Electrostatic Charging Tendency of Ethanol-Gasoline Mixtures

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The paper presents research results of electrostatic charging tendency (ECT) of ethanol-gasoline mixtures. The research work was carried out in a spinning disk system, where the factors influencing the value of the electrification current registered were the composition of the mixture, rotational speed and the disk diameter. The research carried out showed that both hydrodynamic conditions and changing content of ethanol in gasoline influence significantly generation of electrification current. Next, using the measurement results of electrification current and physico-chemical parameters, volume density of charge q_w was evaluated from the mathematical model of static electrification.

Keywords: flow electrification, fuel, electrostatic hazard, spinning disk system, dielectric liquid

Presently, all countries in the world, and especially the industrialized ones, depend on energy sources. Electric power safety of these countries is significantly connected with oil. Different types of perturbations related to the access to oil (related to price, geopolitical, geographic) as well as ecological issues connected with the environment pollution caused the need for searching oil substitutes in the form of alternative energy sources. This tendency poses new challenges for petroleum industry, engine constructors and exploiters. Taking into account the nearest future, it seems that biofuels will be used most widely. Ethanol and vegetable oil are main fuels to be used in vehicles adjusted to traditional fuels. On 8 May 2003 Directive 2003/30/EC on promotion of biofuels and other fuels from renewable energy sources in the means of transport was passed. According to this directive, the power value of biofuels used in the European Union is to reach the level of 5,75 % of the total consumption in 2010 [1].

The static electrification phenomenon is subject to study due to the hazard it may pose in petroleum industry. This refers especially to the situations when fuels are pumped through pipelines and filters or to cars at gasoline stations. It may cause the occurrence of electrostatic charges in those products, which, in unfavourable conditions, may lead to the ignition of the explosive mixture of fuel with air. These hazards stimulated the development of research on these phenomena as early as in the 60s of the last century, which resulted in the development of measurement methods in industrial prophylaxis [2].

Petroleum Equipment Institute (PEI) and other scientific institutions report that static electrification is the most probable source of fuel ignition during refuelling at gasoline stations [3–7].

Also atmospheric factors such as temperature, humidity and fuel flow speed determine clearly generation of static electrification. In ref. [8] for the tested fuel the authors have observed that low temperatures and dry environments increase flow electrification. These results coincide with the data collected by the PEI, which shows that 84 % of refueling fire occurred during the winter months between March and November.

The other subject matter is connected with electrification of fuels with biocomponents. Ethanol, which is used as fuel itself or as a biocomponent both in Diesel and gasoline engines, is used most often. In Europe, the most advanced works on its production are carried out in Sweden and Denmark, and in the world, in the United States, Canada, Brasil and Japan. Biofuels type E10 (containing 10 vol-% of ethanol and 90 vol-% of gasoline) and E85 (containing about 85 vol-% of ethanol and 15 vol-% of gasoline) are used most often. These fuels are offered, among others, in the U.S.A. as an alternative for conventional gasoline. They may be used both in FFV (Flexible Fuel Vehicles) vehicles and in standard cars equipped with gasoline engines, which gained manufacturer's admittance for using such fuel.

In ref. [9] the authors have studied the chargeability of two different kinds of ethanol–gasoline motor fuel mixtures during refuelling in a real dispenser environment. The results show that a high ethanol content mixture E85, containing around 85 vol-% of ethanol and 15 vol-% of gasoline, will not become charged in a dispenser system during refuelling as long as the grounding of the system is working properly. The conductivity of E85 mixture is so high that charge generated in the system will go directly to ground and no charge is accumulated in the fuel. The low ethanol content mixture E10, containing 10 vol-% of ethanol and 90 vol-% of gasoline, will get charged but the charging level is still so low that no real safety risks due to fuel charging exists.

The aim of the research work carried out by author was broadening knowledge on hazards resulting from electrification of biofuels that are mixtures of gasoline and ethanol and comparing the results obtained with the results obtained in other research centres. ECT of fuels were measured in a spinning disk system, where rotational speed, the disk diameter and a changing content of mixtures were the factors influencing the size of the electrification current measured.

Experimental setup

A spinning disk system has been used in research on electrostatic properties of liquid dielectrics for over 30 years [10–12]. In order to take measurements of ECT of ethanol-gasoline mixtures, author used its modified version. This setup is called a spinning electrometer and was developed in Opole University of Technology by Zmarzły. A detailed description of the setup structure and its functioning is in ref. [13]. Thanks to placing the tool on the disk axis inside an object, it is resistant, to a large extent, to external disturbances and makes registration and analysis of the electrification current signal at the level of picoamperes possible. A metal grounded container, which is filled with a sample of a liquid phase, is used in this setup. A solid phase is represented by a disk immersed in water and which is given a definite rotational speed. An electric charge, the changes of which are measured in the form of electrification current, is generated on the spinning disk surface. The measuring system has an integrated form and consists of three sub-systems, the task of which is measurement of electrification current, then its acquisition and initial processing. A computer has the function of a system operator. The software installed enables steering by Bluetooth® with a spinning electrometer and a system for rotational speed adjustment of the engine propelling the disk.

