New Materials, Compounds and Applications
Vol.7, No.3, 2023, pp.156-166

INVESTIGATION OF THE EFFECT OF MAGNETIC FIELD INTENSITY ON THE PROCESS OF PURIFICATION OF DIESEL FRACTION WITH EXTRACTION METHOD BY USING N-METHYLPYRROLIDONE

B.G. Abdulov*, A.A. Hasanov

Azerbaijan State Oil and Industrial University, Baku, Azerbaijan

Abstract. Research materials related to the purification of diesel fuel from aromatic and polycyclic hydrocarbons were examined, and the most effective extraction method was selected for the process. The solvents used in the extraction process were investigated, and N-methylpyrrolidone, which well dissolves aromatic and polycyclic hydrocarbons, was chosen as the extractant. In the study, the influence of a constant magnetic field on the extraction process under conditions of optimal parameters (temperature 25^{0}C, ratio 1:1, number of mixer cycles 70 cycles/min) for the cleaning of diesel fraction from aromatic and polycyclic hydrocarbons with N-methylpyrrolidone was studied and a diagram of the device was presented. The studies were carried out at different magnetic field intensity and the optimal value was determined. The best composition of the diesel fraction was determined at an optimal magnetic field of 20 millitesla (mT). In this fraction, the amount of aromatic hydrocarbons was 6% which corresponding to EURO-5 standards, and the amount of sulfur was 0.032%.

Keywords: *diesel fraction, extraction, aromatic hydrocarbons, sulfur, magnetic field, N-methylpyrrolidone.*

Corresponding Author: *Babak Abdulov, Azerbaijan State Oil and Industrial University, Azadlig ave. 34, Baku, Azerbaijan, Tel:+994556823008, e-mail: babak001@mail.ru*

Received: *4 July 2023;* ***Accepted:*** *23 October 2023;* ***Published:*** *18 December 2023.*

1. Introduction

Due to the harmful effects of exhaust gases emitted by internal combustion engines, the content and the quality of the fuels used are controlled by the application of Euro standards in the countries of the European Union. The main indicators limited by Euro standards are the amount of sulfur and polycyclyc aromatic hydrocarbons. Since 2009, the Euro-5 standard for diesel fuel has been in force, and this standard includes diesel fuel with an ultra-low sulfur content (ULSD - Ultra Low Sulfur Diesel), which contains no more than 8% (wt) polycyclyc aromatic hydrocarbons and no more than 10 ppm. sulfur (Regulation, 2011).

The experience of using nitrogen-containing solvents, especially N-methylpyrrolidone, in the extraction process (Gaile *et al.*, 2019) showed that this method can be used to reduce both the amount of sulfur and the amount of aromatic hydrocarbons. In (Pykhalova *et al.*, 2011; Pykhalova *et al.*, 2012) the heavy diesel fraction with a boiling point above 260°C was purified by using N-methylpyrrolidone as an extractant. The articles (Vereshchagin *et al.*, 2018) and (Gaile *et al.*, 2006) show the efficiency of vacuum

How to cite (APA):
Abdulov, B.G., Hasanov, A.A. (2023). Investigation of the effect of magnetic field intensity on the process of purification of diesel fraction with extraction method by using N-methylpyrrolidone. *New Materials, Compounds and Applications, 7*(3), 156-166.

gas oil purification with N-methylpyrrolidone. Purification of sulfur-containing compounds from gasoline fraction by extraction method was studied (Burmistrova *et al.*, 2019). The separation of aromatic hydrocarbons from aliphatic hydrocarbons by synthesizing various ionic liquids from metal salts with N-methylpyrrolidone was studied in (Hui *et al.*, 2022).

Carcinogenic polycycloarenes were purified by a four-stage countercurrent extraction method using a mixture of dimethyl sulfoxide and N-methylpyrrolidone - ethylene glycol as an extractant from an oil mixture which purified from heavy vacuum gas oil and asphaltogens by the authors of (Gaile *et al.*, 2020). Compared to dimethyl sulfoxide, it is possible to obtain a plasticizer for the tire industry by using as extractant N-methylpyrrolidone and its mixture with 10% ethylene glycol. The proposed mixture is thermally stable compared to dimethyl sulfoxide, which allows for the regeneration of the extract after the extraction process by rectification.

In another study (Shishkin *et al.*, 2012), purification of aromatic and sulfur compounds was carried out from diesel fraction using N-methylpyrrolidone and dimethylformamide as solvents. It has been identified that it is possible to obtain Euro-4 and Euro-5 diesel fuels through the combined extraction and hydrotreating process.

