

Article

Processing of High-Metal Heavy Residues in Resid Fluid Catalytic Cracking: Industrial Experience and Optimization Approaches

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Abstract

The article addresses the challenges associated with processing heavy petroleum feedstock with high metal content in the Resid Fluid Catalytic Cracking (RFCC) unit of the Atyrau Oil Refinery. Elevated concentrations of iron, nickel, and vanadium were shown to cause rapid catalyst deactivation, deterioration of fluidization properties, and instability of the reactor–regenerator system. Analysis of industrial data revealed that the iron content in the feed significantly exceeded the design value, reaching 150 mg/kg, which resulted in increased catalyst consumption and reduced process efficiency. The industrial application of metal-passivating chemical reagents reduced the iron content by 48–62%, thereby improving catalyst performance and increasing the yield of target products. However, the use of these reagents is associated with high operating costs. Therefore, additional demetallization methods were investigated, particularly solvent deasphalting. Experimental studies on a pilot unit demonstrated that deasphalting reduced the concentrations of Fe, Ni, and V by 7–9 times and produced a deasphalted oil yield of 81.1 wt.%. The obtained product exhibited low Conradson carbon residue and improved quality, making it suitable as a feed component for catalytic cracking. An integrated approach combining chemical treatment and solvent deasphalting is proposed to improve refining efficiency and catalyst stability.

Keywords: oil refining; heavy oil residue; catalytic cracking; metals; reagent; demetallization; deasphaltation



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1. Introduction

Industrial processing of hydrocarbon feedstock at modern oil refineries is carried out through complex multistage physical and chemical processes at separate or combined large-tonnage technological complexes designed to produce various components or ranges of commercial petroleum products [1].

Currently, there is a problem in processing feedstock with a high metal content, which is caused by the following factors:

- Due to the depletion of light oil reserves, there is a transition to the processing of heavy oils, characterized by high viscosity, density, and metal, sulfur, and nitrogen content, which causes difficulties with their extraction, transportation, and processing;
- The desire to deepen the processing of heavy oil residues, which contain the majority of metals and hetero-organic compounds, is limited by the need to include additional stages;
- Feedstock must be processed intricately and all of its precious components must be used wisely [2].

Although numerous studies have investigated solvent deasphalting and metal passivation in RFCC units separately, limited attention has been paid to the integrated application of these technologies for processing high-metal heavy residues under industrial refinery conditions. In particular, there is a lack of studies evaluating the combined effects of chemical metal passivation and solvent deasphalting on catalyst performance, feedstock quality, and refinery economics. Although solvent deasphalting and metal passivation processes in RFCC (residual feedstock catalytic cracking) units have been repeatedly studied separately, insufficient attention has been paid to the integrated application of these technologies for processing heavy residues with high metal content under industrial refinery conditions. Specifically, there are no studies evaluating the combined impact of chemical metal passivation and solvent deasphalting on catalyst performance, feedstock quality, and refining economics.

Let us consider the experience of processing such feedstock at one of Kazakhstan's oil refineries. For the first time in the history of Kazakhstan's oil refining, a Resid Fluid Catalytic Cracking (RFCC) unit was built and put into operation at the Atyrau Oil Refinery from 2010 to 2018, the purpose of which is to convert fuel oil, vacuum gas oil, and heavy coking gas oil into high-value-added products, which include gasoline of various brands, jet fuels, diesel fuels, and liquefied petroleum gas [3,4]. The uniqueness of this unit lies in the fact that two regenerators are used in this process. This makes it possible to significantly reduce unit operating costs and increase the efficiency of the feedstock processing process at this plant [5].

The RFCC unit operates in maximum gasoline production mode using two different types of feedstock, designated as winter and summer options. When designing the catalytic cracking plant, the characteristics of the planned feedstock were taken into account, indicating that the maximum iron content should not exceed 5 mg/kg (Table 1).

Irreversible poisons of cracking catalysts include nickel, vanadium, and iron, which are components of crude oil, as well as calcium and sodium (usually due to problems during desalination). In addition, temporary poisons are coke, nitrogen and sulfur, which are removed in the regenerator or in the boiler before CO annealing [3].

During the operation of the catalytic cracking unit, rapid coking of the Axens catalyst was observed, causing it to turn bright red and resulting in the production staff facing the problem of overexpending the catalyst.

The data on the metal content in the feedstock processed at the RFCC catalytic cracking plant have been analyzed, which confirms the excess of the design data. For example, in February–March 2026, the iron content in the feedstock exceeded the planned values for the project by almost 30 times.

The statistics of variation in the iron content in the mixed feedstock at the catalytic cracking plant are shown in the graph (Figure 1), which shows an excess of iron, on average, up to 40 mg/kg, and in some cases, up to 150 mg/kg.

Table 1. Characteristics of the feedstock for the catalytic cracking plant.

Type	Units	Winter Version	Summer Version
Quantity	t/day	7238	6011
Specific gravity, g/cm ³		0.89	0.89
The true boiling point of the fraction	°C		
Dispersal of petroleum coke according to ASTM:	°C	328	357
5%		335	370
10%		343	384
30%		392	429
50%		456	479
70%		549	559
90%		840	830
95%		982	967
The end of the boil		1277	1254
Hydrogen content	wt. %	12.9	12.8
Sulfur	wt. %	0.7	0.74
Total nitrogen	mg/kg	1280	1540
Conradson carbon residue	wt. %	3.1	3.8
Nickel content	mg/kg	8.5	10.7
Vanadium content	mg/kg	10	12.6
Sodium content	mg/kg	2 max.	2 max.
Iron content	mg/kg	5 max.	5 max.