The measurement taking procedure consisted in a careful washing and degreasing of the vessel and disk surfaces, their two-hour sterilization (in temperature 120 °C), 24-hour seasoning of disks in liquid, which was subject to tests later on. Adequate measurements were taken after stabilization of hydrodynamic and electrical conditions in the liquid and repeated a few times every 1 hour. There were no heat sources installed or powerful electric or magnetic fields in the close vicinity of the measuring setup. The measuring container was air-tight with a lid and thermally isolated to avoid the influence of dampness and temperature change. Measurements were carried out at 20–22 °C.

The tests of electric parameters of the liquids under study were carried out in compliance with the standards (ASTM D 257-99 and ASTM D 924). The relative permittivity was measured by Good Will Instrument Co., Ltd. LCR-819 SERIES meter of the parameters: frequency range (12 Hz – 100 kHz), basic accuracy (±0,05 %). The resistivity was measured by Megger BM25 meter of the parameters: test voltages (d.c. 50–5000 V), insulation range (10 kΩ – 5 TΩ), insulation accuracy (±5 % at 1 MΩ to 1 TΩ at 5 kV). The liquid density was marked with a densimeter. The limiting error of the densimeter used was 2 kg/m^3. Dynamic viscosity was marked with a traditional Höppler globular viscometer, the measurement uncertainty of which was 0,5 %.

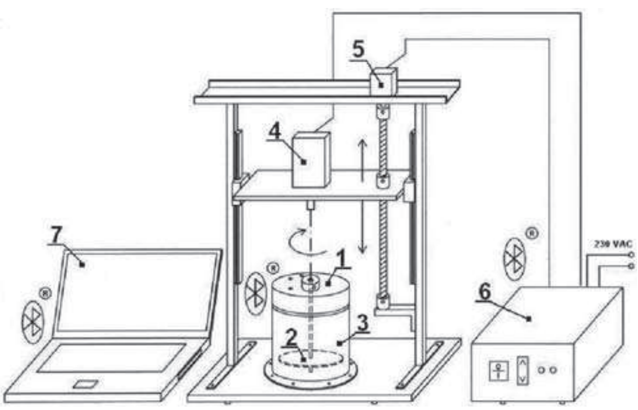

Fig. 1. Setup with a spinning electrometer for ECT investigations of liquid dielectrics: 1 – spinning electrometer, 2 – disk, 3 – measuring tank, 4 – engine for disk rotational speed adjustment, 5 – engine for the location change of the disk, 6 – system controlling the work of engines, 7 – steering computer

Rys. 1. System z wirującym elektrometrem do badań ECT ciekłych dielektryków: 1 – elektrometr wirujący, 2 – tarcza, 3 – zbiornik pomiarowy, 4 – silnik do regulacji prędkości obrotowej tarczy, 5 – silnik do zmiany położenia tarczy, 6 – układ sterujący pracą silników, 7 – komputer sterujący

Tab. 1. Properties of the liquids (at 20 °C) under study and the parameters of the measuring system for the research on ECT

Tab. 1. Właściwości badanych cieczy (dla 20 °C) oraz parametry układu pomiarowego do badań ECT

Property, parameter		Value	
		Gasoline	Ethanol
Density (ρ)	kg/m^3	735	785
Viscosity (ν)	cP	0,457	1,078
Relative permittivity (ε_r)	–	2,26	24,55
Conductivity (γ)	S/m	$77 \cdot 10^{-12}$	$14 \cdot 10^{-10}$
Container diameter (d)	mm	100	
Disk diameter (d)	mm	20, 30, 40, 50	
Liquid volume (V)	ml	500	

Research results

The process of liquid electrification in a measuring setup consists in generating excessive electrical charges due to a rotational movement of a disk. In stationary conditions ($\omega = 0$), volume density of a charge in liquid (q_0) is equal to zero. Only within the double electric layer, on the contact border of the solid and liquid phases, the volume density of charge q_w is stowed. This value, according to the assumptions of the Abediana-Sonin mathematical model [14] is characteristic for a given solid body-liquid border surface and it may function as a material index because it depends on physico-chemical properties of the solid phase and liquid. It does not depend on hydrodynamic conditions. The size of charge q_0 determines the electrification level of liquid in given conditions and it can be measured in the form of electrification current with an electrometer.

