Petroleum and Coal

Analysis, Modeling and Optimization of Reactors for Hydrotreatment of Diesel Fuel with Removing Organosulfur Impurities

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Abstract

The disadvantages of the reaction units of hydrotreatment plants are considered and an approach to process improvement by means of the characteristics of hydrodesulfurization reactions of organosulfur impurities of various nature is substantiated. The mathematical modeling method demonstrates that when dividing the feedstock into three wide fractions, each containing several narrow fractions, differential hydrotreatment of these wide fractions is ensured by a reduction in the catalyst load in the reactor unit of the facility.

Keywords: *Hydrotreatment; Reactor; Diesel fuel; Pseudo-component; Mathematical modeling; Optimization.*

1. Introduction

Hydrotreating of diesel fuel refers to the most large-tonnage oil refining processes. The peculiarity of this process is its implementation in a three-phase system: liquid feed stock, hydrogen-containing gas and bifunctional solid catalysts which ensure hemolytic and hetero-lytic hydrogenation reactions of numerous organosulfur compounds that significantly complicates the formation of mathematical models of the process [1-5]. The process schemes of the interconnection of equipment at the hydrotreatment plants implemented in the industry are very conservative from the standpoint of the hardware design of the reactor unit and usually represent a complex of up to four reactors operating sequentially. The volume of hydrotreating catalysts in the reactor unit is determined by the amount of diesel fuel treated and its purification depth. The required catalyst loading is proportional to the capacity and increases dramatically (several times) with an increase in the purification depth. The design capacity of hydrotreating plants at the level of two million tons per year is achieved only with shallow-treatment with a sulfur content of 350 ppm in purified fuel used for roads and agricultural machinery. For vehicles (mainly cars) according to the Euro-5 standard, the sulfur content is limited to 10 ppm which is achieved by increasing the time of hydrotreatment and, as a result, reducing the capacity of hydrotreatment plants by 3 to 4 times or by construction of additional reactors during the revamping of plants.

The degree of activity of sulfur compounds in hydrogenolysis reactions is different and decreases in the series: mercaptans > sulfides > thiophenes > benzothiophenes > dibenzothi-ophenes. At the same time, the most difficult-to-hydrogenate compounds in the thiophene series are concentrated mainly in heavy fractions boiling above 330°C [6-9]. While ensuring the required quality of diesel fuel hydrotreatment, the purification process as a whole is pre-cisely limited by the interaction with hydrogen of a relatively small amount of difficult-to-hydrogenate organosulfur, while the easily hydrogenated components have already under-gone hydrogenolysis. In this situation, the assessment of the composition of the initial purified diesel fuel, which is necessary for the mathematical modeling of the process [6-7,10-11], is of particular importance.

The identification of an extremely complete set of organosulfur components in diesel fuel and the development of a database of possible reaction pathways is practically impossible due

to the scale of the task, high cost of the necessary reagents, the complication of analytical methods, and the need for expensive precision equipment to define the concentration of dozens of individual organosulfur impurities to be determined at fractions in ppm [12-13]. In many cases, a feedstock model was used in the study of the hydrotreating process in which dibenzothiophene was used as the only one generalizing hydrogenated component instead of a set of organosulfur impurities [14-17]. Most often, researchers consider the grouping of organosulfur impurities of the same homologous series as a certain conditional pseudo-component [18-20], but they do not take into account the fact that homologues with significantly different boiling points also have different reactivity. In this regard, we proposed to consider the feedstock of the hydrotreating process as a set of several narrow fractions, in each of which the aggregate of organosulfur impurities is considered as a conditional pseudo-component. Its concentration in a narrow fraction is determined using the simplest and most accessible analysis for total sulfur [21], that made it possible to significantly simplify the generated mathematical models for the comparative analysis of various hydrotreatment schemes.

2. Computational procedures and programs

Since the task of comparing different versions of the reactor units of the hydrotreatment process from the point of view of removing organosulfur impurities was resolved in this work, there was no need to form and use a complex hierarchical model of catalytic hydrotreatment. In this regard, the operation of the reactor was examined on the basis of the following assumptions:

- quasi-homogeneous reaction stream within the reactor;
- constant velocities of local flow jets and hydrodynamic mode of ideal displacement in the reactor;
- isothermicity of the process;
- stationary nature of the process;
- constant activity of the catalyst;
- the content of total organosulfur in the feedstock or in its narrow fractions is considered as an organosulfur pseudo-component and its concentration in the stream is determined by analysis for total sulfur;
- the rate constants of the hydrodesulfurization reactions of the pseudo-components are effective.

