

Study of Post-Radiation Effects in Gasolines

*Lala Yusif Jabbarova**, *Islam Israfil Mustafaev*, *Navai Ayyub Ibadov*, *Nigar Gacay Guliyeva*, and *Aida Suleyman Mirzayeva*

Institute of Radiation Problems, Baku, Azerbaijan

Abstract. This paper studies the processes of radiation-induced polymerization and post-polymerization in motor fuels. It is important that the fuel components remain stable at high temperatures and radiation under operating conditions. When organic substances are exposed to ionizing radiation, complex chemical changes occur. Therefore, in addition to knowing the usual physicochemical properties of organic fuels and lubricants, it is also important to understand how they behave under the influence of radiation - this is called their radiation resistance. Adding small amounts of aromatic compounds to the fuel can increase its resistance to gamma radiation. The study of this issue is of practical importance. The purpose of this work is to study how the physicochemical properties of gasoline change when small amounts of benzene are added under the influence of ionizing radiation from 60 °C. However, post-polymerization processes in gasoline have not been studied in detail. The processes caused by radiolysis can continue for a long time after the cessation of exposure to radiation, which changes the composition of the fuel. As a result, the performance characteristics of the fuel deteriorate. To study these post-polymerization processes, irradiated samples of pure gasoline and gasoline with various benzene additives were tested immediately after irradiation and again after 2, 4 and 8 months. This study was conducted due to the importance of the problem and the lack of information on it. The kinetics of post-polymerization processes during 8 months after irradiation show that the rate of the process and its contribution to the overall polymerization depend on the irradiation time, the density of the initial mixture and the dose.

Keywords: gasoline, radiolysis, radiation stability, post-polymerization processes.

1 Introduction

The influence of radiation on organic materials is primarily expressed in the occurrence of the ionization process and the subsequent excitation of its orbital electrons. When ionizing radiation acts on hydrocarbon compounds, charged particles and excited molecules are formed. The effect of radiation can be accompanied by the breaking and shifting of chemical bonds, resulting in the formation of free radicals. These chemical transformations are

*Corresponding author: clala@mail.ru

accompanied by changes in the physical properties of the material. Substances resistant to radiation exposure should have the ability to absorb energy without excessive ionization and to form double bonds more readily than to break existing bonds. In the radiolysis of saturated hydrocarbons, the yields of products do not depend on the dose, whereas the yields of other products may increase or decrease with an increase in dose. This can be explained by the occurrence of secondary reactions involving unsaturated products that accumulate during irradiation. The yields of hydrogen and unsaturated hydrocarbons decrease rapidly as the dose increases, while a more moderate decrease is observed for the yields of saturated hydrocarbons. The different nature of the dependence of these yields on the dose indicates that the addition of hydrogen atoms to the π -bonds of alkenes occurs at a significant rate. In contrast to the radiolysis of alkenes, the yield of hydrogen in the radiolysis of alkanes and aromatic hydrocarbons is virtually independent of the dose. Below are studies on the influence of ionizing radiation on various groups of hydrocarbons, motor fuels, heavy oil fractions, light distillates, light and gaseous hydrocarbons, lubricants, polymers, and aromatic hydrocarbons, aimed at providing detailed information on the effects of radiation and the consequences of the changes that occurred in their composition. It is essential to understand the characteristics of radiolytic transformations of hydrocarbons in order to develop syntheses of organic compounds, seek ways to protect fuels and lubricants from radiolytic degradation, study the radiation resistance of various materials for the disposal of radioactive waste, and examine the chemical transformations of heat carriers in nuclear reactors. Under the influence of radioactive radiation, both polymerization, leading to an increase in molecular weight, and their cleavage occur simultaneously. Structuring physically manifests in liquids through changes in viscosity and density. Cleavage leads to a decrease in viscosity in liquids and an increase in softness in solid materials. Sunlight and radiation increase the rate of resin formation in fuels. As a result of radiolysis at ambient temperatures, the operational properties of petroleum fuels and oils deteriorate. In the absence of chain radiolytic processes, the component composition of the irradiated system is always more complex than that of the original system, and at high doses, the system ceases to conform to the initial regularities. The impact of gamma irradiation on the physical and chemical properties of petro-diesel fuel has been examined using various rates and absorbed doses. Diesel fuel samples were subjected to gamma radiation for 1.3 hours at absorbed doses of 3, 6, 10, and 15 kGy, with corresponding dose rates of 2.27, 4.5, 7.4, and 11.15 kGy/h. The physical and chemical characteristics of the diesel fuel were evaluated following ASTM standard testing methods, which included cetane number, distillation recovery points, flash point, calorific value, density, and kinematic viscosity. The influence of gamma irradiation on the organic compounds in diesel fuel was analyzed using the GC/MS technique. Experimental findings indicate that density, distillation recovery, kinematic viscosity, and flash point decreased at absorbed doses of 3, 6, and 15 kGy, while they increased at 10 kGy, in line with the rate doses. The cetane number rose after exposure to 3, 6, and 15 kGy but fell at 10 kGy. These observations can be explained by the breaking and formation of bonds due to the high energy applied. The fragments produced at 10 kGy (7.5 kGy/h) formed new compounds that negatively affected the overall properties of the diesel fuel [1].

