

UDC: 665.541.48-143:542.61

IONIC LIQUID EXTRACTION CLEANING OF PETROLEUM FRACTIONS

H.D. Huseynov

*Y.H. Mammadaliyev Institute of Petrochemical Processes of the National Academy of Sciences of Azerbaijan,
Khojali Ave, 30, Baku AZ1025, Azerbaijan Republic;
e-mail: huseyn-1978@mail.ru*

Received 06.05.2022

Accepted 11.07.2022

Abstract: *The extraction purification process is currently being intensively studied and has a great future as an alternative method of purification of petroleum fractions. The point is that the development of technology and rise in the consumption of fuels and oils calls for tightening of requirements to their quality characteristics. At the same time, special attention is paid to the content of aromatic hydrocarbons, sulfur-containing and resinous compounds in their composition. The present review considers the results of studies of extractive purification of various oil fractions using both traditional and "green" solvents - ionic liquids as an extractant providing for the effectiveness of ion-liquid extraction purification. The article also describes studies on combining the process of ion-liquid extraction with an oxidative purification method. The results of studies carried out at the Institute of Petrochemical Processes of the National Academy of Sciences of Azerbaijan on ion-liquid extraction purification of petroleum distillates for various purposes, in particular, transformer oil distillate, catalytic cracking and reforming gasoline, AMG-10 hydraulic fluid, Naftalan oil, diesel fuel, as well as oil distillates fractions with different viscosity values, are shown in the article. Also, the possibility getting petroleum products when used as a selective solvent of ionic liquids (morpholformate, anilinformate, N-methylpyrrolidone acetate, etc.) differing in cationic-anionic combination is substantiated.*

Keywords: *selective solvent, extraction purification, ionic liquid, raffinate, extractant*

DOI: 10.32737/2221-8688-2022-3-197-212

Introduction

Environmental protection is considered to be the most important global problem of the 21st century, and the development of new, cost-effective methods and technologies that meet stringent environmental requirements is one of the promising approaches to solving this problem.

Currently, with the development of technology, the expansion of vehicle fleets and the ever-increasing environmental issues, there is a tendency to tighten the quality requirements for fuels and oils for various purposes. That said, to obtain high-quality fuels and oils that meet appropriate requirements and standards in terms of physicochemical and operational

properties, one of the technological stages is the extraction purification of petroleum raw materials from undesirable components, in particular, from aromatic hydrocarbons, sulfur and resin compounds, the combustion products that poison environment, including various selective solvents - phenol, furfural, N-methylpyrrolidone (NMP), morpholine, sulfolane, etc.

The advantage of the extraction method of purification in comparison with the existing industrially used methods (hydrogenation, hydrotreatment, adsorption, etc.) of purification of petroleum fractions is associated with the

possibility of implementing the process as follows:

- relatively low temperature and pressure;
- no use of expensive catalysts and hydrogen;
- high efficiency in removing aromatic hydrocarbons, sulfur and resinous

compounds from the composition of raw materials.

In this review the works in the field of selective purification of oil fractions of various purposes with the use of "ionic liquids" as an extractant are considered.

Extragents used for purification of oil fractions

The extraction purification method was first applied by M.A. Butlerov in 1870 in the process of separating a mixture of hydrocarbons [1], and in 1902 the so-called "cold extraction" method by K.V. Kharichkov was used in the process of separating the oil fraction from petroleum feedstock and recommended for the production of oils in industry [2].

The results of systematic studies on the extractive purification of petroleum fractions carried out in 1968-2008 at the Saint Petersburg Institute of Technology are summarized and presented in monographs [3-5] and textbook [6].

The efficiency of the selective solvent used in the extraction purification process is mainly determined by its selectivity over aromatic and unsaturated hydrocarbons, as well as by heteroatomic compounds (dialkyl sulfide, thiophene, thiophane, and other homologues) [7,8].

The selectivity of solvents with respect to aromatic hydrocarbons with different numbers of cycles, using the values of the results of extraction separation, without taking into account the limiting activity coefficients obtained by gas-liquid chromatography, was studied in the work [9].

There is a well-known method of using various selective solvents: furfural, imidazole derivatives, β -methoxypropionitrile, N,N-dimethylimidazolidone and etc. Owing to the insufficient selectivity of the proposed extractants in respect of aromatic hydrocarbons, the yield of raffinate is low [10].

The use of N-methylpyrrolidone as an extractant in the purification of polycyclic aromatic hydrocarbons and sulfur compounds from the straight-run fraction of West Siberian oil with a boiling point range of 315-360 °C at an extraction temperature of 20 °C and a ratio of solvent: raw material equal to 1.5:1 vol. and 2.5:1 wt.h., provides for reduction in the content of sulfur compounds in the composition of

refined oil to 57.19 wt% and 44.4 wt%, respectively [11].

The extraction purification of heavy vacuum gas oil with N-methylpyrrolidone, a nonpolar solvent of the undecane fraction, as well as a mixture of NMP with an undecane fraction was studied in various solvents: raw materials ratios and it was shown that a relatively high yield of raffinate is observed when using a mixture of NMP and undecane fraction as extractant. However, the resulting raffinate is characterized by a low quality index [12].

The prospects for the use of NMP and dimethylformamide in the process of extractive purification of light and heavy vacuum gas oils containing 1.65 wt% and 1.72 wt% of sulfur-containing compounds, as well as 44.5 and 51.2 wt% of aromatic compounds, respectively, are described in the work [13]. It revealed that the sulfur content can be reduced to 0.35-0.57 wt.% by multi-stage extraction cleaning in a rotary-disk extractor.

Extractive purification of high-sulfur Arkhangelsk oil with a total sulfur content of 4.36 wt %, sulfide 1.54 wt %, mercaptan 0.14 wt % with dimethylformamide revealed a relatively higher selectivity of the solvent in respect of thiophenes than to sulfides. 60 structures of organosulfur compounds with the number of carbon atoms from 9 to 16 were identified and it found that the degree of their extraction decreases as molecular weight increases [14].

However, it should be noted that all currently used selective solvents used in the processes of extractive purification of oil fractions are quite toxic, explosive and fire hazardous, environmentally harmful and not selective enough in relation to aromatic and sulfur compounds, which necessitates research in the field of selective cleaning of oil fractions

of various purposes using environmentally safe solvents as extractants. Such solvents include

the so-called "ionic liquids" (IL).

Ionic liquids as effective solvents for extractive purification of oil fractions

Ionic liquids (ILs), in contrast to organic solvents traditionally used in extraction processes, are characterized by ease of synthesis, thermal stability, non-volatility, non-combustibility, good dissolving stability of many inorganic, organic, organometallic and macromolecular compounds, as well as regenerability and multiple reuse with the same efficiency [15-19].

In this aspect, in order to protect the environment during the selective purification of petroleum fractions, in particular, to reduce the content of sulfur-containing, aromatic hydrocarbons and resinous substances in them, special attention should be paid to the replacement of organic solvents with environmentally friendly reagents.

Due to the above properties, ILs attract the attention of researchers as very promising reagents for many chemical processes and are considered as a catalyst and reaction medium in the processes of organic, fine organic and petrochemical synthesis, as well as a selective solvent in the processes of liquid extraction [20-26]. The advantage of using ILs arises not only from their ability to accelerate chemical processes, providing a high yield of the target product by carrying them out at low temperatures and without applying pressure, but also from their versatility as a solvent due to the possibility of regeneration and reuse in the technological process [27-29].

Since the 1980s, interest in ILs has increased. An analysis of the literature data indicates an increase in the volume of studies of ILs as selective solvents in extraction purification processes, which is associated both with their high dissolving power and the possibility of changing their nature by modifying both the cation and anion [30-34].