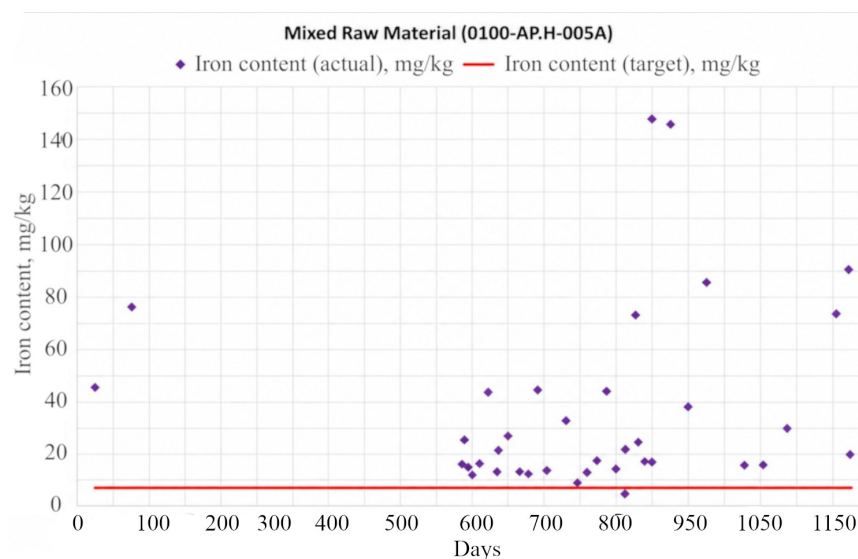


Figure 1. Iron content in the feedstock of the catalytic cracking plant. The presented data was collected up to 31 March 2026. Mixed feedstock (0100.AP.H-005A)—a stream of mixed petroleum feedstock entering the catalytic cracking unit (the code is the pipeline position number adopted at the Atyrau Oil Refinery).

The iron contained in the feedstock of catalytic cracking, which is a poison for the catalyst, destroys its matrix, leading to premature deactivation and destruction, which

increases its consumption and economic costs [6]. Failures in the operation of the reactor-regenerator unit were also recorded at the Atyrau refinery.

In order to reduce the iron content in fuel oil, one of the constituent components of the catalytic cracking feedstock, in 2026, the ELOU–AT-2 (Crude Desalter Unit) technological unit began using the reagents recommended by us, which are fed into the oil stream before the feed pumps and into the flushing water before the electric dehydrogenators. Figure 2 shows the scheme of industrial supply of iron absorbers Chimec 2533 and Chimec 2050.

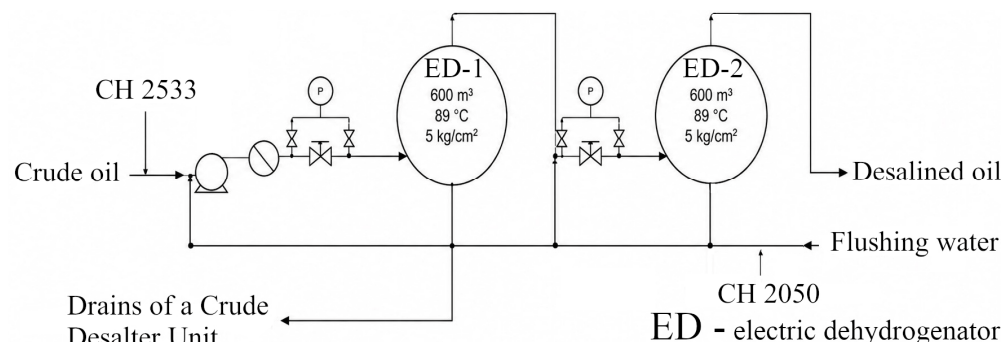


Figure 2. Reagent supply scheme for reducing iron content in feedstock.

Table 2 shows the data from the analytical control of the ELOU-AT-2 unit, from which a decrease in the iron content in the feedstock can be determined, in a percentage ratio from 48 to 62.

Table 2. The results of the analytical control on the iron content in the feedstock.

Date	Iron Content		
	In Oil Before ELOU, mg/dm ³	In Oil After ELOU, mg/dm ³	% Reduction in Iron Content
6 September 2025	17	9.5	56
15 September 2025	24	12.5	52
20 September 2025	14	7.5	54
25 September 2025	12.5	6.5	52
2 October 2025	24	12.5	52
7 November 2025	23.5	14.5	62
16 November 2025	15.5	7.5	48
20 November 2025	16.5	8.5	52
27 November 2025	16.5	9.5	58
4 December 2025	17.5	9.5	54
11 December 2025	15.5	8.5	52
18 December 2025	12.5	6.5	52
22 December 2025	9	4.5	50

Figure 3 shows the monthly results of oil analyses for iron content before and after feeding the metal absorber, which confirm the positive reduction effect: the average value before feeding the reagent was 18.37 mg/kg, and after feeding the reagent—10.67 mg/kg.

The removal of iron from crude oil also reduced the daily consumption of fresh catalyst at the catalytic cracking plant by an average of 6 tons per day (Figure 4). In addition, there was a decrease in the specific consumption of fresh catalyst by 2 kg per ton of feedstock (Figure 5).