Tests were carried out on a Cooperative Fuel Research (CFR) diesel engine using fuels with low aromatic content to better understand how diesel fuel components influence exhaust emissions. A total of 14 diesel fuels were examined, featuring aromatic content ranging from 0% to 27%. Three of these fuels were oxygenated using diglyme and butyl-diglyme (diethylene glycol dimethyl ether and diethylene glycol dibutyl ether). The findings indicated a strong correlation between exhaust smoke and nitrogen oxides (NO_x) emissions and the fuel's monoaromatic content. Oxygenated fuels produced lower smoke and NO_x emissions. A statistical analysis of the CFR exhaust emissions revealed that the most significant factor affecting smoke emissions was fuel density, followed by the carbon-hydrogen mass ratio,

50% distillation temperature, and viscosity. For NO_x emissions, the 5% distillation temperature had the greatest impact, followed by density, 95% distillation temperature, carbon-hydrogen mass ratio, 50% distillation temperature, cetane number, and viscosity [2]. Tests were performed using a Cooperative Fuel Research (CFR) diesel engine to investigate the impact of fuel aromatic and oxygenate compounds on exhaust emissions. The base fuel was heptane, to which varying amounts of monoaromatic toluene and diaromatic methyl-naphthalene were added. Additionally, blends of heptane and toluene with oxygenated compounds (methanol, ethanol, heptanol, and diglyme) were evaluated. The findings revealed that both toluene and methyl-naphthalene significantly increased emissions of smoke, nitrogen oxides (NO_x), and unburned hydrocarbons (UHC). It was also noted that the observed increases in ignition delay could contribute to the rise in these exhaust emissions. In contrast, the oxygenated fuel blends tested resulted in reductions in NO and smoke emissions [3]. Fuel droplet evaporation is critical for spray combustion in important technological applications, making it essential to understand for developing reliable combustion methods for hydrocarbon fuels. This paper analyzes the role of radiation in the unsteady evaporation of a single isolated fuel droplet, which is treated as a spherical and semitransparent entity. A model based on radiative transfer theory is employed to calculate the local volumetric rate of radiation absorption. The model considers the effects of thermal expansion and temperature-dependent thermophysical properties on the evaporation process. Internal circulation within the droplet, influenced by external flow, is addressed through an effective thermal conductivity for the fuel droplet. Model predictions are compared with existing theoretical results and experimental data. The findings indicate that the significance of radiation versus convection heat transfer means that neglecting radiation absorption by a droplet can significantly impact predictions of fuel evaporation rates and droplet lifetime [4]. In this study, ionizing radiation was employed to investigate its effects on the degradation of sulfur compounds in petroleum and diesel fuels. Crude oil and diesel fuel samples were analyzed without any pretreatment and irradiated using a cobalt-60 gamma cell in a batch system at absorbed doses of 30 kGy and 50 kGy. The sulfur compounds were extracted and subsequently analyzed using gas chromatography coupled with mass spectrometry (GC-MS). The results demonstrated a high efficiency of ionizing radiation in degrading sulfur compounds, such as benzothiophene and benzenethiol, and in forming fragments like 1,2-dimethylbenzene and toluene [5]. An experimental study was carried out on a direct injection diesel engine using both conventional and oxygenated diesel fuels. The primary goal was to assess the impact of oxygen-enhanced fuels with varying aromatic content on engine performance and pollutant emissions. Approximately 20% by mass of a mixture of diethylene glycol dimethyl ether (diglyme) and diethylene glycol dibutyl ether (butyl-diglyme) was added to a high-paraffin fuel and two commercial diesel fuels with different aromatic fractions. Engine tests were conducted on a naturally aspirated direct injection diesel engine under various operating conditions. The measurements included cylinder pressure diagrams, fuel consumption, exhaust smokiness, and emissions of nitrogen oxides, unburned hydrocarbons, and carbon monoxide. The experimental results indicated that adding oxygenated agents led to an earlier ignition of combustion and an increase in maximum combustion pressure, primarily due to a higher cetane number. Oxygen enrichment resulted in greater brake specific consumption and reduced combustion duration. The incorporation of glycol ethers into diesel fuels significantly decreased soot opacity, as well as emissions of carbon monoxide and unburned hydrocarbons, with only a slight increase in nitrogen oxides. The changes in diesel exhaust emissions and brake specific fuel consumption due to fuel oxygen enhancement were largely dependent on engine operating conditions, rather than the total aromatic content. Ultimately, the addition of oxygenated fuels proved to be more effective in reducing soot, carbon monoxide, and hydrocarbon emissions than merely lowering the fuel's aromatic content [6]. Efforts by many researchers [7-9] are focused on

developing effective methods for converting gaseous alkanes, particularly methane and ethane, into liquid fuel hydrocarbons (C6-C18). To understand the composition and patterns of accumulation of liquid products from the dimerization of alkyl radicals, the radiolysis of gaseous alkanes was studied under conditions of circulating irradiation. This irradiation mode involves the continuous removal of gas, the liquid products of radiolysis, and the accumulation of light alkanes and alkenes. This work is related to the problem of recycling alkane-containing gas emissions. The results of radiation exposure on low-viscosity mineral bases of hydraulic oils for rocket and space technology control systems are presented [10]. Among the deodorized low-viscosity oils, isoparaffinic structures with varying degrees of branching are the most preferred in terms of radiation resistance. The main components of the radiation decomposition products of mixtures with a viscosity of 4 mm²/s at 50 °C are hydrogen and hydrocarbon gases.

