracking gasoline	$\epsilon_{mix} = 0,0013 \times X + 1,8759$	0,8234
Catalytic reforming gasoline	$\epsilon_{mix} = 0,0066 \times X + 1,8796$	0,9819
Methanol	$\epsilon_{mix} = -0,0031 \times X^2 + 0,2251 \times X + 1,7597$	0,9847
Ethanol	$\epsilon_{mix} = -0,0024 \times X^2 + 0,2097 \times X + 1,7078$	0,9488
Propanol	$\epsilon_{mix} = -0,0007 \times X^2 + 0,1675 \times X + 1,7684$	0,9786
Iso-butanol	$\epsilon_{mix} = -0,0011 \times X^2 + 0,1569 \times X + 1,7668$	0,9852
MMA	$\epsilon_{mix} = 0,0365 \times X + 1,8858$	0,9969
MTBE	$\epsilon_{mix} = -0,0005 \times X^2 + 0,028 \times X + 1,8886$	0,9725
DME	$\epsilon_{mix} = -0,0005 \times X^2 + 0,0187 \times X + 1,8848$	0,9982

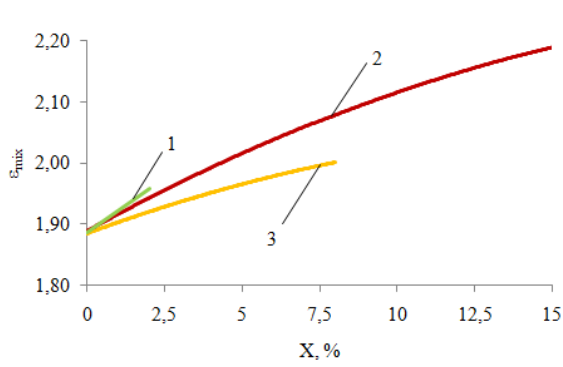


Figure 3. Dependence of (ϵ_{mix}) on the content of additives X:1 - MMA; 2 - MTBE; 3-DME

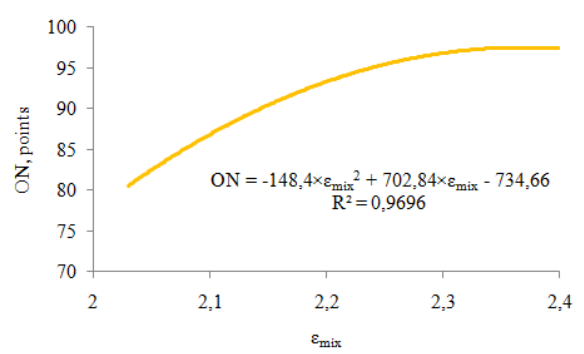


Figure 4. Dependence of octane number of commercial gasolines on their (ϵ_{mix})

When using the above components / additives for the production of commercial gasoline the dependences shown in Fig. 1-4 can be used for compounding control. Then, the compounding scheme, which allows obtaining commercial gasoline brands A-92, A-95 and A-98, will have the form shown in Fig. 5.