Under these assumptions, the mathematical model of a hydrotreating reactor for N pseudo-components takes the following form of a system of equations:

$$\left.\begin{array}{l} \dfrac{dC_{S1}}{d\tau} = -K_1 C_{S1N} \\[2mm] \dfrac{dC_{S2}}{d\tau} = -K_2 C_{S2} \\[2mm] \quad\vdots \\[2mm] \dfrac{dC_{Si}}{d\tau} = -K_i C_{Si} \\[2mm] \quad\vdots \\[2mm] \dfrac{dC_{SN}}{d\tau} = -K_N C_{SN} \end{array}\right\}, \quad (1)$$

where C_{Si} and K_i are the concentration of the organosulfur pseudo-component and the effective reaction rate constant of the i-th pseudo-component, respectively.

The numerical values of the concentration of organosulfur components in the hydrotreating feedstock and the effective rate constants of the hydrodesulfurization reactions were taken from independent literature sources.

The mathematical model was calculated by the Runge-Kutta method and the calculation program made it possible to determine the change in the concentration of pseudo-components during the process, the residence time of the reaction mixture in the reactor until a given degree of purification of feedstock was achieved, and the required volume of catalyst in the reactor. The same assumptions were used when comparing different configurations of reaction

units. It is the specific features of the hydrodesulfurization chemistry in these units that made it possible to quickly compare them in terms of the effectiveness of the hydrotreating process using a fairly simple calculation program instead of complex programs that fully take into account the system of hierarchical modeling of the catalytic process from the catalyst grain to the reactor taking into account its placement in the reaction unit scheme.

3. Results and discussion

3.1. Analysis of efficiency of industrial reactor units of diesel fuel hydrotreating plants

The variety of types of layout for the reactor unit of hydrotreating plants (Fig. 1) requires their comparison from the standpoint of minimizing the loading of the catalyst to obtain high-quality diesel fuel. Since the reactors are structurally the same in all circuits, when solving the problem, it was assumed that in the reactors, with the assumptions made, the temperature and concentration profiles in the height of the catalyst layer should be practically the same.
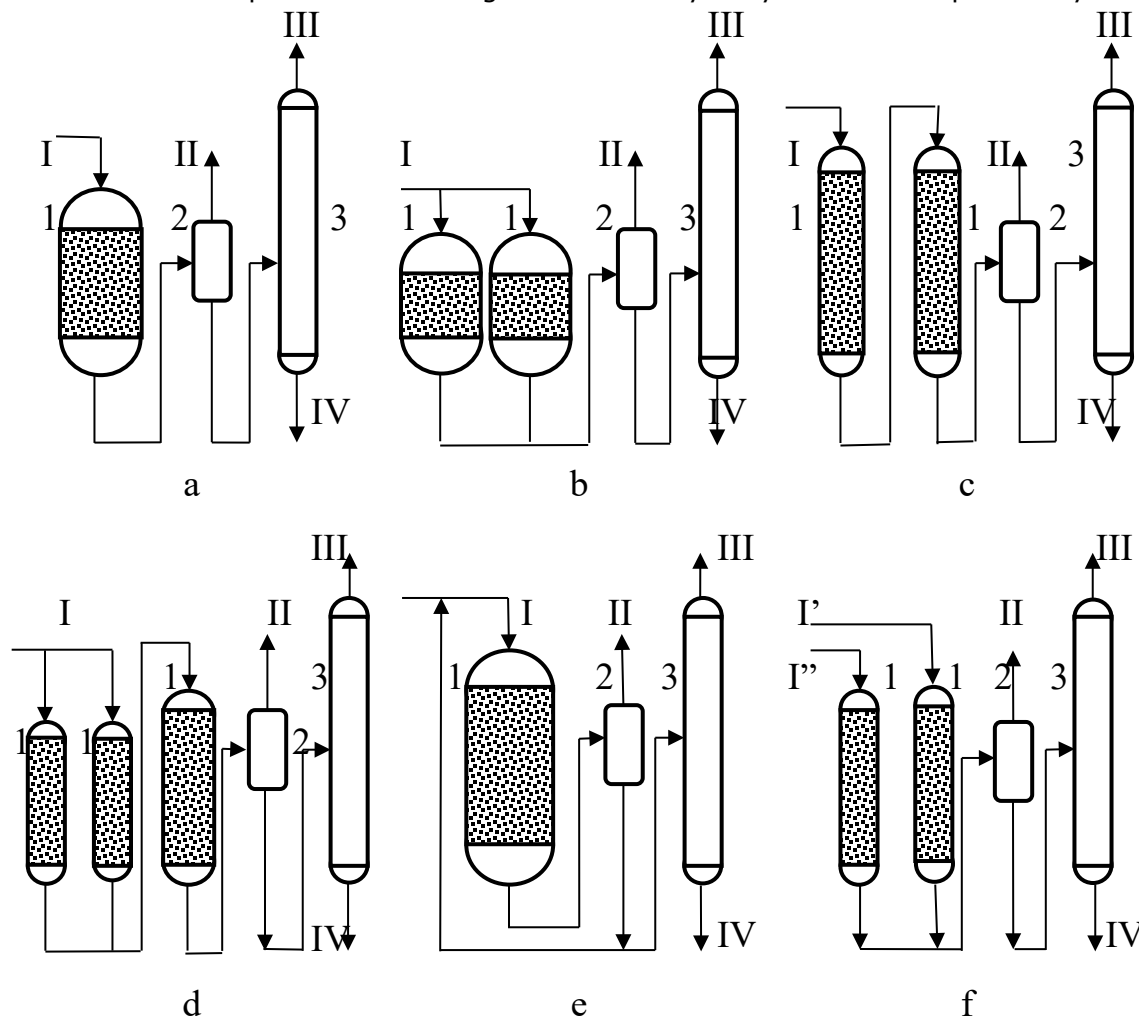