The influence of gamma irradiation on the physicochemical properties of petroleum diesel fuel was investigated [15] at various dose rates and absorbed doses. The samples were exposed to gamma radiation for 1.3 hours with absorbed doses of 3, 6, 10, and 15 kGy at dose rates of 2.27, 4.5, 7.4, and 11.15 kGy/h, respectively. The physicochemical characteristics of the diesel fuel were determined using standard ASTM test methods, including cetane number, distillation recovery points, flash point, calorific value, density, and kinematic viscosity. The effect of gamma irradiation doses on the organic compounds in diesel fuel was analyzed using GC/MS. It was shown that density, distillation, viscosity, and flash point decreased at absorbed doses of 3, 6, and 15 kGy, while they increased at 10 kGy, corresponding to the dose rates. The cetane number increased after exposure to 3, 6, and 15 kGy but decreased at 10 kGy. These results can be attributed to the broken and formed bonds due to the applied high energy. The fragments formed at (10 kGy; 7.5 kGy/h) created new compounds, the physical parameters of which negatively impacted the overall properties of the diesel fuel. The fragments generated in the diesel fuel after exposure to 3, 6, and 15 kGy (2.27, 4.5, and 11.15 kGy/h) transformed some cyclic, aromatic, and branched organic compounds into linear hydrocarbons, contributing to an increase in cetane number up to 54.

Radiation-thermal irradiation of kerosene with low aromatic ring content differs from samples of the same petroleum products with significant amounts of aromatic rings. Zaykin [13,16] studied radiation-thermal irradiation of liquids with a high concentration of C15–C22 hydrocarbons and low levels of polycyclic aromatic hydrocarbons. The results showed low levels of isomerization and high rates of polymerization, along with a low yield of light fractions at low dose values. The molecular weight of the gasoline fraction increases, and the breakdown of kerosene's occurs in the middle of the molecules as the dose rate increases. This enhances the likelihood of alkyl radical recombination, resulting in the formation of kerosene molecules that are lighter than the destroyed molecules but heavier than gasoline molecules. An increase in the number of C–C bonds in the molecule leads to an energetic redistribution of excitation across a greater number of carbon bonds, reducing the efficiency of C–C bond cleavage. To better understand the impact of aromatic compounds on the radiolysis of n-hexadecane, various irradiation scenarios with different additives were studied. The results demonstrated a protective effect of aromatic compounds, which reduced the formation of gaseous hydrogen, decomposition, and cross-linking products. Aromatic compounds exhibited similar protective characteristics for n-dodecane as the model compound for the polymer [17].

The influence of gamma radiation on the physicochemical properties and structural-group composition of olefins was investigated. The results of radiation-chemical studies on decene under static conditions at an absorbed dose of gamma radiation of $D = 65$ kGy, with a dose rate of $R = 0.076$ Gy/s, are presented. A cobalt-60 isotopic source, "MRX- γ -30," was used as the ionizing radiation source. Post-radiation effects of gamma irradiation on decene were studied immediately after irradiation and after 1, 2, and 4 months. Under certain conditions,

irradiation of fuels leads to the polymerization of unsaturated hydrocarbons. Following the cessation of irradiation, post-polymerization processes occur. The chemical instability of olefins results in soot formation within the engine system, in tanks, and on valves. The effect of gamma radiation on the structural-group composition of decene was analyzed using IR spectroscopy, along with measurements of iodine numbers, density, and kinematic viscosity of the irradiated samples [18].

Studies [19-20] have shown that within absorbed doses of 15-150 kGy, chemical processes occur in diesel fuels that lead to changes in fuel characteristics such as density, viscosity, iodine numbers, cetane numbers, and other properties. As a result, the operational properties of diesel fuel deteriorate at ambient temperatures. Changes occurring during radiolysis can be either reversible or irreversible. Reversible effects depend on the dose rate, while irreversible changes in material properties depend on the absorbed dose and temperature, persisting after radiolysis and causing chemical transformations of the molecules. During the storage of such fuels, the content of actual resins significantly increases, leading to sediment formation. The low stability of diesel fuels results in the accumulation of resins, which can deposit on injector nozzles. Soot and deposits on injectors disrupt fuel delivery and reduce engine power. Increased viscosity can lower fuel flow rates, enhance smoke emissions during combustion, and increase fuel consumption. This disrupts the combustion process, leading to a rise in incomplete combustion products and soot accumulation on components, while changing the cetane number of diesel fuel. High-temperature radiolysis of diesel fuel was also investigated [19]. Radiation oxidation processes were examined in the high-temperature range, where chain processes occur. Laboratory studies were conducted using a Co-60 gamma source at a dose rate of $P = 0.18 \text{ Gy/s}$ at various temperatures (50-250°C) and an absorbed dose $D = 0.64 \text{ kGy}$. Concentrations and radiation-chemical yields of the gases produced after irradiation were established at different temperatures for gasoline samples, and their radiation stability was assessed. Iodine numbers, densities, and viscosities were determined before and after irradiation at various absorbed doses of fuel samples, and their radiation stability was evaluated. The results of such studies allow for an assessment of the radiation stability of fuels and an understanding of the influence of irradiation on the overall composition and potential changes in fuel quality. Laboratory studies were conducted on samples of gasoline AI-92 and AI-95 (100 ml each) in flasks, irradiated at various temperatures using a Co-60 gamma source of type MRX γ -30. Viscosity was measured according to GOST 33-66 using viscometers of type VPZh-2 compliant with GOST 10028-81. Iodine numbers were determined using a BRUKER MPA spectrometer. Density was measured using pycnometers according to GOST 3900-85. IR absorption spectra of the investigated samples were recorded on a VARIAN 640-IR spectrometer (VARIAN) in the wavenumber range of 4000-400 cm^{-1} . High-temperature radiolysis represents a chain process of free radical decomposition or accelerated thermal cracking initiated by irradiation, where no other reactions typical of low-temperature radiolysis, except for thermally stimulated chain decomposition of radicals, play a significant role. As the temperature increases, the yield of conversion products rises. Higher temperatures during the irradiation of fuels accelerate the rate of free radical reactions, resulting in an increasing number of gaseous products, mainly hydrogen and polymerization and disproportionation products of radicals. The effect of radiation on hydrocarbon fuels depends on their chemical structure and composition. The conducted studies show that in high-temperature radiolysis at an absorbed dose of 0.64 kGy, the temperature's influence on the course of ion-molecular radiolytic reactions can primarily manifest due to the temperature dependence of reaction rates and the thermal instability of certain ions and free radicals. The increase in temperature also stimulates the formation of aromatic hydrocarbons in the liquid products. Processes that arise due to radiolysis can continue to evolve long after irradiation has ceased, leading to changes in fuel composition. As a result, the operational properties of