Currently, it is becoming more and more difficult to achieve the desired results with the help of modern technologies in the petrochemical industry. Therefore, it is important to use additional means of influence that affect the process, consume less energy, cost-effective and increase the intensity of the process. These include the use of non-traditional methods, such as acoustic, mechanical, electrical, thermal, radiation, magnetic fields (Pivovarova, 2005; Ning *et al.*,2022).

The influence of the magnetic field on the composition and dispersion of the products obtained from the catalytic cracking process of the mixture of cotton oil and vacuum gas oil was studied. It was determined that due to the influence of the magnetic field, the dispersity increases, and the final products are enriched with the target substances (Abbasov *et al.*,2018).

When crude oil is exposed to a magnetic field before primary oil processing, an increase in the yield of light-colored products and a change in viscosity are observed (Galimov & Kharlampidi, 2014; Leontiev *et al.*, 2019; Xuejiao *et al.*, 2018).

The influence of a magnetic field with a strength of 0.165-0.515 T on the purification of acetone by the extraction process was studied (Sun et al., 2007), and the yield increased with increasing magnetic field strength. It has also been found that the magnetic field becomes more effective as the temperature rises.

In (Pivovarova, 2019), the influence of waves on various chemical and petrochemical processes was studied, their grouping was carried out, and the mechanism of influence was discussed.

Having studied the existing research methods, we considered it appropriate to carry out the extraction process under the influence of a magnetic field as an unconventional method, so experiments were carried out in this direction (Abdulov & Hasanov, 2020; 2021).

2. Experimental part

Before studying the effect of the magnetic field, the extraction process was carried out using N-methylpyrrolidone as an extractant, and the diesel fraction obtained from the primary processing of oil was taken as a raw material. The amount of aromatic hydrocarbons and the total amount of sulfur in the raw material is 18.08% (mass) and 0.0895% (mass), respectively (Hasanov & Abdulov, 2019; Hasanov *et al.*, 2021).

Experiments are carried out as follows. Diesel distillate is poured into the mixer, and the solvent is added to it and started. The temperature of the process is monitored by a thermometer. At the end of the extraction process, the mixed phase inside the flask is transferred to a phase separator, and after the mixture settles, the raffinate phase is separated from the extract solution. During numerous experiments, it was determined that the separation of phases ends within 15 minutes. The results of the studies are given in Figs. 1, 2, 3. As can be seen from the graphs, the optimal parameters are as follows:

- temperature 25^{0}C,
- raw extractant ratio 1:1,
- the number of cycles of the mixer is 70 cycles/minute.