As an extractant, ILs were used primarily in the processes of removing traces of heavy metals [35-37], and it was found that both the hydrophobicity of the IL and the pH of the [38] system are of decisive importance to achieve the best results.

In 1998, the Robin Rogers group published a report on the use of an ionic liquid of the composition B[mim]PF₆ in the process of extraction of aromatic hydrocarbons. It showed that the use of ILs as an extractant instead of industrially used organic solvents - sulfolane, N-methylpyrrolidone, morpholine, ethyl glycol reduces the costs associated with their regeneration [39].

When comparing extraction processes during the use of ionic liquids such as 1-butyl-4-methylpyridinedicyanamide or 1-butyl-4-methylpyridine hexafluorophosphate as a selective solvent, Menidgerma and coworkers found 50% annual savings as compared to the sulfolane [40,41] extraction process.

Promising prospects of the use of ILs in industrial processes were first reported in publications and patents of the French Petroleum Institute on the dimerization, oligomerization and polymerization of C₂-C₄ olefins, in the so-called "Difasol process" [42].

The industrial use of IL began in 2003, in the BASF and BASIL processes, in situ acid removal with further removal of the resulting liquid from the mixture was carried out using N-alkylimidazole [43]. The prospects for the use of ILs as environmentally safe selective solvents in the purification of transport fuels with the production of high-quality end products are considered in reviews [44,45].

The results of ion-liquid extraction purification, in particular, desulfurization of model and real liquid fuels are given in works [46,47]. The high extraction ability of 1-butyl-3-methylimidazoletetrafluoroborate and 1-butyl-3-methylimidazole hexafluorophosphate was noted. It is shown that the sulfur content in diesel fuel decreased from 385.13 ppm to 225.19 ppm and 210.31 ppm, respectively, and in the case of gasoline under the same extraction conditions, the degree of desulfurization was higher, 50% and 61.1% of the mass, respectively. The degree of desulphurization of dibenzothiophene (DBT) from a mixture with n-

dodecane 1-butyl-3-methylimidazole chloride was 81 wt% [48].

It ought to be noted that the possibility of ion-liquid extraction purification of diesel fuel from sulfur-containing compounds using a mixture of n-butyl-3-methylimidazole chloride and n-ethyl-3-methylimidazole chloride with AlCl_3 was first described by Bossman and his colleagues [49]. It found that the hydrolytic instability of this ionic liquid makes their application difficult. Successful use in the purification of diesel fuel from sulfur-containing compounds was noted in the works [50,51]. However, in this case, the problem of their regeneration by distillation due to low pressure indicates their ecological and economic futility.

The work [52] presents the results of studies of the influence of various factors - the nature, amount of ionic liquid, extraction temperature, contact time of the components, as well as the nature of sulfur-containing compounds in the composition of raw materials in the process of removing sulfur-containing compounds from the composition of raw materials. In view of this, the conditions for deep ion-liquid extraction purification DBT (degree of removal of 55% by weight) from model diesel fuel are shown.

It established that in the process of purification of dibenzothiophene from liquid fuel, IL 3-butyl-4-methylthiosol thiocyanate can be used five times without reducing its activity [53].

The work [54] shows the relatively high efficiency of 1-butyl-3-methylimidazole tetrahalogenferrate (III) in comparison with 1-butyl-3-methylimidazole hexafluorophosphate and 1-butyl-3-methylimidazole tetrafluoroborate in the process of diesel fuel purification. The observed result is explained by the formation of F^{3+} π -complex compounds between this IL and aromatic sulfur derivatives.

In recent years, the attention of researchers has attracted the oxidative desulfurization of diesel fuel by ion-liquid extraction [55-59]. Zhao D. et al., [Bmim][BF_4], [Bmim][PF_6], $(\text{CH}_3)_3\text{NCH}_2\text{C}_6\text{H}_5\text{Cl}\cdot 2\text{ZnCl}_2$ [60-63], as well as coordinated ionic liquids based on quaternary ammonium and N-methylpyrrolidone with anhydrous SnCl_2 [64,65] showed the possibility of removing sulfur-containing compounds from the

composition model and petroleum oils, light oil and gasoline. It established that ionic liquids after processing 6-8 times can be reused as an extractant without a significant decrease in activity.

Jiang W. et al. used tetrafluoroborate-1-butyl-3-methylimidazole [66] as an extractant for purification of diesel fuel by the method of oxidation-extraction purification in the presence of H_2O_2 and a number of hexacyanoferrates.

The work [67] describes the oxidative desulfurization of model oil with ionic liquids [Bmin][OcSO_4] and [Bmin][Ac] with the participation of H_2O_2 as an oxidizing agent with a mixture of CH_3COOH and H_2SO_4 . It showed that the combined oxidative desulfurization of model oil is more efficient than using [Bmin][OcSO_4] and 70% desulfurization was achieved which is explained by the participation of IL in the extraction process not only as a selective solvent and medium for the oxidative reaction, but possibly also as a catalyst.

The studies presented in the work [68] provide conditions for the removal of thiophene and dibenzothiophene from the model oil with a degree of purification of 78.5% and 84.3% of the mass, respectively, using IL based on butylpyridine as an extractant and an oxidizer of hydrogen peroxide by the method of extraction-oxidative purification. The possibility of using IL after regeneration with the same efficiency up to four times was shown.

Another paper describes the oxidative desulfurization of model oil using IL - [Bmin][BF_4]. With the participation as an oxidizing system consisting of 30% H_2O_2 and phosphotungstic acid at a temperature of 30°C for 1 hour, the degree of removal of DBT was 98.2% of the mass. With increase in temperature to 70°C and contact time of the components up to 3 hours, the degree of desulphurization was 100% by weight [69].

On the basis of the conducted studies, studying the influence of various factors on the process of extractive desulfurization of gasoline and diesel fuel using IL of various compositions as a selective solvent, Rodriguez-Cavo et al. established a relatively high efficiency of 1-ethyl-3-methylimidazole acetate for the oxidative purification of gasoline and 1-hexyl-2,4-dimethylpyridinebis(trifluoromethyl)sulfonyl imide for diesel fuel desulfurization [70].

Another paper [71] shows the possibility of desulfurization of diesel fuel to a degree of 99.9% (from 500 ppm to <1 ppm) using an IL based on N-methylpyrrolidone [Hnmp]-[Hnmp]Cl₂ ZnCl₂ and an oxidizer H₂O₂ as an extractant.

In the case of using IL [Bmim]CH₃COO as an extractant with the participation of an ozone oxidizer, the degree of removal of hard-to-remove sulfur-containing compounds of thiophene and benzothiophene from the composition of diesel fuel reached 99.9 wt% [72]. With the participation of TiO₂/McM-41 as a catalyst, the degree of removal of DBT and 4,6-dimethyldibenzothiophene was 98.6 and 95.2%, respectively.

The oxidative desulfurization of diesel fuel and model oil was studied using 1-octyl-3-methylimidazole hydrosulfate deposited on silica gel as an extractant. It revealed that, in this case, a rather high efficiency was achieved, 99.1% of the mass of dibenzothiophene removal with a loading of only 17% of the mass of the ionic liquid occurred. In this case, the degree of sulfur removal was 73% of the mass [73]. The possibility of using IL four times without a significant decrease in productivity and activity after simple separation of the heterogeneous catalyst from the system by conventional filtration is shown.

Xu J. and co-authors established the high efficiency of using IL 1-butyl-3-methylimidazole as an extractant in the process of oxidative desulfurization of model oil and catalytic cracking gasoline with the participation of a lanthanide-containing catalyst [74]. It has been shown that a high degree of desulfurization is achieved at 30–60°C for 25 minutes, and the specified IL can be reused without significant loss of efficiency.