the fuels deteriorate. In fuels containing a high amount of unsaturated hydrocarbons, storage can slightly increase coke-forming tendencies and worsen color. In [18], post-radiation processes in liquid olefin-containing systems were studied. Research was conducted on a model hydrocarbon mixture of hexane/hexene at various concentrations. Changes in iodine numbers, molecular structure, gas formation kinetics, and the rate of post-polymerization of olefins in relation to concentration and absorbed dose were examined. The kinetics of the processes were studied at a temperature of $T = 20^{\circ}\text{C}$, with a dose rate of $P = 0.072 \text{ Gy/s}$, across absorbed doses of $D = 27\text{-}78 \text{ kGy}$, at olefin concentrations of 5, 10, 20, and 40%. The rate of radiation-stimulated polymerization primarily depends on the concentration of olefins in the system and the intensity of the ionizing radiation. During the experiments, density and viscosity increased, and iodine numbers changed. The change in hexene concentration in hexane from 5% to 40% resulted in iodine numbers changing from 3 to 10, with this change being nearly linear. Hydrogen release in the system during radiolysis and the formation of polymer in the liquid phase also affects the molecular structure. Analysis of IR spectra shows that the predominant direction of radiation-chemical processes in binary systems with low or minimal olefin content (5-10%) is dehydrogenation and olefin formation. At irradiation values exceeding 168 hours ($D = 48 \text{ kGy}$), the olefins present in the system begin to polymerize, leading to a decrease in iodine number. In mixtures rich in olefins (20-40%), both olefin formation and polymerization processes commence simultaneously during radiolysis. The rate of polymerization during the radiolysis of the olefin-paraffin mixture depends on the olefin concentration in the system and the absorbed dose. In systems with doses greater than 45 kGy, polymerization becomes the dominant process in systems containing more than 20% olefins.

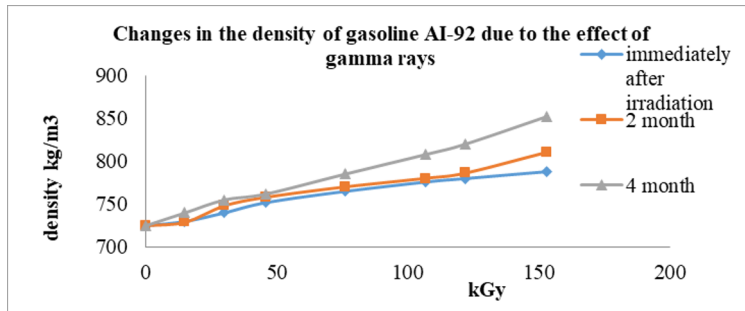
2 Methodology

AI-92 gasoline was used as the raw material. The density, viscosity, and iodine number of the gasoline were measured before and after irradiation at various absorbed doses. Samples of AI-92 gasoline, each 2.5 ml, were placed in molybdenum ampoules, sealed in a vacuum, and irradiated in an MPX- γ -30 type Co^{60} gamma source. The Co^{60} isotope gamma source consists of a container with ampoules placed along the perimeter, and the ampoules are 18 cm tall. The research was carried out at room temperature, with a dose rate of $P = 0.07 \text{ Gy/s}$, and absorbed dose intervals $D = 64.8\text{-}129 \text{ kGy}$. The gasoline + benzene mixture was irradiated at absorbed doses in the range of $D = 64.8\text{-}129 \text{ kGy}$, with benzene concentrations of 1, 2, 4, and 6% (total volume). Chromatographic-mass spectrometric analysis was performed on a Gerstel AGT GC/MS device (Agilent, USA). Dosimetry was determined using ethylene and ferrosulfate dosimeters, with results agreeing within 12-15%. The density, viscosity, and iodine number of the initial gasoline and the gasoline + benzene mixture were measured before and after irradiation at different absorbed doses. Viscosity was measured according to GOST 33-66 using VPZh-2 type viscometers. Iodine numbers were determined on a BRUKER MPA spectrometer, and densities were measured with a pycnometer according to GOST 3900-85.