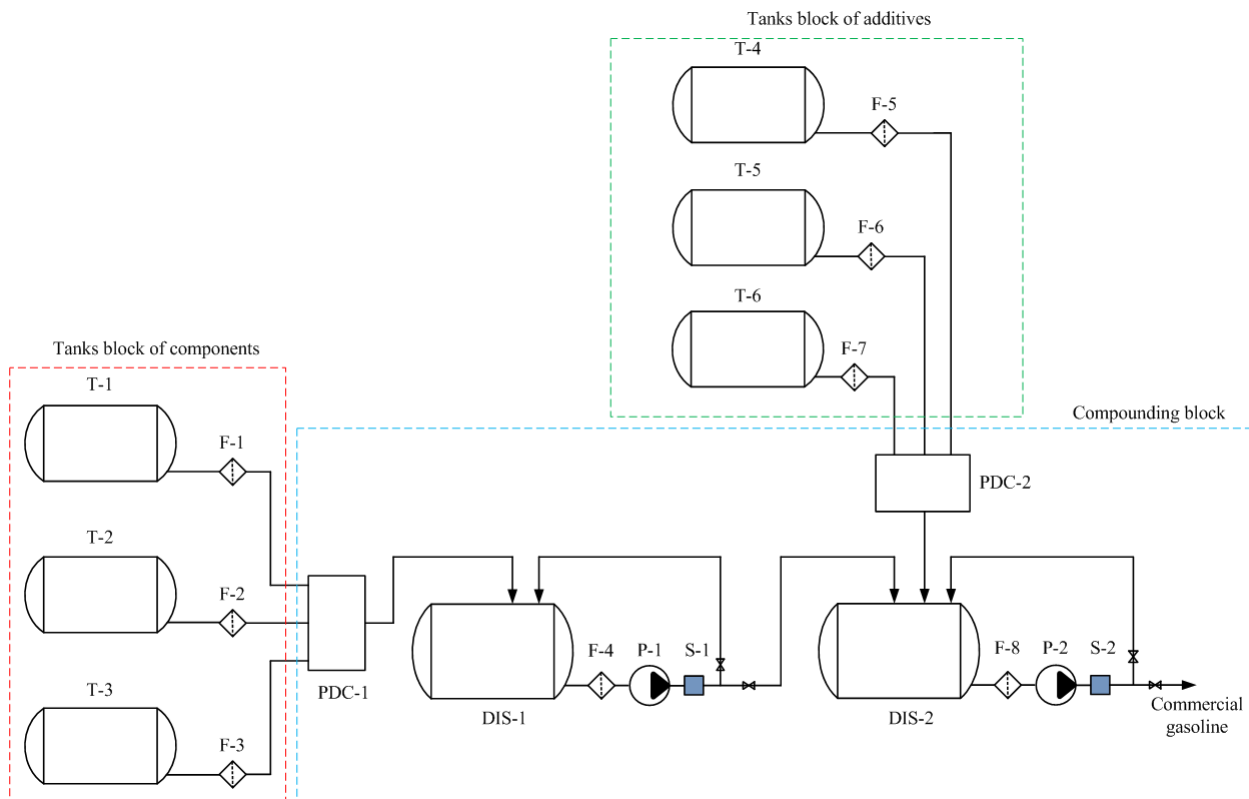


Figure 5. Scheme of automatic compounding of motor gasoline

The gasoline compounding plant is located on a special production place, which has a fence around the perimeter and consists of three blocks (tanks block of components, tanks block of additives and compounding block), operator, software, power shield, control and measuring devices.

The tanks block of components and additives consists of tanks, filters, technological pipelines. The compounding block is represented by pump-dosing complexes, fillters, pumps, control sensors and pipelines.

The functionality of the plant is the following: the main components of the tanks (T-1, T-2, T-3) pass through filters (F-1, F-2, F-3), where they are cleaned of mechanical impurities and

pump-dosing complex (PDC-1) feeds them to the disperser (DIS-1). The dosing of the components is done automatically in strict accordance with the developed recipe by weight or volume. In (DIS-1) a compounding (mixing) of basic components occurs. Then the mixture is pumped by the pump (P-1) through the filter (F-4) and the capacitive sensor (S-1). Thermo-compensation is used in the S-1 sensor to reduce the measurement error (ΔX). Finally, in the software the dependences presented on Fig.1 can be used for control of technological process.

The control of the parameter (ε_{mix}) is carried out according to the equation

$$\varepsilon_{\text{mix}} \approx \varepsilon_{\text{st}} \pm \Delta X \quad (3)$$

where ε_{st} – standard value defined for a mixture of a certain composition.

If equation (3) is not fulfilled, the mixture is returned to (DIS-1) by means of valves along the technological pipeline. In this case, there is an automatic correction of the dosed input to the mixture, which is in (DIS-1) of the main components.

If equation (3) is satisfied, the mixture then enters the disperser (DIS-2), where mixing of basic components with additives supplied by (PDC-2) from tanks (T-4, T-5, T-6) through filters (F-5, F-6, F-7). Then the mixture of components with additives - commercial gasoline is pumped by the pump (P-2) through the filter (F-8) and the sensor of the finished product (S-2). The operation principle of the sensor (S-2) is similar to the principle of the sensor (S-1). But, at this stage, the software monitors the process either by the content of components (see Fig. 2-3) or by the value of the ON (see Fig. 4) of the obtained gasoline. For that the equation similar to equation (3) but obtained for commercial gasoline is used.

If equation (3) is not fulfilled, motor gasoline is returned to (DIS-2) by means of valves along the process pipeline. In this case, there is an automatic correction of the dosed input to the mixture, which is in (DIS-2) additives.

In case equation (3) is fulfilled, commercial gasoline is removed from the installation to the finished product warehouse or to the overflow overpass.

4. Conclusions

The scheme of the plant of motor gasolines automatic compounding in which the operative control of technological process is carried out taking into account electric properties of gasolines (dielmetric method) is offered.

The compounding scheme consists of three blocks (tanks block of components, tanks block of additives and compounding block) and the operational control system is represented by software and a number of sensors located in pipelines on key material flows (at the output of dispersers).

Operational control of compounding is offered to be carried out on the content of components (X , %) or on the size of octane number (ON, point) of mixture on the basis of experimentally received dependences $\varepsilon_{\text{mix}} = f(X)$ and $\text{ON} = f(\varepsilon_{\text{mix}})$.