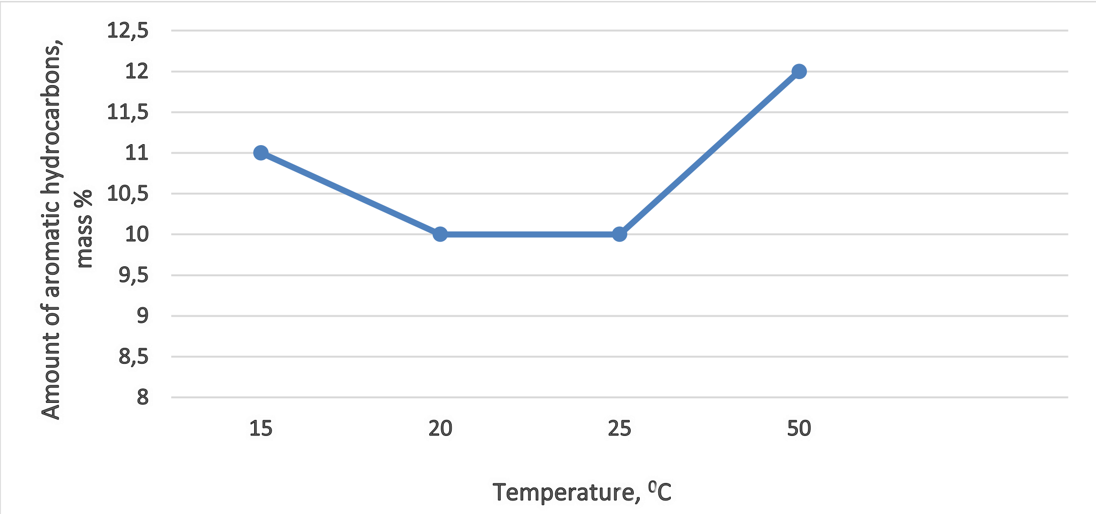


Fig. 1. Effect of temperature on the extraction process

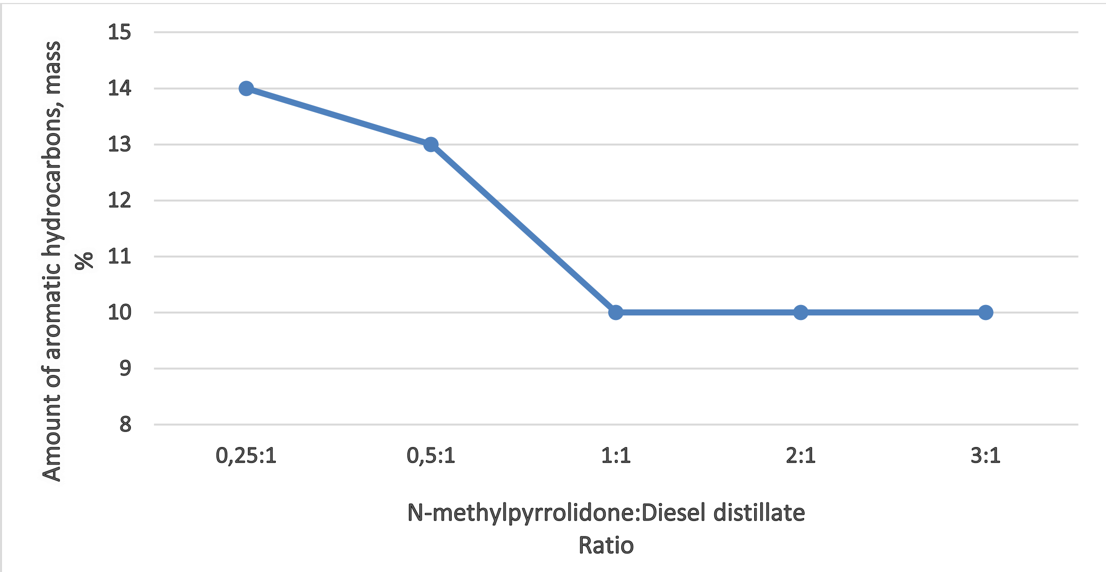


Fig. 2. Effect of raw extractant ratio on the extraction process

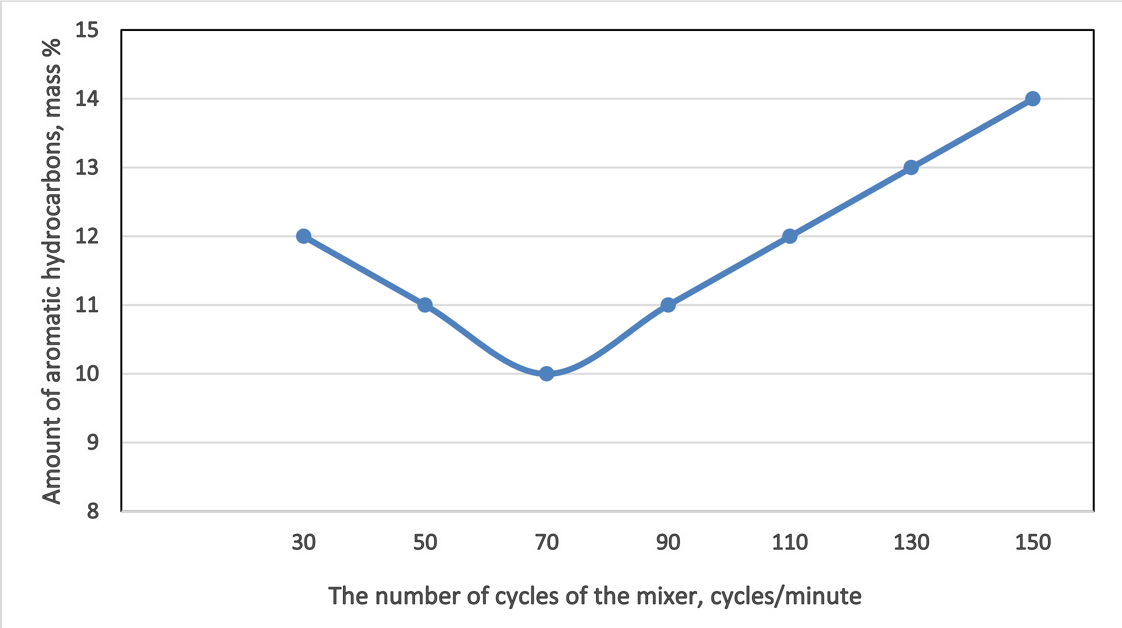


Fig. 3. The effect of the number of cycles on the extraction process

Further studies were carried out under the influence of the magnetic field with conditions of the determined optimal parameters. The principle scheme of the process is given in Fig. 4.

Electromagnets were used to create the magnetic field in the studies. An electromagnet consists of a wire wrapped around a core of special made electrotechnical iron alloy. When an electric current passes through the wire, the iron becomes magnetized and creates a magnetic field around itself.