An efficient process for deep oxidative desulfurization of diesel distillate with a high degree of sulfur removal (88.4% wt) under mild conditions was developed by Liu D. et al. [75]. To remove thiophene, benzothiophene and their derivatives from model oil, a catalytic system consisting of tungstate and Bronsted acid ILs with the participation of H₂O₂ as an oxidizing agent [76] was effective.

In the works [36, 77-78] it was shown

that under optimal conditions the efficiency of desulfurization of diesel fuel and gasoline reached a maximum and the degree of removal of sulfur-containing compounds was nearly 100% of the mass. The advantage of using IL compositions as an extractant in this process was also determined by the possibility of multiple reuse without a significant decrease in their efficiency.

The condition for removing sulfur from model oil by 99 wt % and from gasoline by 91 wt % with initial sulfur content of 200 ppm and 142 ppm, respectively, was described in [79]. It was noted that in this case, a decrease in the octane number of gasoline by only 0.7% of the mass is observed.

In the process of gasoline desulfurization with ionic liquid N-methyl-N-methyl imidazole dimethyl phosphate [MMIM][DMP], N-ethyl-N-methylimidazole with diethyl phosphate [EMIM][DBP], as well as N-butyl-N-methylimidazole with dibutyl phosphate [BMIM][DBP] the relative high efficiency of [BMIM][DBP] was established and high selectivity with respect to the most sterically hindered thiophene [80] was shown.

The results of ion-liquid extraction purification of model oil containing components of various nature using 1-ethyl-3-methylimidazole chloride as an extractant revealed the possibility of using IL of the specified composition in the processes of purification of model oil from nitrogen- and sulfur-containing compounds [81]. It found that in this case the degree of removal of pyridine was 90 wt%, indole - 76 wt%, DBT - 99 wt%. After regeneration with repeated use, the degree of removal of indole was 85 wt%, and dibenzothiophene 85 wt%.

The work [82] describes the oxidative desulfurization of fuel oil by ion-liquid compositions based on pyridine. It was established that this method was suitable only for removing sulfur-containing aliphatic compounds (thiols, thioethers, disulfides, etc.) from fuel oil, and at the same time it was not possible to purify raw materials from sulfur-containing aromatic compounds, in particular from thiophene and its derivatives.

As is known, in industry petroleum acids are removed from petroleum fractions by various methods - extraction, absorption, thermal decomposition, esterification, thermal or catalytic decarboxylation [83]. However, all of the above methods are characterized by certain difficulties, in particular, it is impossible to remove naphthenic acids from the composition of oil fractions by neutralization with alkali or alkaline earth metals, which is explained by their insufficient water solubility. In addition, the purification process is complicated by the formation of an emulsion with high-boiling fractions. The extraction purification process is complicated by a significant loss of the organic solvent, and the adsorption process is suitable only in the case of removal of naphthenic acids from low-boiling distillate fractions. The disadvantage of the decarboxylation process lies in the necessity for a high temperature ($>250^{\circ}\text{C}$), which causes corrosion of the equipment.

A known method of removing naphthenic acids from a model mixture by ion-liquid extraction using ionic liquids based on *n*-butyl-3-methylimidazoline [84] as a selective solvent. It is shown that ILs of the indicated composition, which differ in the anionic fragment (octylsulfate, trifluoromethanesulfonate and etc.), exhibit high efficiency (99wt %) in the process of removing naphthenic acids from the model composition.

Of certain scientific and practical interest are studies on ion-liquid extraction purification of petroleum fractions for various purposes, conducted at the Institute of Petrochemical Processes of the National Academy of Sciences of Azerbaijan.

In the ongoing studies, distillates of oil fractions with different viscosities and different deposits, transformer oils, catalytic cracking and reforming gasoline, distillate of hydraulic fluid AMG-10, distillate of naftalan oil and diesel fuel were used as oil fractions. Ionic liquids synthesized on the basis of formic, acetic and benzoic acids with the use of morpholine, di-, triethyl-, butylamines, *N*-methylpyrrolidone, pyridine, piperidine, etc., were used as an extractant in the purification of the above oil fractions [85-110].

By varying the mass ratio of the ionic-liquid solvent and the feedstock, the temperature and extraction time, the optimal conditions for desulfurization and dearomatization of the studied oil fractions were established to obtain fuels and base oils for various purposes with improved performance properties.

In particular, a cycle of studies revealed that the best results in the selective purification of catalytically cracked gasoline (CCG) were achieved when an IL based on formic acid, aniline, or morpholine was used as an extractant [86]. At an extraction temperature of 40°C , a contact time of the components of 2 h, and equal mass ratios of the extractant to the raw material, the content of aromatic hydrocarbons in CCG decreases from 25.5 wt.% to 19.0 wt.%, the content of total sulfur from 240 ppm to 66 ppm, and mercaptan - to 30 ppm. It should be added that the implementation of the extraction process of gasoline in stages reduces the content of aromatic hydrocarbons to 14% (degree of removal 45.1% wt), total sulfur to 30 ppm (degree of removal 87.5% wt). At the same time, the CCG octane number practically does not change and amounts to 79.8 according to the motor method.

The chromatographic analysis of the group hydrocarbon composition of the samples before and after purification established a relatively high selectivity of the morpholinformate IL [86]. In this case, the octane number of the purified sample - reforming gasoline was 103.7.

The conducted studies on the selective purification of transformer oil distillate confirmed the prospects of using the indicated IL compositions based on formic and acetic acids as a selective solvent [87]. The best results in terms of raffinate yield were achieved when a composition based on formic acid and morpholine was used as a selective solvent for IL. At a mass ratio of extractant:raw material equal to 2.5:1, extraction temperature 60°C , and contact time 2.5 h [87]. The resulting samples were characterized by the dielectric loss tangent of 0.31-0.41 at 90°C .

In case of using anilinformate and *N*-methylpyrrolidone acetate as the selective solvent under the indicated extraction

conditions, the yield of purified raffinate was 83.0 and 81.2 wt%, respectively [88].

It found that in terms of structural and group composition, transformer oil obtained by cleaning with IL composition was close to foreign oil from Shell (England). Similar results were also obtained when using a composition based on formic acid and morpholine as an IL extractant. In this case, a high degree of purification was observed at a threefold weight excess of the ionic liquid [88].

The high yields of the obtained raffinates as compared to the yield during acid-contact cleaning (76.7% of the mass), as well as the high performance of the obtained base transformer oil that meets the requirements of GOST 982-80, indicate the promise of ion-liquid extraction purification and the possibility of creating "green chemistry" technology.

Studies on the selective purification of the oil fraction with a viscosity of 6.89 mm²/s at 100°C using the studied ionic-liquid compositions as a selective solvent showed a relatively high efficiency of ILs based on formic acid and aniline aniline formate. The best results were achieved with a fourfold excess of IL in view of the raw material, an extraction temperature of 50°C, and a contact time of the components of 2 h. In this case, the viscosity index increases by 23 points as compared to the initial distillate and amounts to 87.0, the raffinate yield was 82.0 wt% of the initial raw materials [89].

The authors studied the ion-liquid extraction purification of a distillate from low-paraffin oils with a kinematic viscosity of 7.5 mm²/s at 100°C, as well as a mixture of an oil distillate based on equal weight amounts of distillate with a viscosity of 7.5 and 18 mm²/s at 100°C. In order to obtain the base oil with improved performance, the expediency of carrying out the process using N-methylpyrrolidone acetate as a selective IL solvent was shown [90].