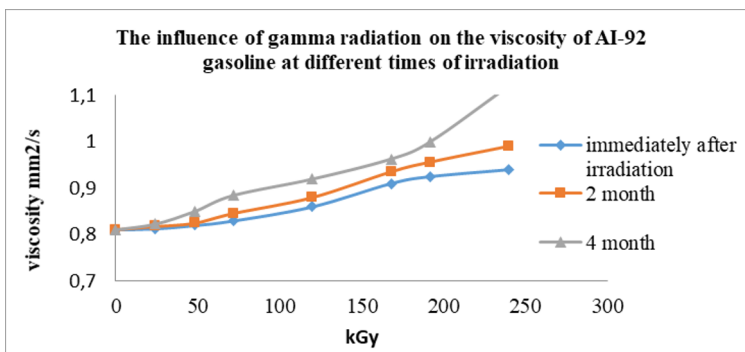
3 Results and discussions

Processes caused by radiolysis can continue for a long time after irradiation stops, leading to changes in the composition of the fuel. As a result, the operational characteristics of the fuels deteriorate. However, the post-polymerization processes in gasoline have not been studied in sufficient detail. To investigate these processes, irradiated samples of pure gasoline and

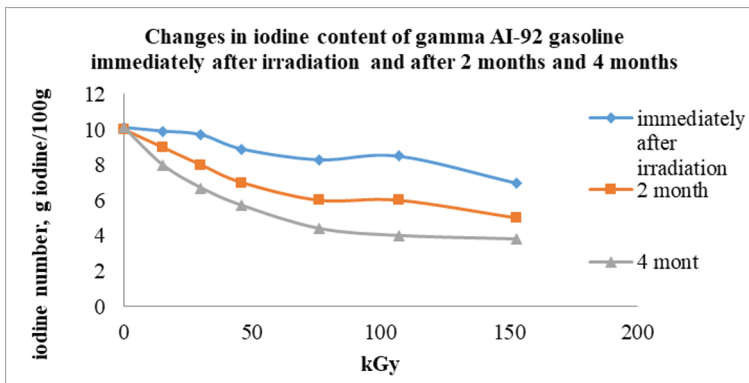
gasoline with varying benzene additives (1%, 2%, 4%, and 6% by total volume) were analyzed immediately after radiation exposure, and then again at 2, 4, and 8 months later.



a)



b)



c)

Fig. 1. The immediate effect of gamma radiation at different times on the viscosity (a), density (b), and iodine number (c) of AI-92 gasoline. $P = 0.07$ Gy/s.

This work was written considering the importance of the problem and the lack of information on the subject. The presence of olefin hydrocarbons in gasoline determines its chemical stability. Unsaturated hydrocarbons are also often high-octane components of gasoline. As a result of radiolysis, ions, electrons, and excited molecules are formed. The interaction of these particles through a chain mechanism leads to the formation of radicals, which recombine to produce radiolysis products. Radiolysis begins to affect the composition

of the fuel. Figure 1 (a, b) shows the effect of gamma radiation on the viscosity and density of AI-92 gasoline at different irradiation times. The original density of the gasoline is 725 kg/m^3 .

As shown in Figure 1 (a, b, c), with an increase in the absorbed dose, the density of AI-92 gasoline increases. High-density fuels, when they accumulate at the bottom of the piston and on the cylinder wall, contribute to an increase in the wear rate of the parts. As a result, the combustion process is disrupted, leading to an increase in the amount of incomplete combustion products and an increase in soot deposits on the parts. Density indirectly characterizes the chemical properties, fractional composition, and volatility of the fuel. The increase in gasoline density affects the characteristics of the exhaust gases.

High viscosity can cause interruptions in the fuel supply due to the high resistance when the fuel flows through the system. Viscosity affects the quality of the fuel, the operation of the pump, the wear of the piston pairs in high-pressure pumps that also serve as lubricants, as well as the completeness of combustion and the composition of the exhaust gases. An increase in viscosity can reduce the rate of fuel consumption, leading to insufficient fuel supply, as well as increasing smoke emissions during combustion and raising fuel consumption, which decreases the efficiency of the engine. For almost all light fuels, the iodine number is regulated as an indicator of the presence of unsaturated hydrocarbons, which contribute to the chemical instability of these products. In the conditions of our experiments, the iodine numbers of the fuels decrease upon irradiation. Under the influence of radiation, the unsaturated hydrocarbons present in the fuel oxidize and polymerize rapidly.