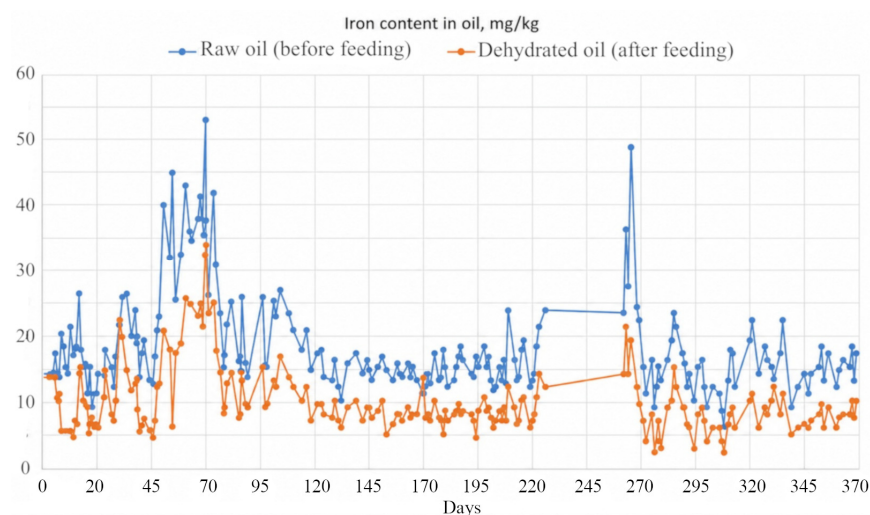


Figure 3. Iron content in crude oil before the supply of reagent Chimec 2533 (blue colour) and after the supply of reagent Chimec 2533 (orange line).

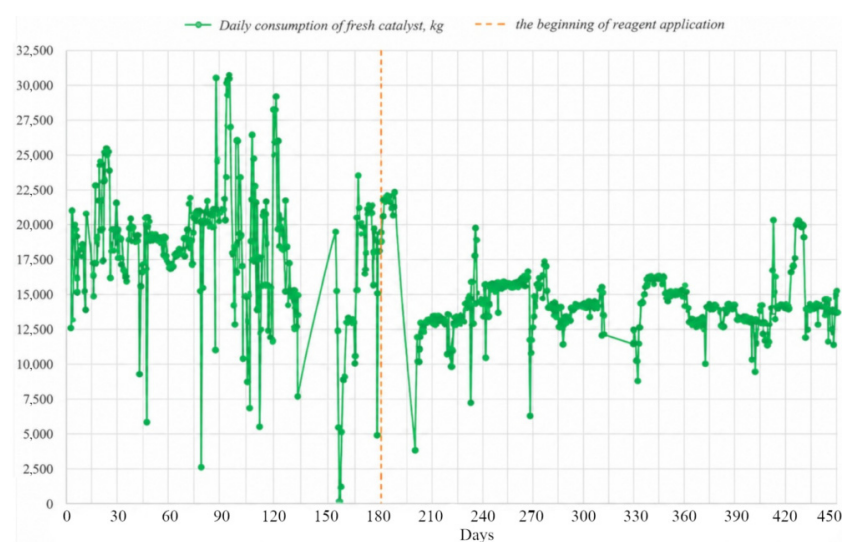


Figure 4. Daily consumption of fresh catalyst at the catalytic cracking plant (trial implementation).

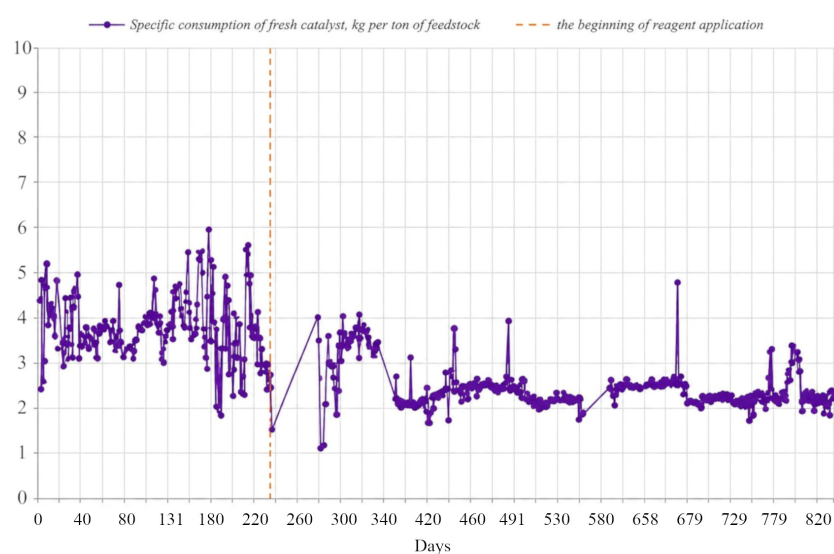


Figure 5. Specific consumption of fresh catalyst in a catalytic cracking plant (industrial application).

A decrease in the iron content in the feedstock of catalytic cracking also led to an improvement in the properties of the catalyst, and disruptions in the catalyst circulation and congestion in the reactor–regenerator unit system practically stopped. Table 3 shows data on the analysis of the iron content in the catalyst of the catalytic cracking unit from the reactor-regenerator unit.

Table 3. Results of analytical control of the iron content in the catalyst.