It said in [91] that the use of an IL based on morpholine and formic acid as a selective solvent in the process of extraction purification of an oil fraction with a viscosity of 8.5 mm²/s at 100°C, isolated from low-paraffin Azerbaijani oils from an offshore field made it possible to find optimal conditions: the ratio of

the distillate of the oil fraction : IL 1:3 mass, the extraction temperature of 80°C and the contact time of the components of 3 hours provided a high yield of raffinate 87.6% mass as compared to the industrially used solvent, furfural - 73.0% mass.

At the same time, the viscosity index of the purified oil increases from 62.5 to 84.23, the acid number decreases from 0.9 to 0.1 mg KOH/g, and the pour point from +7 to -2°C.

Selective purification of oil fractions isolated from deepwater oil of the Gunashli field with a boiling point limit of 350-400°C and significantly different in viscosity (2.56; 4.72 and 11.36 mm²/s at 100°C), IL composition showed that the degree of purification of 350-400°C corresponds to 54.4 wt%, and the high-boiling fraction 450-500°C is slightly higher - 57.37 wt%.

It revealed that with an increase in the boiling point of the studied fractions, the content of aromatic hydrocarbons in them increased from 29.37 to 37.6% wt. The same pattern was observed in the samples of raffinates obtained by ion-liquid extraction purification of oil fractions (from 13.39 to 16.03%).

IR spectral analysis of samples of raffinates obtained by IL purification of fractions with a boiling point of 400-450°C and 450-500°C showed that they contain, along with low molecular weight aromatic hydrocarbons and highly condensed hydrocarbons, the residual amount of condensed cycles in the raffinate fraction 350-400°C with more than in the raffinate sample 450-500°C.

A comparative analysis was performed which revealed the physicochemical properties of oil fractions after selective purification with IL composition and furfural indicates, along with a high yield (87.5-95.65 wt.% versus 78.2-79.55 wt. 0.4% mass), acid number (0.07-0.15 mg KOH/g versus 0.13-0.19 mg KOH/g). The obtained results testify to the efficiency of purification of these oil fractions by ion-liquid extraction in comparison with extraction with an industrially used extractant, furfural [92, 93].

In the selective purification of diesel fuel distillate, a sufficiently high selectivity was observed in the case of using an IL composition based on formic acid and aniline, as well as on

the basis of formic acid and morpholine [94,95]. It showed that at equal mass ratios of raw material to extractant, extraction temperature of 40–45°C, and contact time of 90 min, the content of aromatic hydrocarbons can be reduced from 16.5 wt% to 9.8–10.5%, sulfur from 0.086% to 0.0037–0.0034 to 0.0035%. The cetane number, which was the most important indicator of diesel fuel, rose from 45 to 51–52 units after selective purification with the indicated IL compositions, the main indicators of diesel fuel comply with the technical requirements for fuel class EURO EN 590:2004.

By ion-liquid extraction purification of Naftalan oil with a boiling point of 200–450°C using an IL based on formic acid as a selective solvent, it was found that in the case of using a piperidine-formate ionic liquid, the yield of raffinate with a residual content of aromatic hydrocarbons of 2.78 wt% is 77.8% masses [96]. When using the ionic-liquid composition of N-methylpyrrolidone acetate as an extractant, the conditions were determined that allow almost complete dearomatization of the raw material.

It found that when processing raw materials with a fourfold excess of the extractant at the first stage, and a threefold excess at the second stage, the degree of dearomatization was 96.5 wt%.

A cycle of systematic studies reaffirmed the possibility of obtaining the base of the AMG-10 hydraulic fluid by ion-liquid extraction purification of a distillate obtained by compounding 10 ° C fractions isolated from Balakhani oil and oil from the Neft Dashlari field, using as a selective solvent, synthesized on the basis of formic and acetic acids various ionic liquids [97,98]. The study of the influence on the extraction process, in particular, on the yield and on raffinate performance, proceeded from various factors: the composition of the IL, the mass ratio to the raw material, the temperature and time of extraction, as well as the implementation of the process in one stage or in stages, the determined effective composition of the IL, as well as the optimal conditions obtaining the base of the AMG-10 hydraulic fluid that meets the requirements of TU 0253-021-46693-103-2006.

The authors submitted the results of studies into the development of conditions for

obtaining diesel fuel of improved quality by ion-liquid extraction purification of diesel distillates of various compositions using N-methylpyrrolidone acetate as a selective solvent of IL [99–105].

The conducted cycle of studies established the conditions for obtaining diesel fuel that meets on the main indicators, in particular, the content of aromatic hydrocarbons (3% wt) and sulfur compounds (348 ppm), the requirements of the European standard, by implementation of the process of ion-liquid purification of narrow fractions of straight-run diesel distillate (SDD) with further compounding of the resulting raffinates [102].

The possibility of ion-liquid extraction purification of a mixture of SDD with secondary oil refining products - light coking gas oil (LCG) and catalytic cracking gas oil (LCCG) at a volume ratio of 70:30 was shown as well. The conditions for obtaining a raffinate with a yield of 76.57 wt % based on a mixture of SDD and LCG with a degree of desulfurization (71.3%) and dearomatization (62.5%), as well as SDD and LCCG with obtaining a raffinate with a degree of desulfurization of 72.4 wt %, dearomatization of 79.31 wt % were determined [103, 104].

Combining the hydrotreating method with ion-liquid extraction purification makes it possible to obtain practically completely dearomatized diesel fuel containing only 130 ppm of sulfur compounds [105].

The cycle of studies carried out by the author also revealed the possibility of ion-liquid extraction purification of kerosene fractions with a boiling point of 136–240°C, 145–250°C and 185–250°C with an aromatic hydrocarbon content of 12.0; 16.5 and 17.0 wt%, respectively, using ionic-liquid compositions based on acetic acid as a selective solvent [106–107]. Extraction purification of kerosene samples showed that at a mass ratio of ionic liquid to feedstock equal to 2.5:1.0, an extraction temperature of 22–25°C, and a contact time of the components of 120 min, the residual content of aromatic hydrocarbons in the purified oil fraction with a yield of 81.2–86.4% of the mass made up just 1.0–2.0% wt.

The possibility of regeneration of ionic liquids - N-methylpyrrolidone, as well as morphoformate, used as an extractant in the

purification of various oil fractions and reuse without a significant decrease in efficiency, as well as the simplicity of the process, clearly

demonstrated the advantage of ion-liquid extraction purification of oil fractions [99, 110].

Conclusion

The volume of research in the field of liquid-liquid extraction purification is growing day by day, and this review is just a short list of works, the analysis of which allows us to speak about the feasibility and prospects of the method

of extraction purification of petroleum fractions using ionic liquids as a selective, "green" solvent to obtain fuels and oils for various purposes with improved indices.