Fig. 1. Concepts for reactor units of the process of hydrotreating of diesel fuel a – single-reactor system, b – block double-reactor with parallel the supply of raw materials, c – double-reactor unit with a consistent supply of raw material, d – three-reactor unit with a parallel-to-serial flow of raw materials, d – single-reactor system with recirculation of purified diesel fuel, e – double-reactor unit with differential input preliminary fractionation of raw materials into various reactors.
1 - reactor, 2 - separator, 3 - stabilization column. I – a mixture of raw materials with hydrogen-containing gas, II - blowing off of hydrogen-containing gas, III - light hydrocarbons and hydrogen sulfide, IV - purified diesel fuel.

To compare different hydrotreating reactor systems (Figure 1), mathematical modeling of the hydrodesulfurization process of 250 m^3/h of diesel fuel with a sulfur content of 6000 ppm, the volumetric feed rate of feedstock 2 h^{-1} and the accepted effective rate constant of the hydrodesulfurization reaction 2 h^{-1} was performed [12]. The efficiency of the reaction system in ensuring the final concentration of sulfur in purified diesel fuel from 500 to 10 ppm was estimated by the total volume of the catalyst in the reaction system, represented by a single reactor, two parallel reactors, two sequentially operating reactors, three parallel-sequentially operating reactors (Figure 1, a, b, c,). Calculations have shown (Table 1) that the volume of the catalyst in a single reactor and in a parallel and sequential reactor system required to achieve a given residual sulfur concentration in diesel fuel is the same and the configuration of the installation scheme is determined by technical limitations. This conclusion is valid not only for two-three reactor circuits, but also for a four-reactor [22], as well as for a combined parallel-serial circuit (Figure 1, d), allowing us to assume that all actual industrial reactor units, regardless of their configuration and number of reactors, are equivalent to the operation of a single reactor.

Table 1. Results of mathematical modeling of various reaction blocks of diesel fuel hydrotreating plants

Reaction system	Volume flow rate of recirculate, m^3/h	Final concentration of sulfur in purified fuel, ppm	Duration of reaction, h	The volume of the catalyst in the system, m^3
Systems (Figure 1, a, b, c, d) - single-reactor system, block double-reactor with parallel the supply of raw materials, double-reactor unit with a consistent supply of raw material,	0	2000	0.550	68.8
Systems (Figure 1, a, b, c, d)	0	500	1.245	155.6
Systems (Figure 1, a, b, c, d)	0	350	1.420	177.5
Systems (Figure 1, a, b, c, d)	0	50	2.395	299.4
Systems (Figure 1, a, b, c, d)	0	10	3.199	400.0
System (Figure 1, e) - single-reactor system with recirculation of purified diesel fuel	10	500	1.220	164.7
System (Figure 1, e)	30	500	1.175	182.1
System (Figure 1, e)	50	500	1.130	197.7
System (Figure 1, e)	10	350	1.400	189.0
System (Figure 1, e)	30	350	1.350	209.2
System (Figure 1, e)	50	350	1.310	229.2
System (Figure 1, e)	10	50	2.370	319.9
System (Figure 1, e)	30	50	2.325	360.4
System (Figure 1, e)	50	50	2.285	399.8
System (Figure 1, e)	10	10	3.175	428.6
System (Figure 1, e)	30	10	3.130	485.1
System (Figure 1, e)	50	10	3.085	539.8

For a single reactor proposed in the patent [23] with a purified diesel fraction fed into it as a recycle after separation of hydrogen-containing gas (Figure 1, d), it was assumed that the reaction duration should have been reduced by reducing the sulfur concentration at the reactor inlet. However, mathematical modeling has shown that the supply of a recycle of purified diesel fuel from the separator to the reactor is not rational, since this technique leads to an increase in the reaction volume, all other things being equal (Table.1).