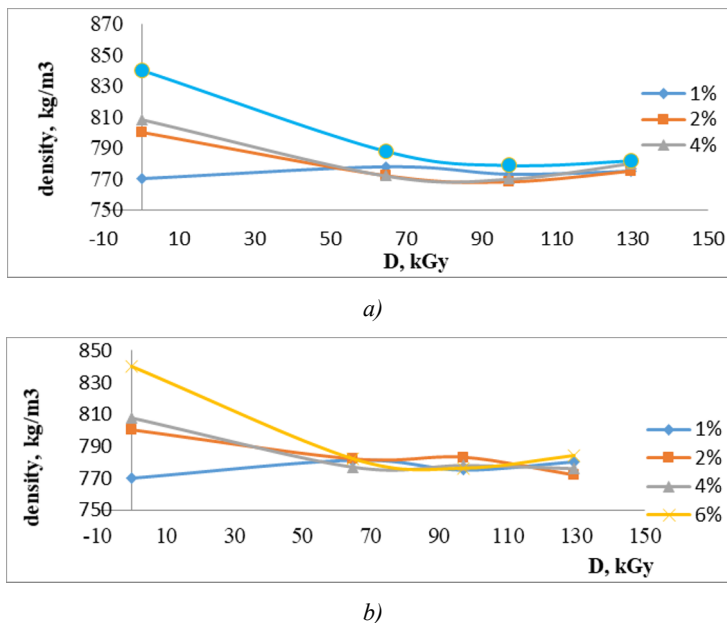
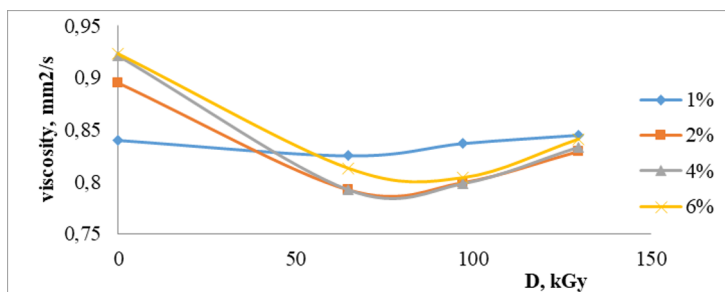


Fig. 2 Irradiation of different concentrations of gamma radiation. immediately after (a), 4 months (b) effect on density of gasoline-benzene mixture.

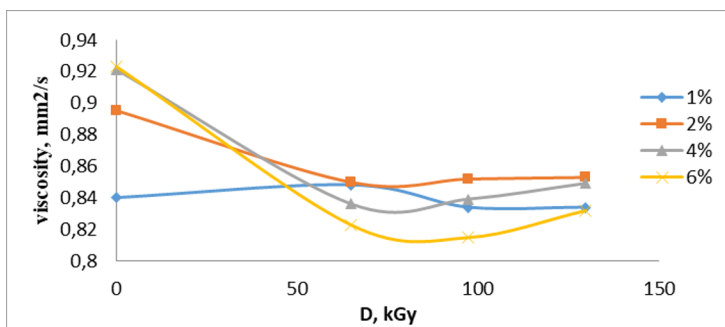
The concentration of olefin hydrocarbons doubles, which can lead to the formation of tar and deposits in the engine intake system. When such fuels are stored, the actual amount of tar significantly increases, leading to deposit formation. Furthermore, their evaporation as chemically active substances contribute to ozone formation, and their combustion products produce toxic dienes. Structuring is physically manifested in changes in viscosity and density in gasoline. The higher the absorbed radiation dose, the greater the change in viscosity.

Transformations resulting from radiation occur with varying intensities depending on the chemical structure and composition of the irradiated substance. The effect of gamma radiation on the density of the gasoline-benzene mixture at different concentrations is shown in Figure 2 (a, b), immediately after irradiation and 4 months later.

The graphs show that even a small amount of benzene added to gasoline increases its radiation resistance. The effect of gamma radiation on the viscosity of the gasoline-benzene mixture at different concentrations is shown in Figure 3 (a, b) immediately after irradiation (a), 4 months later (b).



a)



b)

Fig. 3. The effect of gamma radiation on the viscosity of gasoline-benzene mixture at different concentrations immediately after irradiation (a), 4 months (b).

Fuels and lubricants used under radiation conditions must have sufficient radiation resistance. For this purpose, antirads can be added to them. The most common antirads are aromatic compounds: benzene, naphthalene, anthracene, phenanthrene, pyrene, phenylene diamines, phenyl-naphthylamines, phenols, thiophenols, diphenyl sulfide, benzokinones, naphthoquinones, and others. The amount of aromatic antirads added to the fuel usually constitutes 0.1-10% of the total weight. The post-effect (post-polymerization effect) refers to the unstable process from the moment the reaction begins until it completely stops (breakdown of the kinetic chain). Studies of the kinetics of post-polymerization effects immediately after irradiation and sometime later show that the speed of the process and its share in total polymerization depend on the irradiation duration, the initial density of the mixture, and the dose. Post-polymerization effects are calculated as the percentage increase of a specific characteristic to its initial value. The graphs (Figure 4) show that even with the addition of 1% benzene to gasoline, the radiation resistance increases.