References

1. Samadova F.I. Theoretical basis of petroleum oil production processes. Baku: Elm Publ., 1992, 180 p. (In Azerb.)
2. Sergienko S.R. Essay on the development of chemistry and oil refining. Moscow: USSR Academy of Sciences. 1955. 283 p.
3. Gaile A.A., Somov V.E., Zhalishchevsky G.D. Selective solvents. Separation and purification of hydrocarbon-containing raw materials. Moscow: Himizdat Publ., 2008, 736 p. (In Russian).
4. Gaile, A.A., Somov V.E. Sulfolan. Preparation, properties and use as a selective solvent. Moscow: Himizdat Publ., 2014, 392 p.
5. Gaile A.A., Kolesov V.V., Chistyakov V.N. Low-tonnage processing of oil, gas and gas condensate. Moscow: Himizdat Publ., 2010, 336 p.
6. Gaile, A.A., Somov V.E., Kameshkov A.V. Processes of separation and purification of oil and gas processing products. Moscow: Himizdat Publ., 2018, 432 p.
7. Gaile A.A., Zhalishchevsky G.D., Semenov L.V. Extraction purification of straight-run diesel fractions from organosulfur compounds and aromatic hydrocarbons. *Oil Processing and Petrochemistry*. 2004, no. 1, pp. 23-27. (In Russian).
8. Gaile A.A., Somov V.E., Zhalishchevsky G.D. selective solvents. Separation and purification of hydrocarbon-containing raw materials. St. Petersburg: Himizdat Publ., 2008, 736 p. (In Russian).
9. Benobidi B., Gaile A.A., Zhiganova A.G., Kuzichkin N.V., Lisitsin N.V. Selectivity of solvents with respect to arenes with different numbers of aromatic rings. *Oil Processing and Petrochemistry*. 2015, no. 12, pp. 15-18. (In Russian).
10. Krasnogorskaya N.N., Gabdikeyev A.R., Grushevenko A.E. Extraction of medium oil fractions. Moscow: Chemistry Publ., 1989, 72 p.
11. Kolbin, V.A., Dezortsev, S.V., Telyashev, E.G. Extraction Upgrading of a Heavy Component of Diesel Fuel with N-Methylpyrrolidone. *Bashkirskij himicheskij zhurnal* 2016, vol. 23, No.1, pp. 3-6. (In Russian).
12. Vereshchagin A.V. Gaile A.A., Klementiev V.N. Extraction purification of heavy vacuum gas oil from the AVT-2 unit "According to Kirishinefteorgsintez" with N-methylpyrrolidone and the N-methylpyrrolidone-undecane fraction extraction system. *Oil Processing and Petrochemistry*. 2018, no. 9, pp.10-15. (In Russian).
13. Vereshchagin A.V., Gaile A.A., Klement'ev V.N., Lazunenko F.A. Extraction purification of light vacuum gas oil from the AVT-2 unit of Kirishinefteorgsintez LLC with N-methylpyrrolidone. *Chemistry and Chemical Technology*. 2017, no. 40, pp. 69-77. (In Russian).
14. Lyapina, G.N. Marchenko G.N., Parfenova M.A. Identification of organosulfur compounds isolated by dimethylformamide from Arkhangelsk oil.

- Bashkirskij himicheskij zhurnal*. 2007, vol. 14, no.1, pp. 55-61. (In Russian).
15. Pugacheva D.A., Glebov M.B. Study of the properties of aprotic ionic liquids by molecular dynamics. *Journal Advances in Chemistry and Chemical Technology*. 2018, vol. 32, pp. 20-22. (In Russian).
 16. Sheldon R. Catalytic reactions in ionic liquids. *Chem. Commun.*, 2001, iss.23, pp. 2397-2407.
 17. Azizov A.H. Preparation methods and solvent properties of low temperature ionic liquids. *Processes of petrochemical and oil refining*, 2002, no. 1 (8), pp. 90-115.
 18. Azizov A.H. Low temperature ionic liquids in organic and petrochemical synthesis. *Processes of petrochemical and oil refining*. 2002, no. 2 (9).pp. 25-48.
 19. Wasserscheid P., Welton T. *Ionic Liquids in Synthesis* (2nd Edition) Wiley – VCH, Weinheim 2007, 355 p.
 20. Pletnev I.V., Smirnova S.V., Khachatryan K.S., Zernov V.V. Application of ionic liquids in extraction. *Russian Journal of General Chemistry*. 2004, vol. 58, no. 6, pp. 51-58.
 21. Jochen E., Wasserscheid P., Andreas J. Deep desulfurization of oil refinery streams by extraction with ionic liquids. *Green Chem*. 2004, vol. 6, no. 7, pp. 316-322.
 22. Atanassova M. Solvent extraction chemistry in ionic liquids: An overview of f-ions. *Journal of Molecular Liquids*, 2021, vol. 343, pp. 117-130.
 23. Swatloski R.P., Spear S.K., Holbrey J.D., Rogers R.D. Dissolution of Cellose with Ionic Liquids. *Journal of the American Chemical Society*, 2002, no. 124/18, pp. 4974-4975.
 24. Paucar N.E., Kiggins P., Blad B. Ionic liquids for the removal of sulfur and nitrogen compounds in fuels: a review. *Environmental Chemistry Letters*, 2021, vol. 19, pp. 1205–1228.
 25. Wilkes J.S. A short history of ionic liquids—from molten salts to neoteric solvents. *Green Chem*. 2002, vol. 4, pp. 73-80.
 26. Dyson P.J. Review: Synthesis of organometallics and catalytic hydrogenations in ionic liquids. *Appl. Organometal Chem*. 2002, vol. 16, pp. 495-500.
 27. Sheldon R. Catalytic reactions in ionic liquids. *Chem. Commun*. 2001, iss. 23, pp. 2399-2407.
 28. Fernández J.F., Neumann J., Thöming J. Regeneration, Recovery and Removal of Ionic Liquids. *Current Organic Chemistry*, 2011, vol. 15, pp. 1992-2014
 29. Zhou J., Sui H., Jia Z. et.al. Recovery and purification of ionic liquids from solutions: a review. *RSC Adv.*, 2018, no. 8, pp. 328-332.
 30. Brennecke, J.F., Maginn, E.J. Ionic liquids: Innovative fluids for chemical processing. *ICChE Journal*, 2001, vol. 47, no. 11, pp. 2384–2389.
 31. Farlane J.Mc., Ridenour W.B., Luo H. Room temperature ionic liquids for separating organics from produced water. *Separation Science and Technology*, 2005, vol. 40(6), pp. 1245–1265.
 32. Liu, J.F., Jonsson, J.A., Jiang, G.B. Application of ionic liquids in analytical chemistry *Trends in Analytical Chemistry*, 2005, vol. 24(1), pp. 20–27.
 33. Chaumont A., Schurhammer R., Wipff G. Aqueous interfaces with hydrophobic room-temperature ionic liquids: A molecular dynamics study. *The Journal of Physical Chemistry*, 2005, vol. 109 (40), pp.18964–18973.
 34. Fortunato R., Gonzalez-Munoz M.J., Kubasiewicz M. Liquid membranes using ionic liquids: the influence of water on solute transport. *Journal of Membrane Science*, 2005, vol. 249(1-2), pp.153–162.
 35. Dai S., Ju Y., Barnes C. Solvent extraction of strontium nitrate by a crown ether using roomtemperature ionic liquids. *Journal of Chemical Society, Dalton Transactions*, 1999, iss. 8, pp. 1201–1202.
 36. Xu Y., Zhou J., Zhou T. Extraction joined with adsorption and catalytic oxidation of dibenzothiophene with commercially available tungsten carbide. *Key Engineering Materials*, 2014, vol. 575-576, p. 539–542.
 37. Sayar N., Filiz M., Sayar A.A. Extraction of Zn(II) from aqueous hydrochloric acid solutions into Alamine 336-m-xylene systems. Modeling considerations to