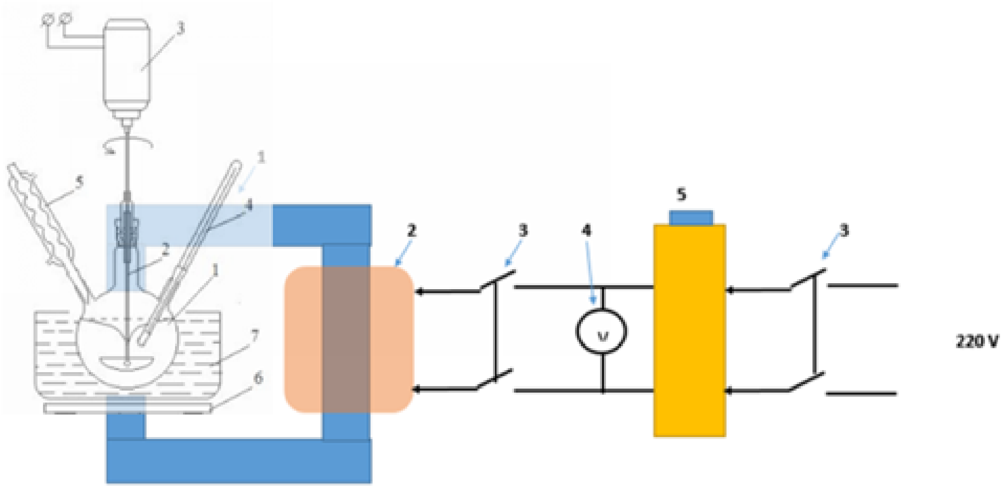


Fig. 4. The principle scheme of the process

A device that creates a magnetic field: 1- a special metal case, 2- a copper winding, 3- an electric switch, 4- a voltmeter, 5- a latr (for adjusting the voltage);

Extraction device: 1- Three-neck round-bottomed flask, 2- glass stirrer, 3- stirring electric motor, 4- thermometer, 5- countercooler, 6- heater, 7- water bath.

The influence of the magnetic field on the extraction process was studied at intensity values of 5-50 millitesla (mT). It was found that the effectiveness of the process increases and the process goes deeper under the influence of a magnetic field. Table 1 shows the results of the study.

Table 1. Effect of different intensity magnetic field on the extraction process

Intensity magnetic field, mT	Amount of aromatic hydrocarbons, % (mass)		Sulfur content, % (mass)	
	Under normal circumstances	In the magnetic field	Under normal circumstances	In the magnetic field
0	10	10	0,075	0,075
5		10		0,075
10		9		0,051
15		7		0,037
20		6		0,032
25		7		0,032
30		7		0,032
35		8		0,034
40		7		0,035
45		7		0,035
50		7		0,035

As can be seen from the table, the effect of the magnetic field leads to a sufficient decrease in the amount of aromatic hydrocarbons and sulfur in the raffinate.

The mechanism of influence of the magnetic field on the process is explained as follows.

The increase in the selectivity of the extraction process under the influence of the magnetic field is explained according to the theory of oil dispersed systems.

The effect of the magnetic field on the diesel fraction causes the redistribution of its components and the transfer of part of the solvate film molecules to the dispersed medium, as a result of which the size of the dispersed particles decreases. In addition, under the influence of the magnetic field, the position of the molecules changes and the structure of the oil dispersion system is adjusted. As a result, a new structure is formed, which is characterized by high homogeneity, regularity, low viscosity and promotes molecular and convective diffusion of components. This leads to a selective redistribution of components between the phases and a better separation of hydrocarbons in the selective purification process with N-methylpyrrolidone.

As a result of the influence of the magnetic field on the diesel fraction, the redistribution of the particles of the dispersed phase causes a displacement of the components in the complex molecular structure, which leads to an increase in the solubility of aromatic hydrocarbons in N-methylpyrrolidone, which is used as an extractant, and at the same time, a decrease in the solubility to normal and cycloalkanes, and thus the process leads to an increase in selectivity. As can be seen from Table 1, increasing the intensity of the magnetic field up to 20 mT leads to a decrease in the content of aromatic hydrocarbons and sulfur in the diesel fraction.

During the experiments, the best result was obtained at a magnetic field value of 20 milli Tesla. At this time, the amount of aromatic hydrocarbons and the amount of sulfur after purification by the extraction process were 6% (mass) and 0.032% (mass), respectively. The amount of polycyclic aromatic hydrocarbons meets the Euro-5 standard.

The results of studies showing the influence of the magnetic field on the extraction process are given in Table 1. As can be seen from the table, an increase in the intensity of the magnetic field up to a certain limit (20 mT) leads to an increase in the intensity of the interaction force between the components of the diesel fraction and N-methylpyrrolidone molecules and the easier dissolution of aromatic hydrocarbons by the extractant. The increase of the magnetic field intensity after 20 mT does not affect the selectivity of the process.