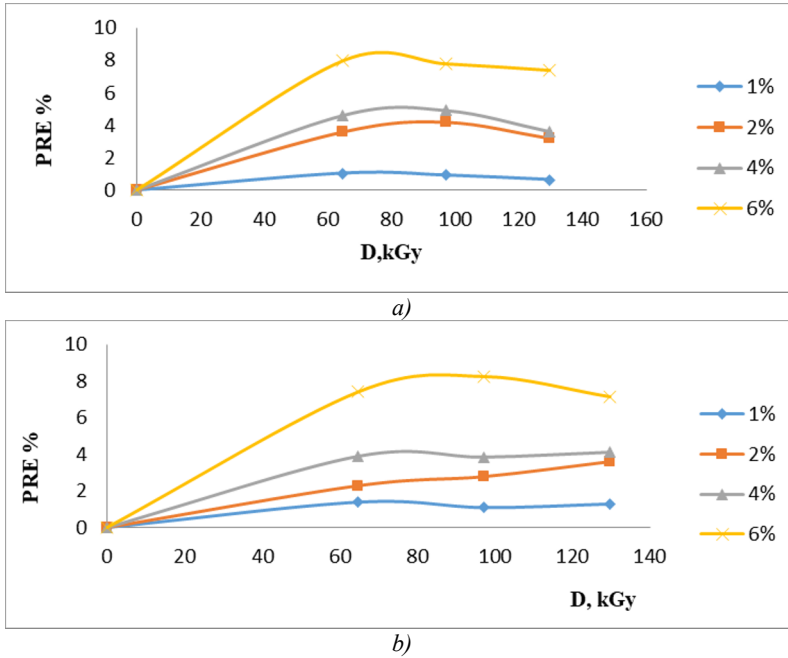


Fig. 4 Dependence of the absorbed dose (%) of the post-radiation effect of the density of the gasoline/benzene mixture immediately after gamma irradiation(a) and 4 months later(b).

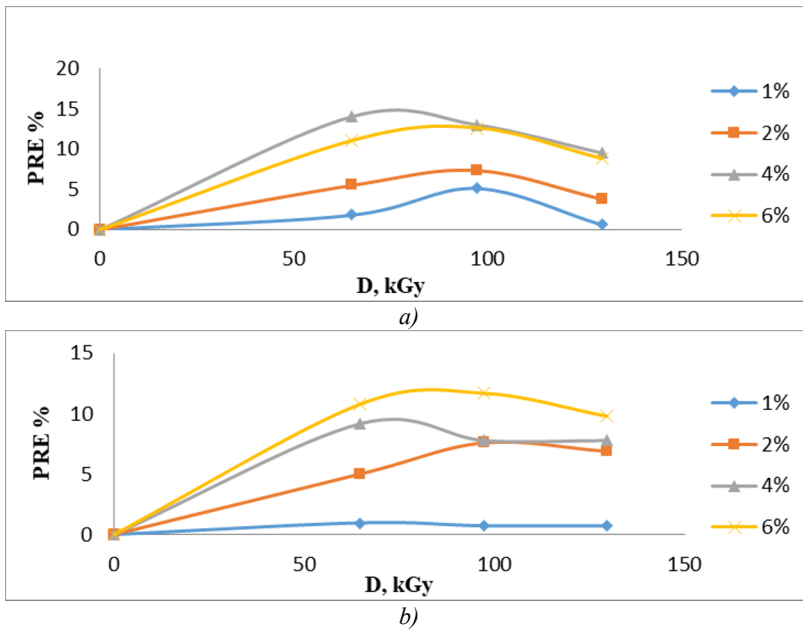


Fig. 5. Dependence of the post-radiation effect of the viscosity of the gasoline/benzene mixture immediately(a), 4 months (b)after gamma irradiation on the absorbed dose (%).

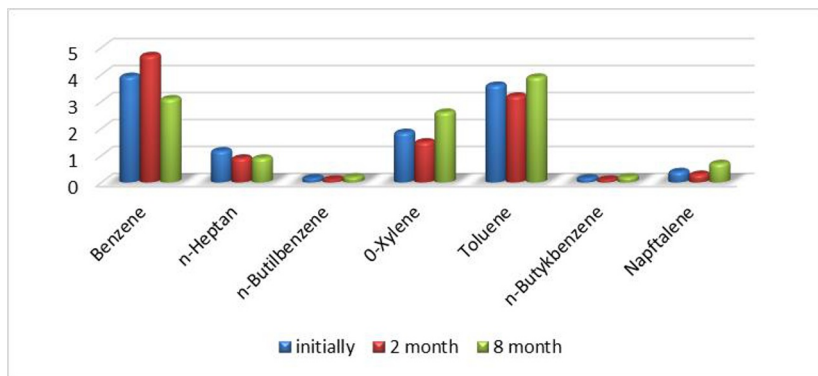
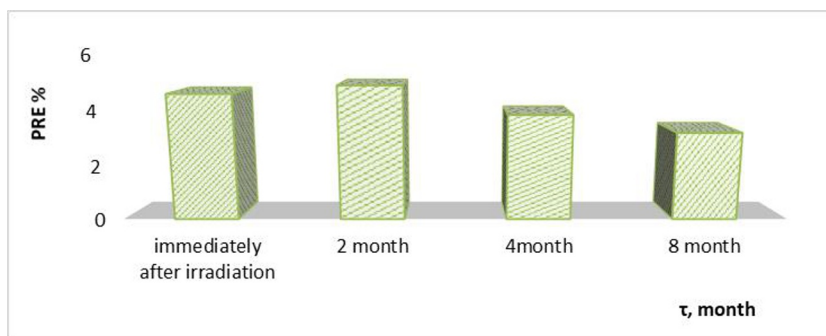
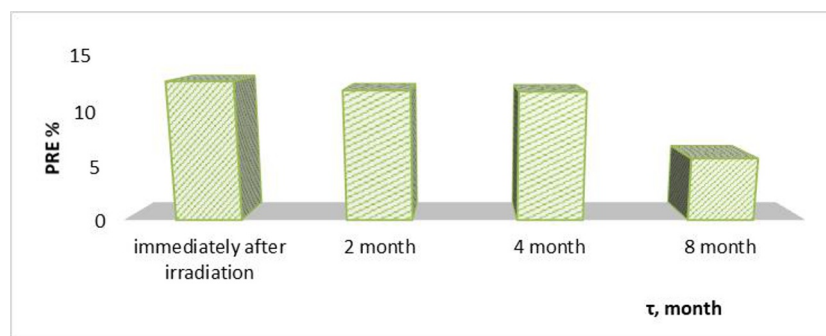


Fig. 6. Indicators of hydrocarbons in gasoline components immediately, 2 months and 8 months after irradiation (%).



a)



b)

Fig. 7. Time (month) dependence of the post-radiation effect of the density of a1% (a) and 6%(b) benzene/gasoline mixture. $D = 97$ kGy.