- predict optimum operational conditions. *Hydrometallurgy*, 2007, vol. 86(1), pp. 27–36.
38. Nockemann P., Thijs B., Pittois S. Task-specific ionic liquid for solubilizing metal oxides. *The Journal of Physical Chemistry B*, 2006, vol. 110(42), pp. 20978–20992.
39. Huddleston J.G., Rogers R.D. Room temperature ionic liquids as novel media for ‘clean’ liquidliquid extraction. *Chemical Communications*, 1998, iss. 16, pp. 1765–1766.
40. Meindersma G.W., Podt A.J., Haan A.B. Ternary liquid- liquid equilibria for mixtures of an aromatic + an aliphatic hydrocarbon + 4-methyl-N-butylpyridinium tetrafluoroborate. *Journal of Chemical & Engineering Data*, 2006, vol. 51(5), pp.1814– 1819.
41. Meindersma G.W., Podt A.J., Haan A.B. Ternary liquid-liquid equilibria for mixtures of toluene + n-heptane + an ionic liquid. *Fluid Phase Equilibria*, 2006, vol. 247(1-2), pp. 158–168.
42. Branco, L.C., Crespo, J.G., Afonso, C.A. Highly selective transport of organic compounds by using supported liquid membranes based on ionic liquids. *Angewandte Chemie International Edition*, 2002, vol. 41(15), pp. 2771–2773.
43. Plechkova N.V., Seddon K.R. Applications of ionic liquids in the chemical industry. *Chemical Society Reviews*, 2008, vol. 37(1), pp.123-150.
44. Seidova S.A. Extraction methods for cleaning motor fuel *ChemChemTech*. 2019, no.10, pp. 30-39.
45. Dharaskar S.A. Ionic Liquids (A Review): The Green Solvents for Petroleum and Hydrocarbon Industries. *Research Journal of Chemical Sciences*, 2012, vol. 2(8), pp. 80-85.
46. Swapnil D., Mahesh V., Kailas W. Deep removal of sulfur from model liquid fuels using 1-Butyl-3-Methylimidazolium Chloride. *Procedia Engineering*, 2013, vol. 51, pp. 416 – 422.
47. Swapnil D., Kailas W., Mahesh V. Ionic liquids: environmentally benign solvent for extractive deep-desulfurization of liquid fuels. *Journal of Modern Chemistry & Chemical Technology*, 2014, vol. 5(3), pp. 28-34.
48. Swapnil A.D., Mahesh N.V., Diwakar Z.S. Synthesis, characterization and application of 1-butyl-3-methylimidazolium chloride as green material for extractive desulfurization of liquid fuel. *The Scientific World Journal*, 2013, vol.9, iss.4, pp. 578-587.
49. Bosmann A., Datsevich L., Jess A. Deep desulfurization of diesel fuel by extraction with ionic liquids. *Chemical Communications*, 2001, iss. 23, pp. 2494–2495.
50. Esser J., Wasserscheid P., Jess A. Deep desulfurization of oil refinery streams by extraction with ionic liquids. *Green Chemistry*, 2004, vol. 6(7), pp. 316–322.
51. Kuhlmann E., Haumann M., Jess A. et.al. Ionic liquids in refinery desulfurization: comparison between biphasic and supported ionic liquid phase suspension processes. *ChemSusChem*, 2009, vol. 2(10), pp. 969–977.
52. Xuemei C. Yufeng H., Jiguang L. et.al. Desulfurization of diesel fuel by extraction with [BF₄]⁻-based ionic liquids. *Chinese Journal of Chemical Engineering*, 2008, vol. (16), pp. 881-884.
53. Swapnil A., Dharaskar K.L., Wasewar M.N. Extractive desulfurization of liquid fuels by energy efficient green thiazolium based ionic liquids. *Industrial & Engineering Chemistry Research*, 2014, vol. 53(51), pp. 19845–19854.
54. Gao H., Xing J., Li Y. et.al. Desulfurization of diesel fuel by extraction with Lewis-Acidic ionic liquid. *Journal separation Science and Technology*, 2009, vol. 44, pp. 971-982.
55. Cheng S.S., Yen T.F. Use of ionic liquids as phase-transfer catalysis for deep oxygenative desulfurization. *Energy & Fuels*, 2008, vol. 22(2), pp. 1400–1401.
56. Chi Y., Li C., Jiao Q. et.al. Desulfurization by oxidation combined with extraction using acidic room temperature ionic liquids. *Green Chemistry*, 2011, vol.1 3(5), pp. 1224–1229.

57. Fang D., Wang Q., Liu Y. et.al. High-efficient oxidation-extraction desulfurization process by ionic liquid 1-butyl-3-methyl-imidazolium trifluoroacetic acid. *Energy & Fuels*, 2014, vol. 28(10), pp. 6677–6682.
58. Liang W., Zhang S., Li H. et.al. Oxidative desulfurization of simulated gasoline catalyzed by acetic acid-based ionic liquids at room temperature. *Fuel Processing Technology*, 2013, vol.109, pp. 27–31.
59. Lu H., Wang S., Deng C. et.al. Oxidative desulfurization of model diesel via dual activation by aprotic ionic liquid. *Journal of Hazardous Materials*. 2014, vol. 279, pp. 220–225.
60. Wang, J., Zhao D., Li K. Oxidative desulfurization of dibenzothiophene using ozone and hydrogen peroxide in ionic liquid. *Energy & Fuels*, 2010, vol. 24(4), pp. 2527–2529.
61. Wang T., Zhao D., Sun Z., et.al. One-step oxidative desulfurization of dibenzothiophene using cyclohexanone peroxide in N-alkyl-imidazolium-based ionic liquid extraction systems. *Petroleum Science and Technology*, 2011, vol. 30(4), pp. 385–392.
62. Zhao D., Liu R., Wang J. et.al. Photochemical oxidation-ionic liquid extraction coupling technique in deep desulfurization of light oil. *Energy & Fuels*, 2008, vol. 22(2), pp.1100–1103.
63. Li F., Liu R., Wen J., et.al. Desulfurization of dibenzothiophene by -chemical oxidation and solvent extraction with $\text{Me}_3\text{NCH}_2\text{C}_6\text{H}_5\text{Cl}\cdot 2\text{ZnCl}_2$ ionic liquid. *Green Chemistry*, 2009, vol. 11(6), pp. 883–888.
64. Zhao D., Sun Z., Li F. et.al. Oxidative desulfurization of thiophene catalyzed by $(\text{C}_4\text{H}_9)_4\text{NBr}\cdot 2\text{C}_6\text{H}_{11}\text{NO}$ coordinated ionic liquid. *Energy & Fuels*, 2008, vol. 22(5), pp. 3065–3069.
65. Li F., Kou C., Sun Z., et.al. Deep extractive and oxidative desulfurization of dibenzothiophene with $\text{C}_5\text{H}_9\text{NO}\cdot\text{SnCl}_2$ coordinated ionic liquid. *Journal of Hazardous materials*, 2012, vol. 205-206, pp. 164–170
66. Jiang W., Zhu W., Chang Y. et.al. Oxidation of aromatic sulfur compounds catalyzed by organic hexacyanoferrates in ionic liquids with a low concentration of H_2O_2 as an oxidant. *Energy & Fuels*, 2014, vol. 28(4), pp. 2754–2760.
67. Taha M.F., Atikah N., Chong F.K., Shaharun M.S. Oxidative desulfurization of dibenzothiophene from model oil using ionic liquids as extracting agent. *AIP Conference Proceedings*, 2012, vol. 1482(1), pp. 258-262.
68. Zhao D., Wang Y., Duan E. Oxidative desulfurization of fuel oil by pyridinium-based ionic liquids. *Molecules*, 2009, vol. 14(11), pp. 4351–4357.
69. Li H., He L., Lu J., et.al. Phosphotungstic acid in ionic liquids at room temperature *Energy Fuels*, 2009, vol. 23(3), pp.1354-1357.
70. Rodriguez-Cabo B., Rodriguez H., Rodil E., Arce A., Soto A. Extractive and oxidative-extractive desulfurization of fuels with ionic liquids. *Fuel*, 2014, vol. 117, pp. 882-889.
71. Xiaochun C., Hansong G., Ahmed A.A. et.al. Bronsted - Lewis acidic ionic liquids and application in oxidative desulfurization of diesel fuel. *Energy & Fuels*, 2015, vol. 29 (5), pp. 2998–3003.
72. Ma C., Dai B., Liu P., et.al. Deep oxidative desulfurization of model fuel using ozone generated by dielectric barrier discharge plasma combined with ionic liquid extraction *Journal of Industrial and Engineering Chemistry*, 2014, vol. 20(5), pp. 2769–2774.
73. Mahdieh S., Babak M., Hamid R. et.al. Oxidative Desulfurization of Diesel Fuel Using a Brønsted Acidic Ionic Liquid Supported on Silica Gel. *Energy & Fuels*, 2017, vol. 31(9), pp. 10196–10205.
74. Xu J., Zhao S., Chen W. et.al. Highly efficient extraction and oxidative desulfurization system using $\text{Na}_7\text{H}_2\text{LaW}_{10}\text{O}_{36}\cdot 32\text{H}_2\text{O}$ in $[\text{bmim}]\text{BF}_4$ at room temperature. *Chemistry a European Journal*, 2012, vol. 18(15), pp. 4775–4781.
75. Liu D., Gui J., Liu D., et.al. Deep