Fig. 2 shows classical dependencies of electrification current of the liquids under study (1 – ethanol, 2 – gasoline, 3 – E5 mixture containing 95 vol-% of gasoline and 5 vol-% of ethanol) in the function of a changing rotational speed of a 50 mm disk. Analyzing the characteristics it can be observed that static electrification of liquid is strongly determined by changing hydrodynamic conditions in the measuring setup. This is also confirmed by the electrification current characteristics in the function of increasing disk diameter for E5 mixture (Fig. 3). The research carried out showed that particular liquids differ in ECT. At the highest speed n = 450 rpm, the electrification current was 102 pA, of gasoline 178 pA, and in the case of E5 mixture it was at the level of 1,32 nA. The characteristics in Fig. 4 shows that ECT of the particular mixtures highly depends on the per cent content of ethanol in gasoline. These results are close to the results obtained by author in ref. [15], where electrification of the ethanol-hexane mixtures was investigated. It is interesting that in both cases maximum ECT value occurred at

5 vol-% ethanol in the mixtures. An increase or decrease of its content within the same value causes the drop of electrification current. The mixtures, the volume of which is constituted mostly by ethanol (Fig. 5), are characteristic of a low value of electrification current, which maintains at a relatively constant level (about 100 pA) regardless of increasing admixture of gasoline. These and prior results obtained by author [16, 17] show that the biggest ECT changes occur at small contents of admixtures (e.g. ethanol, hexane or cyclohexane) in mixtures. However, it is

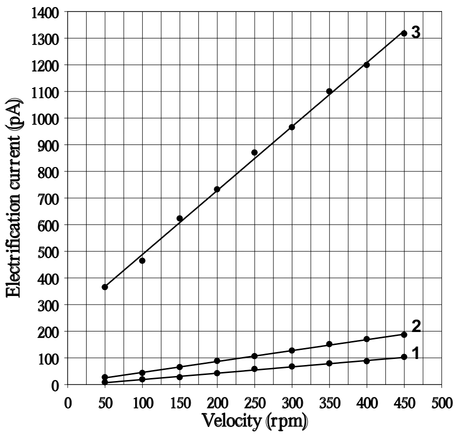

Fig. 2. Electrification current vs. rotational speed of disk ($\varphi = 50$ mm) for: 1 – ethanol, 2 – gasoline, 3 – mixture E5 containing 95 vol-% of gasoline and 5 vol-% of ethanol

Rys. 2. Zależność prądu elektryzacji od prędkości obrotowej tarczy ($\varphi = 50$ mm) dla: 1 – etanolu, 2 – benzyny, 3 – mieszaniny E5 zawierającej 95 % benzyny i 5 % etanolu

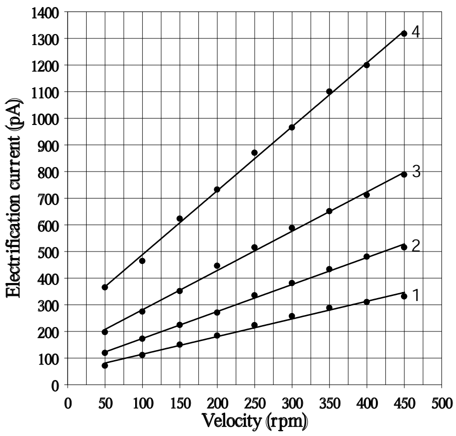

Fig. 3. Electrification current of mixture E5 containing 5 vol-% of ethanol and 95 vol-% of gasoline vs. rotational speed of disks (1 – $\varphi = 20$ mm, 2 – $\varphi = 30$ mm, 3 – $\varphi = 40$ mm, 5 – $\varphi = 50$ mm)

Rys. 3. Zależność prądu elektryzacji mieszaniny E5 zawierającej 95 % benzyny i 5 % etanolu od prędkości obrotowej tarczy (1 – $\varphi = 20$ mm, 2 – $\varphi = 30$ mm, 3 – $\varphi = 40$ mm, 5 – $\varphi = 50$ mm)

difficult to explain the causes of the phenomenon occurrence. It seems, however, that the conclusions inferred may be useful for creating various types of liquid dielectric mixtures both in power and petroleum industries. Fig. 6 shows the dependence of the volume density of charge q_w in the function of a changing content of ethanol-gasoline mixtures. This parameter, determined from the electrification model for the disk system, is a resultant of the electrification current changes and physic-chemical properties [10–12]. Also, analyzing the above characteristics, a characteristic maximum for E5 mixture may be observed.