The presented scheme of automatic compounding and the system of its operative control can be used at production of jet and diesel fuels of various types, boiler fuel with the improved operational properties, and also lubricating oils of various functional purpose.

References

- [1] Astapov VN. Analiticheskiy obzor elektrofizicheskikh kharakteristik uglevodorodnykh zhidkostey i primeneniye ikh v informatsionno-izmeritel'nykh sistemakh dlya kontrolya kachestva topliv. Nauchnoye obozreniye. Tekhnicheskkiye nauki, 2016; 5: 5-27.
- [2] Wu M, Dedong T. The oil product moisture meter based on the electromagnetic resonance. J. Instrument Technique and Sensor, 2008; 4:16-18.
- [3] Guan L, Feng XL, Li ZC, Lin GM. Determination of octane numbers for clean gasoline using dielectric spectroscopy. Fuel, 2009; 88(8): 1453-1459.
- [4] Grigorov AB, Karnozhitskiy PV, Naglyuk IS. Izmeneniye dielektricheskoy pronitsayemosti dizel'nykh motornykh masel v ekspluatatsii. Avtomobil'nyy transport, 2007; 20: 95-97.
- [5] Topлива. Proizvodstvo, primeneniye, svoystva: [Spravochnik] / pod red. T. N. Mitusovoy. – SPb.: TSOP «Professiya», 2012: 416.
- [6] Dielectric Constant Table. Honeywell, 2011: 51.
<https://www.honeywellprocess.com/library/marketing/tech-specs/DielectricConstant>

- [7] Dielectric Constants of Liquids. The Engineering Tool Box, 2008.
https://www.engineeringtoolbox.com/liquid-dielectric-constants-d_1263.html
- [8] Speight JG. Handbook of Petroleum Refining. CRC Press, 2017: 789 .
- [9] Sadeghbeigi R. Fluid Catalytic Cracking: Handbook.-4th Edition. Butterworth-Heinemann. 2020: 392.
- [10] Oyekan SO. Catalytic Naphtha Reforming Process 1st Edition. - CRC Press. 2018: 378.
- [11] Karpov SA, Kunashev LKH, Tsarev AV, Kapustin VM. Primeneniye alifaticheskikh spirtov v kachestve ekologicheskikh chistykh dobavok v avtomobil'nyye benziny. Neftegazovoye delo, 2006: 1-12. <http://www.ogbus.ru>
- [12] Eyidogan M, Ozsezen AN, Canakci M, Turkcan A. Impact of alcohol-gasoline fuel blends on the performance and combustion characteristics of an SI engine. Fuel, 2010; 89(10): 2713-2720.
- [13] Pouloupoulos S. Influence of MTBE addition into gasoline on automotive exhaust emissions. Atmospheric Environment, 2000; 34(28): 4781-4786.
- [14] Ehrlich RL, Philbrick KP, Jonas MS. Methyl Tertiary Butyl Ether (MTBE) and Clean Gasoline Alternatives. Report to the Senate Education, Health, and Environmental Affairs Committee and the House Environmental Matters Committee. January 2006. Maryland Department of the Environment Air and Radiation Management Administration. 2006: 74. https://clu-in.org/download/contaminantfocus/mtbe/mtbe-MD2-Report_2006.pdf
- [15] TR TS 013/2011. TEKHNIЧЕСКИЙ РЕГЛАМЕНТ ТАМОЖЕННОГО СОЮЗА. О требованиyakh k avtomobil'nomu i aviatsionnomu benzinu, dizel'nomu i sudovomu toplivu, toplivu dlya reaktivnykh dvigateley i mazutu. Data vvedeniya 31.12.2012. Data aktualizatsii 01.01.2021: 22.
- [16] Rudnev VA, Boichenko A, Karnozhytskiy PV. Classification of gasoline by octane number and light gas condensate fractions by origin with using dielectric or gas-chromatographic data and chemometrics tools. Talanta, 2011; 84(3): 963-70.
- [17] Shatokhina YeV. Ekspress-analiz kachestva i ekologicheskoy bezopasnosti motornykh topliv. Khimiya i tekhnologiya topliv i masel, 2007; 3: 46-48.
- [18] Mamikin AV, Kukla AL, Maystrenko AS, Matsps YeP, Matviyenko LM. Sposob ekspress-otsenki oktanovogo chisla benzina s ispol'zovaniyem portativnogo spektroimpedansnogo izmeritelya i metodov statisticheskogo analiza. Tekhnologiya i konstruirovaniye v elektronnoy promyshlennosti, 2017; 4-5: 52-60.

To whom correspondence should be addressed: Dr. Andrey Grigorov, National Technical University «Kharkov Polytechnic Institute», 61002, 2 Kirpichova str., Kharkov, Ukraine; e-mail: grigorovandrey@ukr.net