- oxidative desulfurization of real diesel catalyzed by Na_2WO_4 in ionic liquid. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 2013, vol. 35(1), pp.1–8.
76. Zhang B., Jiang Z., Li J. et.al. Catalytic oxidation of thiophene and its derivatives via dual activation for ultra-deep desulfurization of fuels. *Journal of Catalysis*, 2012, vol. 287, pp. 5–12.
77. Ge J., Zhou Y., Yang Y. et.al. Catalytic oxidative desulfurization of gasoline using vanadium (V)-substituted polyoxometalate/ H_2O_2 /ionic liquid emulsion system. *China Petroleum Processing and Petrochemical Technology*, 2012, vol. 14(1), pp. 25–31.
78. Ge J., Zhou Y., Yang Y., et.al. The deep oxidative desulfurization of fuels using $\text{Na}_2\text{WO}_4 \cdot 2\text{H}_2\text{O}$ in acidic ionic liquids. *Petroleum Science and Technology*, 2013, vol. 31(21), pp. 2280–2286.
79. Zhou M., Meng W., Li Y. et.al. Extractive and catalytic oxidative desulfurization of gasoline by methyltrioxorhenium in ionic liquids. *Energy & Fuels*. 2014, vol. 28(1), pp. 516–521.
80. Nie Y., Li C., Sun A. et.al. Extractive desulfurization of gasoline using imidazolium-based phosphoric ionic liquids. *Energy & Fuels*, 2006, vol. 20 (5), pp. 2083–2087.
81. Anugwom I., Maki-Arvela P., Salmi T., Mikkola J.P. Ionic liquid assisted extraction of nitrogen and sulphur-containing air pollutants from model oil and regeneration of the spent ionic liquid. *J. Environ. Prot.* 2011, vol. 2, no. 6, pp. 796–802.
82. Kaisy G. M. J., Mutalib M. I., Bustam M. A. and etc. Liquid-Liquid extraction of aromatics and sulfur compounds from base oil using ionic liquids. *J. Environ. Chem. Eng.*, 2016, vol. 4, no. 4, pp. 4786–4793.
83. Wang Y. Z., Sun X.Y., Liu Y. P. Removal of naphthenic acids from a diesel fuel by esterification. *Energy & fuels*, 2007, vol. 21, pp. 941-943
84. Kamarudin H., Mutalib M. and etc. Extraction of Naphthenic Acids from Liquid Hydrocarbon using Imidazolium Ionic Liquids. *International Conference on Environment Science and Engineering*, 2012, vol. 32, pp.17-23.
85. Azizov A.G., Huseynova A.D., Ibragimova M.D. Application of ionic liquids in the process of obtaining high-quality environmentally friendly motor gasolines. *Technical and Physical Problems of Engineering*. 2007, no. 6, pp. 25.
86. Ibragimova M.D., Azizov A.G., Guseynova A.D. etc. Study of the process of selective purification of gasoline reforming by morphoformate ionic liquid *Processes of Petrochemistry and Oil Refining*. 2011, vol. 12, no. 3(47), pp. 189-194.
87. Huseynov H.J. Selective purification of transformer oil by the method of ionic liquid extractive purification. *Technical and Physical Problems of Engineering*, 2021, vol. 13, iss. 49, no. 4, pp.135-13.
88. Ibragimova M.D., Nagiyev V.A., Guseynov G.J. Ionic liquid N-methylpyrrolidone acetate as an extractant in the processes of selective purification of transformer oil distillate. *Oil Processing and Petrochemistry*. 2019, no. 5, pp. 45-48. (In Russian).
89. Ibragimova M.D., Azizov A.G., Nagiev V.A. Extraction purification of petroleum distillate with a viscosity of $18.0 \text{ mm}^2/\text{s}$ at 100°C with an ion-liquid composition based on aniline and morpholin. *Oil Processing and Petrochemistry*. 2014, № 9, c. 36-38. (In Russian).
90. Ibragimova M.D., Abbasov V.M., Nagiev V.A. Obtaining base engine oil by extraction purification of oil distillates with ionic liquids. *World of Oil Products. Bulletin of oil companies*. 2017, no. 4, pp. 21-26. (In Russian).
91. Samedova F.I., Ibragimova M.D., Azizov A.G. Selection of optimal conditions for selective purification of oil distillate using morpholinformate as a selective solvent. *Oil Processing and Petrochemistry*. 2010, no. 12, pp. 35-38. (In Russian).
92. Ibragimova M.D., Mamedov R.B.,