Radiation-chemical processes under the influence of gamma rays lead to the fragmentation, polymerization, oxidation, and reduction of organic compounds due to the replacement, dissociation, and addition of radicals from unsaturated molecules, as well as the combination of these processes in the reactions of radical isomerization. The effect of radiation on hydrocarbons depends on their chemical structure, the composition of the mixture, and the degree of irradiation. During gamma irradiation, the molecules of gasoline are destroyed, resulting in the formation of ions, electrons, and excited molecules. The recombination of these radicals through a chain mechanism leads to the formation of

radiolysis products. Processes occurring under the influence of radiation change the physical-chemical and operational properties of fuel. The course of radiation-chemical processes and the yield of radiolysis products are significantly affected by the physical state of the irradiated substance, as well as by linear energy transfer, the presence of various additives, temperature, and the dose of radiation. After gamma irradiation, all operational properties of gasoline deteriorate, resulting in the formation of deposits and darkening of the color. The negative effects of radiation are more pronounced at higher temperatures. The amount of fragmented hydrocarbons increases with radiation intensity and total radiation dose. By changing the hydrocarbon composition of petroleum products or applying additives (antirads), it is possible to select a fuel composition that can better withstand radioactive effects. Aromatic hydrocarbons are characterized by high radiation resistance, which is related to the delocalization of excited energy along the aromatic ring due to the presence of a system of π -bonds in a specific fragment of the molecule. As a result, the probability of breaking the ring decreases. The main channel for the decomposition of excited aromatic molecules involves the formation of phenyl radicals through the cleavage of C-H bonds: $C_6H_6^* \rightarrow C_6H_5 + H$. The resulting H atoms are quickly captured by surrounding molecules, producing cyclohexadienyl radicals: $H + C_6H_6 \rightarrow C_6H_7$. Phenyl radicals can undergo a similar reaction to form phenyl cyclohexadienyl radicals. The subsequent reactions of radical recombination and disproportionation lead to the formation of isomeric cyclohexadienes and polymer products. In bimolecular reactions during the radiolysis of small amounts of arenes, excited molecules are formed that compete with deactivation processes during collisions with surrounding molecules: $C_6H_6^* + C_6H_6 \rightarrow H_2 + C_{12}H_{10}$. The oxidation of fuel components is a complex and multi-stage process, making its study important. The stability of fuel depends on long-term storage conditions and the reactivity of the combustion chamber's fire quality components. The chain radical nature of oxidation makes these processes highly sensitive to various inhibitors. The rate and depth of oxidation and polymerization are influenced by the interaction of the fuel with oxygen, temperature, light, radiation, and gaseous, liquid, and solid oxidizers, which can cause the process to stop and the chain to break, halting the accumulation of free radicals. The π -electron structure of the rings during the radiolysis of aromatic hydrocarbon compounds determines some of their important properties.

4 Conclusion

1. Samples of AI-92 gasoline and benzene-gasoline mixtures with benzene concentrations of 1%, 2%, 4% and 6% (by volume) were irradiated at room temperature using a Co60 gamma radiation source of the MPX γ -30 type with a dose rate of $P = 0.07$ Gy/s, covering the range of absorbed doses $D = (64.8-129)$ kGy.
2. It was noted that with an increase in the absorbed dose, the viscosity and density of the fuel increases, which negatively affects the technical properties of gasoline. The iodine number decreases, probably due to polymerization processes. Increased viscosity leads to an increase in smoke and fuel consumption during combustion, thereby reducing the efficiency of the engine. Accordingly, this disrupts the combustion process, which leads to a greater number of incomplete combustion products and the formation of soot on the parts.
3. Oxidation and polymerization processes lead to the formation of deposits in gasoline, which appear as resin. Fuels with a higher density contribute to increased wear of vehicle parts and increased thermal stress.
4. The radiation resistance of aromatic compounds is associated with their relatively low initial excitation energy. The energy absorbed by the aliphatic part of the molecule can be transferred to the aromatic part, which allows delocalization along

the aromatic ring. To increase the radiation resistance of gasoline, benzene is added to it in concentrations of 1%, 2%, 4% and 6%. The optimal concentration is 1%, with viscosity and density remaining relatively stable despite the increase in the absorbed dose.

5. Studies of the kinetics of post-polymerization processes, conducted immediately after irradiation and several months later, show that the rate of these processes and their contribution to the overall polymerization depend on the duration of irradiation, the initial density of the mixture, and the dose. Including antiradiation agents, it is possible to determine the composition of benzene, which demonstrates greater radiation resistance.
6. The post-irradiation effect describes the unstable development that occurs from the beginning of reactions to their complete stop (when the kinetic chain breaks).

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