The increase in selectivity due to the influence of the magnetic field is explained as follows.

As we know, the composition of diesel fuel consists of aromatic, alkane, naphthene, paraffin hydrocarbons. Each hydrocarbon group has its own layer. The introduction of the solvent into the system creates a layer different from the one formed by the components of the diesel fraction, and the solvent penetrates all layers. In this case, the complex molecular structure in the core of the raw material remains unchanged and the core and complex molecular structure with the included solvent molecule are surrounded by oil dispersion systems in the form of a solvate layer. When a magnetic field is created in the system, redistribution of the components with a complex molecular structure occurs due to its influence, and the size of the dispersed particles decreases as a result of the transition of the molecules of the solvate layer to the dispersed medium. On the other hand, as a result of the influence of the magnetic field, and also due to displacement of the molecules of the dispersed systems, the organization of the structure occurs, more homogeneity, regularity, low viscosity structure is created, it facilitates the molecular and convective diffusion of the components. The mentioned changes ensure selective distribution of components between phases and their dissolution by N-methylpyrrolidone. Since the system is more homogeneous, the solvent molecule is surrounded by the molecules that make up the core and the solvate layer, a new complex structure with a molecular structure consisting of only the solvent molecule is created.

Thus, aromatic and polycyclic aromatic hydrocarbons are more prone to be dissolved by the solvent after exposure to the magnetic field, which makes the process more selective.

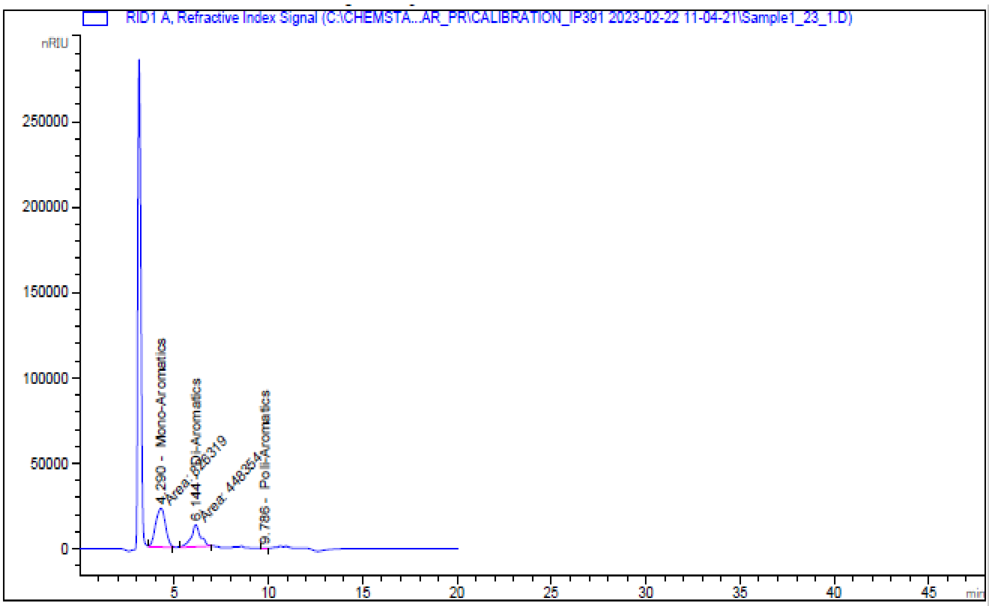
The mentioned changes are reflected in the following way. As can be seen, the influence of the magnetic field causes the disintegration of the supramolecular structure and the formation of a new dispersed phase. The formation of a new dispersed phase increases the homogeneity, ensures the transition of aromatic and polycyclic hydrocarbons to the dispersed phase, thus ensuring the depth and high selectivity of the process.

Spectra were drawn to determine the aromatic hydrocarbons contained in the raw material, the diesel fraction refined under normal conditions and the diesel fraction refined under the influence of a magnetic field. According to the spectra, the amount of aromatic hydrocarbons contained in the diesel fraction obtained from the primary processing of oil is shown in Fig. 5.

The spectrum of the refined diesel fraction under normal conditions is given in Fig. 6.

The spectrum of the refined diesel fraction under the influence of the magnetic field is shown in Fig. 7.

It should be noted that the regulations have been developed for the application of the research results in the Technology Park of the Azerbaijan Academy of Sciences in the pilot plant with a productivity of 10 tons/hour.