- Samedova F.I. Analysis of the results of studies on the selective purification of oil fractions of oil with furfural and ionic liquid. *World of Oil Products. Bulletin of oil companies*. 2011, no. 1, pp. 15-17. (In Russian).
93. Ibragimova M.D., Samedova F.I., Azizov A.G. et al. Study of the structural-group composition of the raffinate and extract from the process of selective ion-liquid purification of the oil fraction. *Processes of Petrochemistry and Oil Refining*, 2011, no. 1(45), pp. 10-14.
94. Ibragimova M.D., Azizov A.G., Sultanov S.A. Selective purification of diesel fuel using an ion-liquid composition based on formic acid and morpholine as an extractant *World of Oil Products. Bulletin of oil companies*. 2009, no. 3, pp. 20-22. (In Russian).
95. Ibragimova M.D., Azizov A.G., Gasanova R.Z. Purification of petroleum distillates by ion-liquid compositions. *Azerbaijan oil industry*. 2009, no. 10, pp. 42.
96. Ibragimova M.D., Abbasov V.M., Seidova S.A., Guseynov G.J. Ion-liquid extraction purification of naftalan oil. *Bulletin of the Voronezh University, Chemistry series*. 2021, no. 2, pp. 5-13. (In Russian).
97. Ibragimova M.D., Abbasov V.M., Alieva S.G. Obtaining the basis of hydraulic oil AMG-10 from Azerbaijani oils using ionic liquids as an extractant *Oil Processing and Petrochemistry*, 2016, no.12, pp. 36-40. (In Russian).
98. Ibragimova M.D., Abbasov V.A., Seidova S.A., Huseynov G.J. Study of the process of regeneration of the ion-liquid composition of N-methylpyrrolidone acetate from the extract solution of selective purification of distillate isolated from Balakhani oil. *Oil Processing and Petrochemistry*. 2017, no. 12, pp. 41-45. (In Russian).
99. Seidova S.A., Ibragimova M.D., Huseynov G.D. and others. Environmentally friendly diesel fuel obtained by ion-liquid extraction purification. *Journal of Baku Engineering University, Chemistry and Biology*, 2017, no. 2, pp. 98-105.
100. Seyidova S.A. Justification of high efficiency of ionic liquid in the process of extraction cleaning of diesel fraction. *Processes of Petrochemistry and Oil Refining*, 2019, no. 3, pp. 291-296.
101. Ibragimova M.D., Seidova S.A., Huseynov G.D. et al. Ion-liquid extraction purification of diesel fractions with different content of aromatic and sulfur compounds. *Vestnik BSU. Series: Chemistry. Biology*. 2019, no.4, pp. 26-32.
102. Ibrahimova M.J., S.A.Seyidova, Huseynov H.J. et.al. Extraction ennoblement of diesel fuel and the close-cut fractions on its basis. *Azerbaijan Chemical Journal*, 2018, no. 4, pp. 60-68.
103. Ibragimova M.D., Seidova S.A., Huseynov G.J. et al. Study of the structural-group composition of the raffinate and extract obtained by dearomatization of a mixture of straight-run diesel fraction with products of secondary oil refining. *Oil Processing and Petrochemistry*, 2018, no. 8, pp. 14-20. (In Russian).
104. Ibrahimova M.J., Abbasov V.M., Seyidova S.A., Huseynov H.J. Group hydrocarbon composition of the mixture of straight-run diesel fraction with light gas oil coking before and after purification of ionic liquid extraction. *Processes of Petrochemistry and Oil-Refining*, 2019, no. 4, pp. 433-439.
105. Ibragimova M.D., Improvement of quality of the hydropurified diesel fuel by ion-liquid extraction. *International Journal of Scientific Engineering and Applied Science (IJSEAS)*, 2018, vol. 4 (5), pp. 91-94.
106. Ibrahimova M.J., Mamedova T.A., Guseinov G.J., Seidova S.A. et.al. Investigation of dearomatization process of the kerosene fraction by a method of ion-liquid fraction. *Chemical Problems*, 2019, no. 4 (17), pp. 576-586.
107. Huseynov H.J. Study dearomatization of kerosene by IR and UV spectral analysis. *Modern Physics Letters B*, 2021, vol. 35, no.12, pp. 2150505(1-7).
108. Huseynov H.J., Ibragimova M.J.,

- Gasanova R.Z. Ionic liquid based on diethylamine and formic acid in the process of selective purification of oil distillates of various viscosities. *Modern Physics Letters B*, 2022, vol.36, no. 4, p. 2150505.
109. Abbasov V.M., Ibragimova M.J., Huseynov H.J. Selective Treatment Methods of the Refinery and Petrochemical Products by Solvent Extraction with Ionic Liquids. *Himija v interesah ustojchivogo razvitija*. 2019, vol. 27, pp.123–133. (In Russian).
110. Ibragimova M.D., Azizov A.G., Mamedov R.B. Regeneration of the morpholinoformate ion-liquid extractant from the extract solution of the selective purification of the oil fraction. *World of Oil Products*. 2012, no. 9, pp.18-20. (In Russian).

НЕФТ ФРАКСИЯЛАРИНИН ИОН-МАЙЕ ЭКСТРАКСИЯ ÜSULU İLƏ TƏMİZLƏNMƏSİ

H.C. Hüseynov

*AMEA-nın akad. Y.H. Məmmədəliyev adına Neft-Kimya Prosesləri İnstitutu,
AZ 1025 Bakı ş., Xocalı pr.,30; e-mail: huseyn-1978@mail.ru*

Xülasə: Hal-hazırda texnikanın sürətli inkişafı ilə yanaşı müxtəlif təyinatlı yağ və yanacaqların keyfiyyət göstəricilərinə qoyulan tələbatın artması ilə əlaqədar neft fraksiyalarının maye-maye ekstraksiya üsulu ilə təmizlənməsi alternativ bir üsul kimi tədqiqatçıların diqqət mərkəzindədir və bu üsulun effektivliyi götürülmüş distillatın tərkibində aromatik karbohidrogenlərin, kükürlü və qətranvarı birləşmələrin miqdarı ilə müəyyən olunur. Təqdim olunmuş icmal məqalədə müxtəlif təyinatlı neft fraksiyalarının ənənəvi olaraq tətbiq olunan həlledicilər ilə yanaşı ekoloji zərərsiz ion maye tərkiblərdən seçici həlledici kimi istifadə etməklə ekstraksiya üsulu ilə təmizlənməsinə dair çap olunmuş işlər nəzərdən keçirilmiş və ion maye ekstraksiya üsulunun effektiv olduğu açıqlanmışdır. Məqalədə ion maye ekstraksiya prosesinin oksidləşdirici iştirakında təmizlənmə üsulu ilə birgə tətbiqinə dair tədqiqatlar da şərh olunmuşdur. Bundan əlavə icmalda Azərbaycan Milli Elmlər Akademiyasının Neft-Kimya Prosesləri İnstitutunda müxtəlif neft distillatlarının - transformator yağ distillatı, katalitik krekinq və riforminq benzini, AMG-10 hidravlik maye distillatı, naftalan nefti, dizel yanacağı distillatı və müxtəlif özlülüyə malik neft fraksiyalarının ion ekstraksiya üsulu ilə təmizlənməsi üzrə aparılan tədqiqatların nəticələri öz əksini tapmış və kation-anion fraqmentinə görə fərqlənən ion mayələrinin (morfolformat, anilinformat, N-metilpirolidon asetat və s.) seçici həlledici kimi istifadəsi ilə keyfiyyətli neft məhsullarının alınmasının mümkünlüyü göstərilmişdir.

Açar sözlər: seçici həlledici, ekstraksiya üsulu ilə təmizləmə, ion mayesi, rafinat, ekstragent.

ИОННО-ЖИДКОСТНАЯ ЭКСТРАКЦИОННАЯ ОЧИСТКА НЕФТЯНЫХ ФРАКЦИЙ

Г.Д. Гусейнов

*Институт Нефтехимических Процессов им. Академика Ю.Г. Мамедалиева
Национальной Академии Наук Азербайджана,
AZ 1025, Баку, пр.Ходжалы,30 e-mail: huseyn-1978@mail.ru*

Аннотация: Процесс экстракционной очистки на сегодняшний день интенсивно изучается и имеет большое будущее в качестве альтернативного метода очистки нефтяных фракций, так

как с развитием техники и ростом объёма потребления топлив и масел наблюдается ужесточение требований к их качественным показателям. При этом особое внимание уделяется содержанию в их составе ароматических углеводородов, серосодержащих и смолистых соединений. В представленном обзоре рассмотрены результаты исследований экстракционной очистки различных фракций нефти с использованием в качестве экстрагента как традиционных, так и «зеленых» растворителей – ионных жидкостей, показывающих на эффективность процесса ионно-жидкостной экстракционной очистки. В статье описаны и исследования по комбинированию процесса ионно-жидкостной экстракции с окислительным методом очистки. Приведены результаты исследований, проводимых в Институте Нефтехимических процессов Национальной АН Азербайджана по ионно-жидкостной экстракционной очистке нефтяных дистиллятов различного назначения, в частности, дистиллята трансформаторного масла, бензина каталитического крекинга и риформинга, гидравлической жидкости АМГ-10, нафталанской нефти, дизельного топлива, а также дистиллятов масляных фракций с различным значением вязкости. Показана возможность получения качественных нефтяных продуктов при использовании в качестве избирательного растворителя ионных жидкостей (морфолинформиата, анилинформиата, N-метилпирролидонацетата и др.), отличающихся катионно-анионными фрагментами.

Ключевые слова: избирательный растворитель, экстракционная очистка, ионная жидкость, рафинат, экстрагент