Calculations made it possible to detect the anti-battery effect of the recycle feed on the main parameters characterizing the hydrotreating process (Figure 2). When the recycle is fed to the top of the reactor, the concentration of sulfur in the mixture of feedstock and the recycle only slightly reduces the required duration of contact of the reaction mixture with the catalyst,

but at the same time the volume of flow increases significantly and, as a result, the required volume of the catalyst in the reactor increases. The supply of the recycle to the zones of the catalyst layer different in height of the reactor also negatively affects the results of hydrotreating diesel fuel.
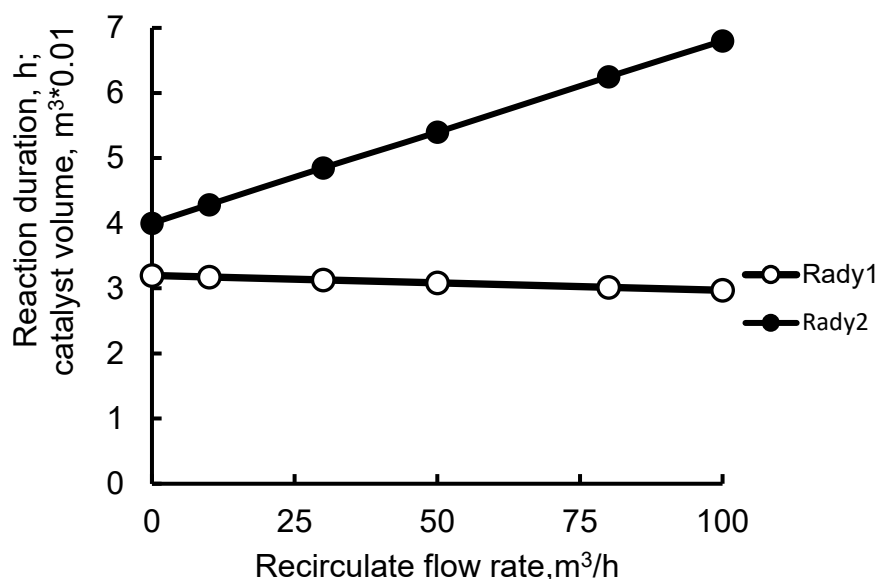

Fig. 2. The dependence of the reaction duration (line 1) and the volume of the catalyst (line 2) on the recirculate flow rate at a residual sulfur concentration in diesel fuel of 10 ppm

Table 2. Composition of products leaving reactor R-2, based on total sulfur content in narrow fractions at different boundaries of division M of the feedstock into wide fractions

Sulfur concentration C_S in narrow fraction number Z in product at											
M=4						M=8					
Z	C_S, ppm	Z	C_S, ppm	Z	C_S, ppm	Z	C_S, ppm	Z	C_S, ppm		
5	10^{-37}	9	10^{-33}	13	$1.8*10^{-10}$	9	10^{-37}	13	10^{-12}		
6	10^{-37}	10	10^{-27}	14	$6.8*10^{-6}$	10	10^{-30}	14	10^{-6}		
7	10^{-37}	11	10^{-21}	15	$2.3*10^{-2}$	11	10^{-23}	15	$2.3*10^{-2}$		
8	10^{-37}	12	10^{-15}	16	119.8	12	10^{-17}	16	79.8		
Reaction time 2.46 h						Reaction time 2.66 h					

For the transition of the degree of hydrotreatment of feedstock from the residual sulfur content of 350 ppm to the level of 10 ppm during the process with the recirculation feed, it is necessary to increase the duration of the process and, accordingly, the catalyst loading into a single reactor in comparison with any of the schemes in Fig. 1, a, b, c and d by 1.2-2.2 times with a recirculation coefficient of 0.1-1.0.

Computer calculations of mathematical models of various versions of reaction units of industrial diesel hydrotreating plants have shown that further improvement of existing plants with the enlargement of the hydrotreating process is possible only through the use of a more active catalyst or an increase in the volume of reactors.