Date of the Analysis	Iron Content, wt. %	Date of the Analysis	Iron Content, wt. %	Date of the Analysis	Iron Content, wt. %
13 September 2025	0.45	15 December 2025	0.49	21 February 2026	0.59
18 September 2025	0.46	22 December 2025	0.5	28 February 2026	0.6
25 September 2025	0.47	29 December 2025	0.51	8 March 2026	0.62
1 November 2025	0.48	5 January 2026	0.51	15 March 2026	0.63
8 November 2025	0.49	12 January 2026	0.51	23 March 2026	0.64
15 November 2025	0.49	17 January 2026	0.52	29 March 2026	0.66
20 November 2025	0.49	24 January 2026	0.53	5 April 2026	0.65
27 November 2025	0.5	31 January 2026	0.53	12 April 2026	0.66
4 December 2025	0.52	7 February 2026	0.48	17 April 2026	0.67
8 December 2025	0.54	14 February 2026	0.57	22 April 2026	0.68

Having studied the material balance data of the catalytic cracking unit (Table 4), it can be noted that the total yield of the target products (gasoline + heavy gas oil) increased by about 2.5% by weight, while losses decreased by 1.3% and gas output by 0.4%, indicating a more complete conversion of feedstock into liquid fractions [7].

Table 4. Material balance of the catalytic cracking plant before and after the introduction of the iron absorbent.

Name	Before the Introduction of the Iron Absorber		After the Introduction of the Iron Absorber	
	Output, Weight %	Output, t/Year	Output, Weight %	Output, t/Year
Received:				
Feedstock of catalytic cracking	100.0	2,431,000	100.0	2,431,000
Received:				
Fuel gas	5.3	128,843	5.1	123,981
Light gas oil	12.4	301,444	12.4	301,444
Liquefied gas	18.1	440,011	18.1	440,011
Stable gasoline	52.8	1,283,568	54.9	1,334,619
Heavy gas oil	2.9	70,499	3.3	80,223
Filtered oil	4.4	106,964	3.7	89,947
Acidic gas in an amine solution	0.9	21,879	0.6	14,586
Losses	3.2	77,792	1.9	46,189

The use of the iron passivator decreased the rate of catalyst deactivation and improved the selectivity to liquid products.

Using an iron absorbent proved to be an effective solution, but it was also economically costly. For example, in 2025, 252 tons of Chimec 2533 reagent and 62.75 tons of Chimec 2050 reagent were purchased for a total amount of 3.63 million US dollars. In addition, the design indicators for the iron content have not been definitively achieved.

The high level of metals in petroleum feedstock necessitates the use of additional demetallization processes, the purpose of which is not only to improve the purification

of petroleum feedstock, the service life of catalysts, the efficiency of refining processes, and the quality of commodity products, but also to obtain metal concentrates, including heavy metals.

As a further effort to remove metals from petroleum feedstock and concentrate them, it is recommended to use the following:

- Physical methods [6];
- Chemical methods (visbreaking, coking, extraction, adsorption, adsorption-catalytic, hydrogenation processes) [8,9];
- Non-traditional methods (electrochemical method, exposure to microwave radiation, ultrasonic exposure) [10,11].

There are also industrial methods for demetallizing crude oil directly in the fields during preparation for transportation [12].

As a result of the use of heavy oil demetallization technologies, it is possible not only to significantly improve the quality of commercial oils for the production of the most valuable petroleum products, but also to increase the associated production of rare metal concentrates.

Demetallization of heavy oil feedstock is usually considered within the framework of general approaches to refining and processing heavy oils, ensuring improved quality and efficient use of the organic part of the oil feedstock [8]. In this regard, the removal of metals from heavy petroleum feedstock can be achieved to varying degrees as a result of destructive thermal and thermocatalytic processes, as well as non-destructive mass transfer processes [13].

The main advantages of thermal processes for processing heavy oil residues include lower capital investments and operating costs compared to catalytic processes, as well as their broad applicability, primarily in terms of coking and metal content of the processed feedstock. Their main disadvantage is the low quality of the liquid products produced.

Significantly higher yields and quality of distillate products are achieved in catalytic and hydrocatalytic processes [8]. Hydrogenation catalytic processes make it possible to refine heavy petroleum feedstock by demetallization, removal of heteroatomic compounds and saturation with hydrogen, while obtaining commercial motor fuels or high-quality feedstock for further processing. However, these processes are characterized by significant capital and operational costs associated with high consumption of catalyst and hydrogen [14].

Based on the experience of theoretical and experimental studies conducted at Atyrau Oil and Gas University, it is suggested that the problem of demetallization of oil and petroleum products should be solved by deasphalting using various organic solvents such as liquefied propane, normal alkanes up to C₈, petroleum ether, gasoline, and other light hydrocarbon fractions.

The literature [15] indicates that the processing of heavy crude oil requires a deeper understanding of the impact of elevated levels of undesirable compounds, such as acids or asphaltenes, and the processes involved in their reduction. In addition to the well-known problems of flowability and corrosion, there are also difficulties regarding crude oil compatibility and the precipitation of asphaltenes from mixtures, and several methods for testing asphaltene stability have been described.

According to the authors [16–20], due to the higher content of heavy compounds, deasphalting is the primary upgrading process carried out prior to conventional refining. There are other common oil upgrading processes at refineries, which are generally classified as catalytic (e.g., catalytic cracking, hydrocracking) and non-catalytic (e.g., gasification, coking, visbreaking). Field upgrading is also an option for upgrading crude oil from the well, usually by injecting a coagulant into the well; however, this leads to crude oil

losses and well plugging due to deposits on the wellbore walls. Of all these methods, deasphalting is the best option for upgrading crude oil prior to conventional refining, as it does not require stringent temperature and pressure conditions, nor does it require the use of catalysts, which are expensive and can be poisoned by the large quantities of asphaltenes present in the oil.