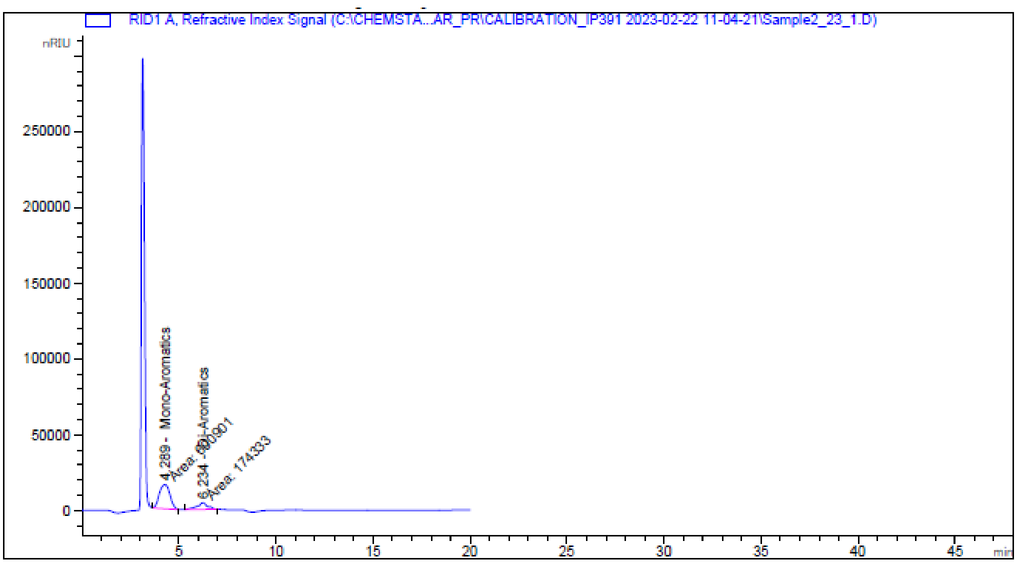

```
=====================================================================
                     External Standard Report
=====================================================================

Sorted By             :      Signal
Calib. Data Modified  :      1/6/2023 9:38:10 AM
Multiplier            :      1.0000
Dilution              :      1.0000
Sample Amount:        :      1.00000  [%]   (not used in calc.)
Do not use Multiplier & Dilution Factor with ISTDs

Signal 1: RID1 A, Refractive Index Signal

RetTime  Type     Area      Amt/Area     Amount    Grp   Name
 [min]         [nRIU*s]                   [%]
-------|------|----------|----------|----------|--|------------------
  4.290 MM     8.26319e5  1.38429e-5   11.43861    Mono-Aromatics
  6.144 MM     4.48354e5  7.37382e-6    3.30608    Di-Aromatics
  9.786 BB      789.11151 5.25173e-6 4.14420e-3    Poli-Aromatics

Totals :                               14.74884
```

Fig. 5. Spectrum of diesel fraction

The conducted studies were carried out under the influence of a magnetic field of different intensity, and the optimal value is 75.4 watts, in other words, the energy consumption is 0.0754 kW/h. In the Republic of Azerbaijan, its value is 0.058 dollars, which is reflected in technical economic indicators. Also it should be noted that the economic efficiency of the unit with a productivity of 10 tons/day is 1710 dollars/day.

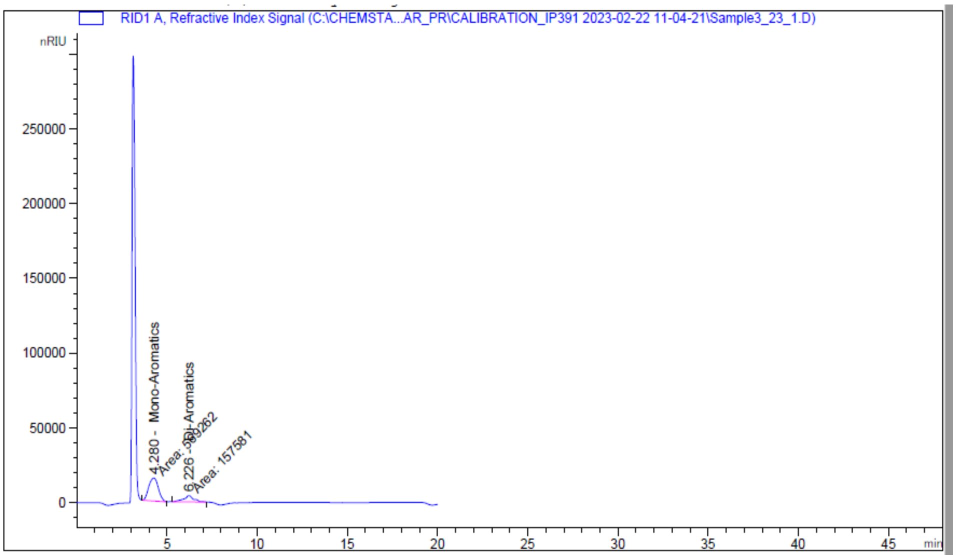
As can be seen from the results of the research, since the amount of sulfur and aromatic hydrocarbons in the target product is reduced, the harmful effects on the environment during the combustion of diesel fuel are eliminated. As we mentioned, the amount of aromatic hydrocarbons in the obtained fraction corresponds to the EURO-5 standard, which indicates that the amount of harmful substances in the flue gases generated from its combustion is within the allowable emission standards. Since the analyzes in the research work were carried out by various methods, including nuclear magnetic resonance, IR-spectroscopy, chromatography, and the percentage of error between their results is 2-5%, the results obtained are beyond doubt.