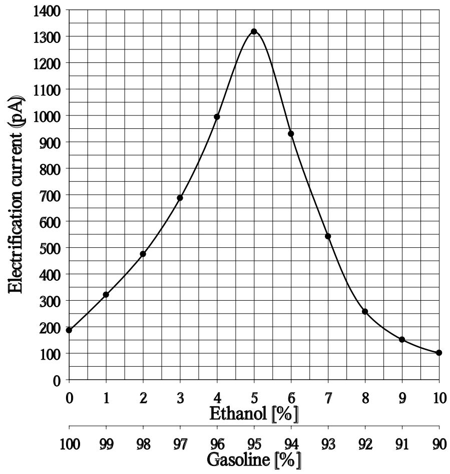

Fig. 4. Electrification current vs. percentage content of ethanol in gasoline at the rotational speed n = 450 rpm, the disk diameter of 50 mm

Rys. 4. Zależność prądu elektryzacji od procentowej zawartości etanolu w benzynie przy prędkości obrotowej n = 450 obr/min, tarczy o średnicy 50 mm

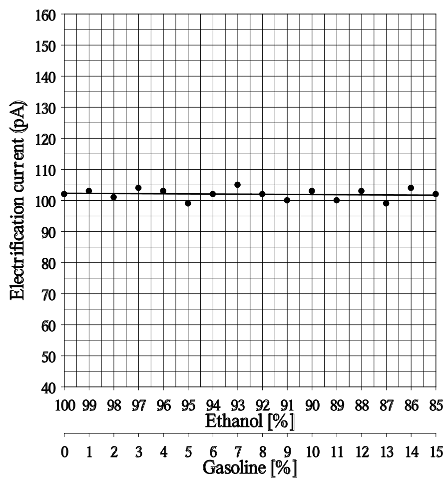

Fig. 5. Electrification current vs. percentage content of gasoline in ethanol at the rotational speed n = 450 rpm, the disk diameter of 50 mm

Rys. 5. Zależność prądu elektryzacji od procentowej zawartości benzyny w etanolu przy prędkości obrotowej n = 450 obr/min, tarczy o średnicy 50 mm

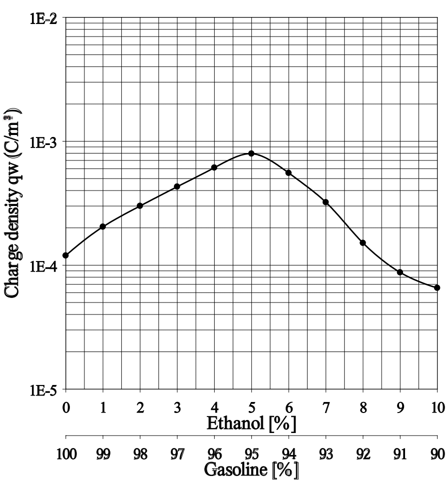

Fig. 6. Volume density of charge q_w vs. percentage content of ethanol in gasoline

Rys. 6. Zależność objętościowej gęstości ładunku q_w od procentowej zawartości etanolu w benzynie

Conclusion

Excessive consumption of oil fuels and natural environment pollution caused by rapid development of the motor industry are main reasons for intensified research on biofuels. Presently, ethanol is the most commonly used biocomponent in mixtures with conventional fuels. Investigations of electrostatic properties of these mixtures are interesting from the scientific point of view and are of a very important practical aspect connected with safety of their use. The research results obtained in the spinning disk system show that changing hydrodynamic conditions, represented by rotational speed and the disk diameter, significantly influence generation of static electrification. Moreover, the mixtures based on ethanol and gasoline are characteristic of ECT dependent on the content of the particular components. Particularly interesting electrification current changes are observed at small concentrations of ethanol in gasoline. The highest ECT has E5 mixture containing 95 vol-% of gasoline and 5 vol-% of ethanol. In the case of the most commonly used biofuels (E10 and E85) ECT is at the level of 100 pA and the volume density of charge is about $6 \cdot 10^{-5}$ C/m^3. Finally, it can be observed that from the point of view of electrostatic properties, the safest biofuels used are the ones containing no more than 5 vol-% ethanol in the mixture with fuel. The results obtained comply with the data published, among others, in ref. [9] and can be an interesting contribution to research on ECT of biofuels.

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Tendencja do elektryzacji mieszanin etanol-benzyna

W artykule przedstawiono wyniki badań tendencji do elektryzacji (ECT) mieszanin etanol-benzyna. Badania przeprowadzono w układzie wirującej tarczy, gdzie czynnikiem wpływającym na wielkość mierzonego prądu elektryzacji był skład mieszaniny oraz prędkość obrotowa i średnica tarczy. Prowadzone badania wykazały, że zarówno warunki hydrodynamiczne, jak również zmieniająca się zawartość etanolu w benzynie istotnie wpływają na generację prądu elektryzacji. Następnie przy wykorzystaniu wyników pomiarów prądu elektryzacji oraz parametrów fizykochemicznych wyznaczono z modelu matematycznego elektryzacji statycznej objętościową gęstość ładunku q_w.

Słowa kluczowe: elektryzacja strumieniowa, paliwo, zagrożenie elektrostatyczne, układ wirującej tarczy, ciekły dielektryk

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