The publication [21] examined the modelling of the deasphalting process, carried out using Aspen Plus software version 12.1 by combining a crude oil model, consisting of 33 molecules and capable of describing a complex composition, with a phase equilibrium model utilizing liquid–liquid equilibrium equations and a modified UNIFAC (Dortmund) model.

In addition, one of the rational approaches, according to the authors [22], is the processing of heavy oils by combining the processes of direct distillation of oil and deasphaltization of fuel oil, which results in demetallized oil and non-oxidized road bitumen. The effectiveness of the combination of propane–butane deasphalting of tar, delayed coking, and production of road bitumen has also been proven: with this combination, it is possible to achieve almost complete utilization of highly viscous products and the production of high-quality products.

2. Materials and Methods

Table 5 shows the physico-chemical and operational parameters of fuel oil obtained from a mixture of oils from the Mangyshlak deposits:

Table 5. Physico-chemical characteristics of the fuel oil of the EDU-AT-2 unit.

Name	Units of Measurement	Value
Density at 20 °C	kg/dm ³	0.890–0.920
Density at 15 °C	kg/dm ³	0.895–0.925
Kinematic viscosity at 100 °C	mm ² /s	not more than 6.8
Hydrogen sulfide content	mg/kg	<1
Sulfur content	weight %	<1
Total nitrogen content	mg/kg	1852
Total acid number	mg KOH/g	0.25
Flash point in an open cup	°C	not lower than 110
Pour point (not higher)	°C	not lower than 42
The content of paraffinic hydrocarbons	weight %	30–40
Water content	weight %	<0.1
Salt content, in terms of NaCl	mg/kg	24.5
Mass fraction of mechanical impurities	weight %	0.035
Calcium content	mg/kg	<3
Arsenic content	mg/kg	<50
Mercury content	mg/kg	<3
Nickel content	mg/kg	<19
Vanadium content	mg/kg	22
Sodium content	mg/kg	3
Iron content	mg/kg	56

The study of the deasphalting process for petroleum residues was carried out using the EPD-2 batch deasphalting pilot plant. A diagram of the EPD-2 pilot plant is shown in Figure 6.

The deasphalting process of heavy crude oil feedstock was carried out in a pilot plant in batch mode using n-pentane as a selective solvent. Experiments were conducted at a temperature of 55–60 °C and a pressure of 0.52–0.55 MPa, which maintained the solvent in

a liquid state and created favourable conditions for the efficient separation of the feedstock components.

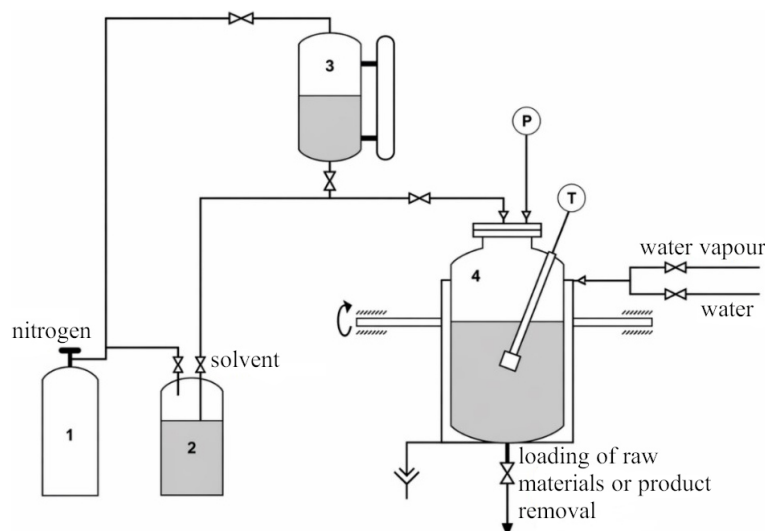


Figure 6. Schematic diagram of the EPD-2 batch extractor: 1—nitrogen cylinder, 2—solvent cylinder, 3—measuring cylinder, 4—extractor, P, T—sensors.

The solvent:feedstock mass ratio was 3:1. This ratio ensures sufficient solvent capacity for the oil components of the feedstock and facilitates the selective precipitation of asphaltenes and resinous-asphaltene substances, which contain the bulk of organometallic compounds, sulfur, and nitrogen-containing components.

Before the experiment, the feedstock was heated to a predetermined temperature, after which a calculated amount of solvent was added to the reactor. The reaction mixture was vigorously stirred for 60 min, ensuring phase equilibrium between the liquid and solid phases and maximum deasphalted oil recovery. Upon completion of the process, the mixture was separated into deasphalted oil and asphalt.

The plant operates as follows. A 500 g batch of feedstock is loaded into extractor 4, then the apparatus is closed, and a specified quantity of solvent is forced into it via measuring device 3 from cylinder 2 using nitrogen. After this, the extractor is disconnected from the cylinder and measuring device, and the extractor jacket is heated with steam to the operating temperature and pressure. The contents of the extractor are stirred by rotary motion at the operating temperature for 1 h.