Since the goal set in our research is to reduce the amount of aromatic hydrocarbons and sulfur in the diesel fraction obtained from the primary processing of crude oil at the Oil Refinery named after H.Aliyev, the process of purifying raw materials with other components was not carried out. It is impossible to conclude that the results of our research will be satisfactory when the amount of aromatic hydrocarbons and sulfur in the raw material is high.




```
=====================================================================
                      External Standard Report
=====================================================================

Sorted By              :      Signal
Calib. Data Modified   :      1/6/2023 9:38:10 AM
Multiplier             :      1.0000
Dilution               :      1.0000
Sample Amount:         :      1.00000  [%]   (not used in calc.)
Do not use Multiplier & Dilution Factor with ISTDs

Signal 1: RID1 A, Refractive Index Signal

RetTime  Type     Area      Amt/Area     Amount   Grp   Name
 [min]          [nRIU*s]                  [%]
-------|------|----------|----------|----------|--|------------------
  4.289 MM     6.00901e5  1.38428e-5    8.31818    Mono-Aromatics
  6.234 MM     1.74333e5  7.36932e-6    1.28472    Di-Aromatics
  9.983            -          -           -        Poli-Aromatics

Totals :                                9.60289
```

Fig. 6. Spectrum of refined diesel fraction under normal conditions




```
=====================================================================
                       External Standard Report
=====================================================================

Sorted By              :      Signal
Calib. Data Modified   :      1/6/2023 9:38:10 AM
Multiplier             :      1.0000
Dilution               :      1.0000
Sample Amount:         :      1.00000  [%]    (not used in calc.)
Do not use Multiplier & Dilution Factor with ISTDs

Signal 1: RID1 A, Refractive Index Signal

RetTime  Type     Area      Amt/Area     Amount    Grp   Name
 [min]          [nRIU*s]                  [%]
-------|------|----------|----------|----------|--|------------------
  4.280 MM     5.69262e5  1.38428e-5    7.88020     Mono-Aromatics
  6.226 MM     1.57581e5  7.36854e-6    1.16114     Di-Aromatics
  9.983            -          -           -         Poli-Aromatics

Totals :                                9.04134
```

Fig. 7. Spectrum of refined diesel fraction under the influence of magnetic field

3. Conclusion

1. For the first time, the extraction method of the diesel fraction obtained from the primary processing of oil was carried out under the influence of a magnetic field.
2. The influence of the intensity of the magnetic field on the process was studied and the optimal value of 20 mT was determined.
3. The amount of polycyclic aromatic hydrocarbons in purified diesel fuel meets the EURO-5 standard at the optimal value of the intensity of the magnetic field.
4. The mechanism of the effect of the magnetic field on the process of cleaning the diesel fraction from aromatic hydrocarbons is given.

References

Abbasov, V.M., Mamedova, T.A., Khalafova, I.A., Movsumov, N.E., & Latifova, T.C. (2018). Influence of a magnetic field on the dispersion and composition of cracking products of vacuum gas oil and its mixture with cottonseed oil, *Oil and Gas Chemistry*, (2), 21-24 ([in Russian).

Abdulov, B.G., Hasanov, A.A. (2020). Obtaining of ecologically pure diesel fuel by using N-methylpyrrolidone under the influence of magnetic field, *AJCN*, *2(*2), 23-28.

Abdulov, B.G., Hasanov, A.A. (2021). Study dearomatization of diesel fuel under the infulence of magnetic field by IR spectroscopy. *International Journal of Modern Physics B*, *35*(08), 2150122.

Burmistrova, D.A., Kuzmin, V.V., Smolyaninov, I.V., & Berberova, N.T. (2019). N-methylpyrrolidone–selective solvent for oxidative desulfurization of light gasoline fractions. *Chem. Chem. Tech.*, *62*(12), 57-64.