The mixture is then allowed to settle for 1.5 h, after which the asphalt, containing a portion of the dissolved solvent, is discharged from the bottom of the extractor. To discharge the deasphaltate, the extractor is heated with steam. The residual solvent is evaporated from the deasphaltate and then returned to the measuring tank, after which the deasphaltate with the solvent leftover is drained from the bottom of the extractor.

The selected process parameters ensured a high yield of deasphalted oil while simultaneously reducing the content of asphaltenes, sulfur and metals (nickel, vanadium and iron), which allows us to consider the obtained product as a promising raw material for catalytic cracking processes and other deep oil refining processes.

The iron, nickel, and vanadium contents of the feedstock and deasphalted oil samples were determined using inductively coupled plasma atomic emission spectrometry in accordance with the requirements of ST RK ASTM D 5185-2013. To ensure the reliability of the results, each determination was performed in at least three parallel experiments. The final concentration value of each element was calculated as the arithmetic mean of the three

measurements. The results are presented as the mean $\pm$ standard deviation (Mean $\pm$ SD) calculated from parallel determinations.

Process simulation was performed using Aspen HYSYS V12.1. The Peng–Robinson Equation of State (PR EOS) thermodynamic properties package, widely used to calculate the phase equilibria of hydrocarbon systems and oil refining processes, was employed to model the deasphalting process. To ensure the reliability of the results, the model was verified by comparing the calculated data with industrial and experimental plant parameters. The discrepancy between the calculated and experimental values of product yield and their main properties did not exceed 5%.

In addition, convergence criteria for the calculations were included. The calculations were considered complete upon achieving:

- A relative material balance error of less than 1%;
- A relative heat balance error of less than 1%;
- A residual iterative calculation error of less than 10^{-6} .

The process of deasphalting heavy crude oil at the pilot plant was carried out in batch mode using n-butane/n-pentane as selective solvents. The experiments were carried out at a temperature of 55–60 °C and a pressure of 0.52–0.55 MPa, which ensured that the solvent remained in a liquid state and created favourable conditions for the effective separation of the feedstock components. The mass ratio of solvent to feedstock was 3:1. The chosen ratio ensures sufficient solubility with regard to the oil components of the feedstock and facilitates the selective precipitation of asphaltenes and resinous-asphaltene substances, which contain the majority of organometallic compounds, sulfur and nitrogen-containing components.

Prior to conducting the experiment, the feedstock was heated to a specified temperature, after which the calculated quantity of solvent was fed into the reactor. The reaction mixture was stirred vigorously for 60 min, ensuring that phase equilibrium was achieved between the liquid and solid phases and that the maximum degree of deasphaltate extraction was attained. Upon completion of the process, the mixture was separated to isolate the deasphaltate and asphalt.

The selected process parameters ensured a high yield of deasphaltate whilst simultaneously reducing the content of asphaltenes, sulfur and metals (nickel, vanadium and iron), which allows the product obtained to be considered as a promising feedstock for catalytic cracking and other deep refining processes.

3. Results

Solvents produced by the Atyrau Oil Refinery cannot be used for the deasphalting process for the following reason. Since the solvent in the SDA deasphalting process is circulating, it cannot contain olefins. Olefins are unstable and will polymerize and coke over time, clogging the internal devices of the extraction separators and blocking the extraction process. The solvent must be a stable saturated alkane. Normal butane was used as a solvent in the deasphalting process. Table 6 shows the results of the deasphalting process.

According to the calculations of the material balance, 81.1% of deasphaltate and 18.9% of asphalt fraction were obtained. The deasphaltate selected from fuel oil is characterized by the absence of asphaltenes, low coking capacity (Conradson carbon residue 1.13% weight) and contains 0.864% sulfur by weight, 2.0 mg/kg of nickel, 3.0 mg/kg of vanadium, and 6.0 mg/kg of iron. Deasphaltate mixed with vacuum gas oil from the EDU-AVT unit can serve as a component of the feedstock of the catalytic cracking installation.

Table 6. Yield and quality of the products of deasphalting when butane fractions are used as solvents.

Stream Properties	Fuel Oil	Asphalt Fraction	Deasphaltate
Yield, % by mass	100	18.9	81.1
Relative density at 15.6 °C	0.925	1.044	0.901
Density by API	21.473	4.06	25.52
Nitrogen content, %	0.185	0.419	0.130
Sulfur content, %	1000	1.585	0.864
Conradson coking index, %	5.20	22.72	1.13
Nickel content, mg/kg	19	89	2
Vanadium content, mg/kg	22	103	3
Iron content, mg/kg	56	273	6

The resulting asphalt has a density at 15 °C of 1.044 kg/dm³, a softening temperature of 143 °C and a high coking capacity (Conradson carbon residue 22.72% weight), due to the high content of asphalt-resinous compounds, which makes it possible to use it as a component of the feedstock of the delayed coking plant. Asphalt contains 1.585% sulfur by weight, 89 mg/kg of nickel, 103 mg/kg of vanadium, and 273 mg/kg of iron. From these results, it follows that the solvent deasphalting process effectively reduces the metal content in straight-run fuel oil: vanadium by 7 times, nickel and iron by 9 times.

Pentane was used as the solvent for comparison. Table 7 shows the quality results of the deasphalting unit.

Table 7. Quality of the products of deasphalting when pentane fractions are used as solvents.

Stream Properties	Deasphaltate
Yield, % by mass	87.0
Relative density at 15.6 °C	0.905
Density by API	24.86
Nitrogen content, %	0.140
Sulfur content, %	0.900
Conradson coking index, %	1.11
Nickel content, wpm	4
Vanadium content, wpm	8
Iron content, wpm	18

The metal content in the deasphaltate obtained using pentane is higher than that in the deasphaltate obtained using butane fractions: the nickel content is 4 mg/kg, vanadium is 8 mg/kg, and iron is 18 mg/kg. This indicates that butane fractions provide more thorough demetallization, whereas pentane allows for a higher yield of deasphaltate.

Thus, a comparison of the two solvents shows that the use of pentane contributes to an increase in the yield of deasphaltate, whereas butane fractions are more effective in terms of reducing the content of metals and asphaltene compounds.

Comparative studies of butane and pentane solvent systems demonstrated that the pentane mixture provided a higher deasphalted oil yield, whereas the butane mixture exhibited significantly better demetallization efficiency. Since the primary objective of the present study was to reduce the concentration of catalyst-poisoning metals in the RFCC feedstock, the butane solvent system was selected as the optimal solvent. Comparative studies of butane- and pentane-based solvent systems showed that the pentane mixture provided a higher yield of deasphalted oil, while the butane mixture demonstrated significantly higher demetallization efficiency. Since the primary goal of this study was to reduce the concentration of catalyst-poisoning metals in the RFCC feedstock, the butane-based system was chosen as the optimal solvent.

The heat balance of the process streams indicates significant energy consumption associated with feed heating and solvent regeneration (Table 8).

Table 8. Heat balance of deasphalting.

Stream	Heat Flow, kW
Raw materials	−72,640
Mixture of raw material and solvent	−276,200
Deasphaltate	−56,690
Asphalt fraction	−16,680
Regenerated solvent	−50,560

The highest heat flow is observed for the mixture of feedstock and solvent and is approximately −276 MW, confirming the high energy intensity of the deasphalting process. At the same time, solvent regeneration ensures its return to the technological cycle and reduces the overall consumption of fresh solvent.

Using the Aspen HYSYS V12.1 software, the author modelled a process flow diagram for the Solvahl deasphalting process, designed for the processing of fuel oil to produce deasphaltate and asphalt (Figure 7).

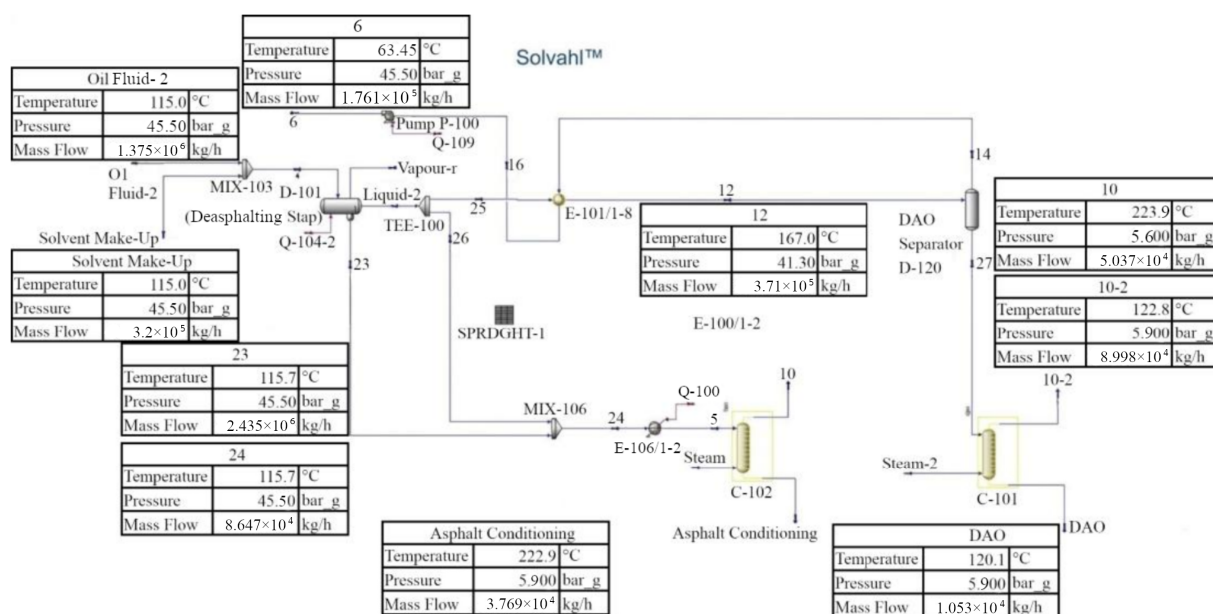


Figure 7. Technological diagram of the deasphalting unit, designed using the software Aspen HYSYS.

The feedstock is mixed with a solvent (butane) in a mixer, and the mixture then enters the deasphalting column. Phase separation results in two streams: a light phase (deasphaltate with solvent) and a heavy asphalt phase. The light phase is directed through heat exchanger E-101/1-8 to separator D-102, where the deasphaltate is separated.

The heavy phase, after additional heating and mixing (MIX-108, E-108/1-2), enters column C-102 for solvent stripping with steam. Similarly, the solvent is removed from the deasphaltate in column C-101. The regenerated solvent is returned to the process, ensuring its circulation.

Thus, the scheme implements a closed-loop solvent cycle, effective separation of feedstock into target products, and thermal integration of streams, which contribute to improved energy efficiency and the depth of processing of heavy petroleum residues.