Gale A.A., Somov V.E., Zalishchevsky G.D. (2019). *Selective solvents. Separation and purification of hydrocarbon-containing raw materials.* St. Petersburg: Khimizdat, p.896.

Gaile, A.A., Somov, V.E., Zalishchevskii, G.D., Kaifadzhyan, E.A., & Koldobskaya, L.L. (2006). Extractive refining of atmospheric gas oil with N-methylpyrrolidone. *Russian Journal of Applied Chemistry*, *79*, 590-595.

Gaile, A.A., Klementev, V.N., Shchepalov, A.A., & Yu.A. (2020). Extraction purification of a mixture of heavy vacuum gas oil and deasphalted oil extract from carcinogenic hydrocarbons with a mixed extractant N-methylpyrrolidone - ethylene glycol, *Izvestiya SPbGTI(TU)*, *53*(79), 57-60.

Galimov, R.A., Kharlampidi, H.E. (2014). Effect of an alternating electromagnetic field on oil. *Bulletin of the Kazan Technological University*, 4, 266-268.

Hasanov, A.A., & Abdulov B.G. (2019). Obtaining ecologically clean diesel fuel by the extraction method. *Actual Problems of Modern Natural and Economic Sciences*, 258-259.

Hasanov, A.A., Ajamov, K.Y., Huseynova, E.A., Abdulov, B.G., & Ismayilova R.A. (2021). The method of cleaning the diesel fraction from aromatic hydrocarbons, Invention I 2022 0040, Industrial property, Inventions. *Utility models, Industrial examples, Bulletin*, 11.

Yu, H., Li, X., Geng, C., Wu, X., Zhang, F., Tian, S., ... & Ren, Z. (2022). Low-cost N-methylpyrrolidone-based coordinated ionic liquids as extractants for separating aromatics from aliphatics. *Separation and Purification Technology*, *302*, 122149.

Leontiev, A.Yu., Poletaeva, O.Yu., Shakirov, R.A., Khasanov, I.I., & Babaev, E.R. (2019). Influence of the magnetic field on the rheological properties of heavy high-viscosity oils. *NefteGazoKhimiya*, 3-4, 18-22 (in Russian).

Dai, N., Cai, Z., Zhang, X., & Li, K. (2022). The effects and mechanism of the magnetic field on the hydrogen abstraction reaction of benzophenone and isopropanol. *Chemical Physics*, *555*, 111452.

Pivovarova, N.A. (2005) Intensification of hydrocarbon raw materials refining processes by the influence of a constant magnetic field. PhD thesis, 362.

Pivovarova, N.A. (2019). The use of wave effects in the processing of hydrocarbon raw materials (review). *Petrochemistry*, *59*(6-2), 727-738.

Pykhalova, N.V., Appazov, A.Yu., & Balamedova, U.A. (2011). Study of the influence of the conditions for the liquid extraction of the diesel fraction with N-methylpyrrolidone on the environmental performance of diesel fuel. *Oil Refining and Petrochemistry*, *12*, 19-23.

Pykhalova, N.V., Appazov, A.Yu., & Balamedova, U.A. (2012). Extractive refinement of diesel fractions using N-methylpyrrolidone. *Oil Refining and Petrochemistry*, *4*, pp.12-15.

Regulation (2011). (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information". Eur-lex.europa.eu. Retrieved 2011-02-02. /6a "European Commission plans legislative framework to ensure the EU meets its target for cutting CO2 emissions from cars. Ref: IP/07/155 07/02/2007". Europa.eu. Retrieved 2011-02-02. Retrieved from http://data.europa.eu/eli/reg/2007/715/oj

Shishkin, S.N., Gaile, A.A., Bakaushina, D.A., & Kuzichkin, N.V. (2012). Combined process of extraction-hydrotreatment of diesel fractions. *Izvestiya SPbGTI(TU)*, *17*(43), 113-115.

Yongli, S.U.N., Yong, L.I.U., Songhai, W.U., & Shaoyi, J.I.A. (2007). Effect of magnetic field on the extraction process of acetone-water-trichloroethane system. *Chinese Journal of Chemical Engineering*, *15*(6), 916-918.

Vereshchagin, A.V., Gaile, A.A., Klementiev, V.N., & Lazunenko, F.A. (2018). Extractive purification of heavy vacuum gas oil from the AVT-2 unit of LLC "PA "Kirishinefteorgsintez" with N-methylpyrrolidone and N-methylpyrrolidone-undecane extraction system fraction, *Oil Refining and Petrochemistry, 9,* 10-15.

Chen, X., Hou, L., Li, W., Li, S., & Chen, Y. (2018). Molecular dynamics simulation of magnetic field influence on waxy crude oil. *Journal of Molecular Liquids*, *249*, 1052-1059.