Figure 8 shows a flow chart integrating the deasphalting process into the existing structure of the Atyrau Oil Refinery. The resulting deasphalted oil is characterized by

reduced metal, asphaltene, and coke-forming components content, making it suitable for use as a feedstock for the catalytic cracking unit. The asphalt fraction, enriched in resin-asphaltene substances and high-molecular compounds, is sent to the delayed coker for further advanced processing.

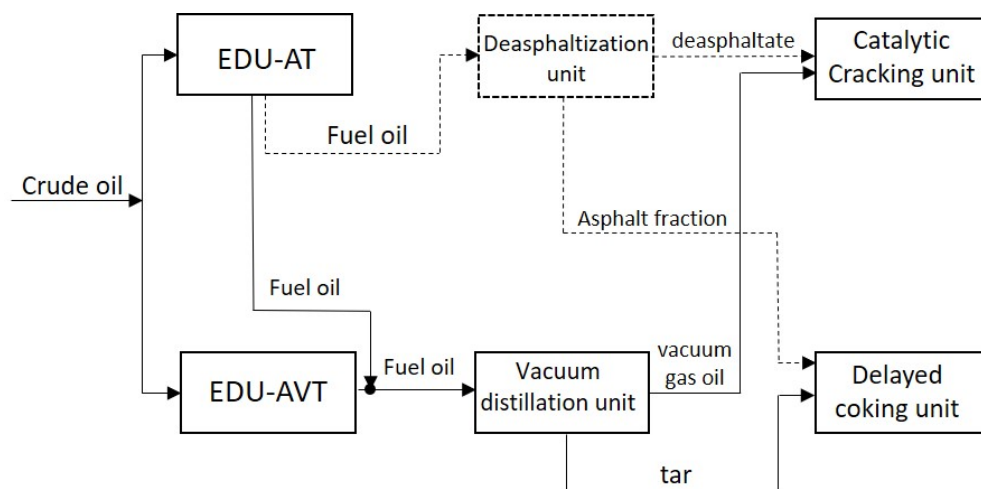


Figure 8. Block diagram of fuel oil processing with introduction of deasphalting process.

The proposed block scheme makes it possible to increase the depth of oil refining, reduce the load on the catalytic cracking unit for metals and asphaltenes, and ensure the rational use of heavy oil residues with the production of additional volumes of light oil products and petroleum coke.

Reducing metal concentrations in the RFCC feedstock decreases catalyst disposal requirements and extends catalyst lifetime, thereby reducing the environmental footprint of refinery operations. In addition, solvent deasphalting contributes to deeper utilization of heavy residues and reduces the generation of low-value fuel oil.

The proposed integrated technology can be implemented at refineries processing high-metal heavy residues without significant modifications to existing RFCC units. The technology may be particularly attractive for refineries seeking to increase refining depth and improve catalyst stability. Reducing metal content in RFCC (heavy feedstock catalytic cracking) feedstock reduces spent catalyst disposal volumes and extends its service life, thereby reducing the environmental impact of refinery operations. Furthermore, the solvent deasphalting process promotes deeper processing of heavy residues and reduces the production of low-grade fuel oil. The proposed integrated technology can be implemented at refineries processing heavy residues with high metal content without significant upgrades to existing RFCC units. This solution may be of particular interest to companies seeking to increase refining depth and improve catalyst stability.

4. Conclusions

The selection of an effective technology for processing heavy petroleum feedstock is largely determined by its composition, particularly the content of metal impurities, which significantly affect catalyst performance and process stability.

Industrial operation of the RFCC unit at the Atyrau Oil Refinery demonstrated that an increase in the iron content of the feedstock from 0.45 to 0.68 wt.% resulted in intensified metal contamination of the circulating catalyst, deterioration of catalyst performance, and increased fresh catalyst consumption.

The application of an iron absorbent proved to be an effective short-term measure for mitigating the adverse effects of iron deposition. The use of the reagent reduced the iron

content in the catalyst by up to 62%, decreased fresh catalyst consumption, and improved process stability.

Following the introduction of the iron absorber, the total yield of valuable liquid products (stable gasoline and heavy gas oil) increased by approximately 2.5 wt.%, while process losses decreased by 1.3 wt.% and fuel gas production decreased by 0.4 wt.%, indicating improved conversion selectivity toward liquid products. Experimental studies on solvent deasphalting using normal butane produced 81.1 wt.% deasphalted oil and 18.9 wt.% asphalt fraction.

The deasphalted oil contained only 2 mg/kg of nickel, 3 mg/kg of vanadium, and 6 mg/kg of iron, demonstrating effective demetallization of the feedstock. The solvent deasphalting process reduced the concentration of vanadium by approximately seven times and nickel and iron by approximately nine times, significantly decreasing the content of coke-forming and metal-containing compounds in the feedstock intended for catalytic cracking.

Comparative evaluation of solvents showed that pentane provided a higher deasphaltate yield (87.0 wt.%), whereas butane exhibited superior demetallization efficiency and, therefore, represents a more suitable solvent for preparing RFCC feedstock from high-metal petroleum residues. Integration of the deasphalting unit into the existing refinery configuration can reduce the metal load on the RFCC catalyst, increase refining depth, improve operational reliability, and increase the production of valuable liquid petroleum products.

Therefore, a combined strategy involving the use of an iron absorbent for short-term process stabilization and solvent deasphalting for deep feed pretreatment is proposed as an effective technological solution for processing high-metal heavy petroleum residues under refinery conditions.

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