3.2. Modeling and optimization of promising method of hydrodesulfurization of diesel fuel

In the works of Loginov *et al.* that remained unnoticed by the industry [24-25], an original idea was expressed about the possibility of separate hydrogenation of two fractions of diesel fuel (light I' and heavy I") in the reactors of a hydrotreating plant under different operating modes of reactors, taking into account the distribution of easily hydrogenated and difficult-to-

hydrogenate organo-sulfur in light and heavy feedstock (Figure 1,e) and an experiment was performed on a pilot plant for hydrotreating diesel fuel boiling within 180-360℃, divided into two broad fractions 180-300℃ and 300-360℃ with an arbitrary division boundary of 300℃ [25]. In the development of this idea, we have substantiated the position that when dividing the feedstock into two separately hydrogenated broad fractions, there is such a temperature division boundary at which the costs of the process catalyst and its quantity can be minimized [26].

As the initial data for mathematical modeling of the separate hydrotreating of diesel fuel and the characteristics of feedstock, we took the results of analysis of the diesel fuel fraction 180-360°C in terms of total sulfur content and experiments on a pilot plant 16500 ppm [17] that made it possible to describe the composition of feedstock in terms of sulfur by the following equation:

$$C_S = 5000 + 11500N/16 \qquad\qquad (2)$$

where C_S is the concentration of total sulfur in the narrow fraction, ppm; N is the serial number of the narrow fraction as the boiling point of diesel fuel increases; 16 - the number of narrow 6.25% v/v fractions in diesel fuel.

The data on the total sulfur content in the catalysts at different times of hydrotreating the diesel fuel fraction of 180-360°C on the CoMo catalyst obtained in [17] made it possible to calculate the range of reaction rate constants within 2-16.3 h^{-1}.

For narrow fractions with numbers N equal to 1, 2, 3, ..., 15,16, the values of the reaction rate constants K_i were taken as 17, 16, 15, ..., 3, 2.
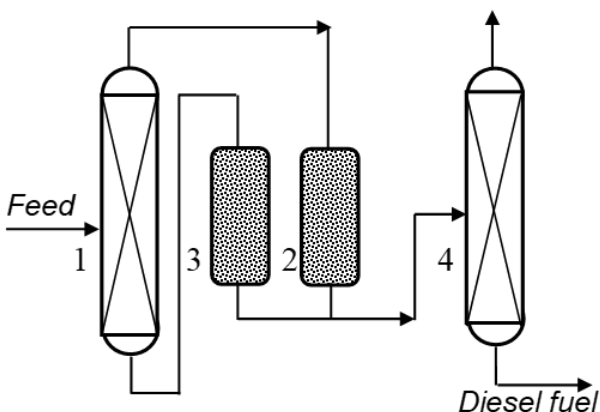

Fig. 3. Schematic diagram of a reactor block with separate hydrogenation of raw materials, previously divided into light and heavy fractions:
1 - rectification column, 2 - reactor R-1 for hydrogenation of light fraction of raw material, 3 - reactor R-2 for hydrogenation of heavy fraction of raw material, 4 - stabilization column

At the first stage of modeling the process of diesel fuel hydrotreating with separate hydrogenation of two wide fractions (Figure 3), the influence of the feedstock division boundary in a complex of 16 narrow fractions with two resulting broad fractions for the required amount of catalyst necessary for purification of wide fractions from sulfur up to 10 ppm was considered. The consumption of the feedstock is taken to be 100 m^3/h, the volumetric feed rate of the feedstock is 1 h^{-1}.

Fractions with numbers 1, 2, ..., M were introduced into the first reactor R-1sequentiallyat the fission boundary between the M-th and M+1-th fractions; fractions with numbers M+1, M+2,…N were introduced into the second reactor R-2. The boundary fraction M changed its number from 1 to N, thus all 16 possible variants for the distribution of the feedstock between the two reactors were calculated. At M = N, all feedstock was introduced into the reactorR-1, at M = 0, all feedstock was introduced into the reactor R-2 - these calculation options corresponded to the operation of the plant with a single reactor or with two parallel reactors or with two reactors operating in series and gave the same results of calculation.

Mathematical modeling of the hydrotreating process made it possible to understand the characteristic features of hydrodesulfurization of organosulfur impurities in two reactors.

The R-1 reactor is characterized by an obvious increase in the required contact and catalyst loading times associated with the weighting of feedstock in R-1 and an increase in its sulfur content as the numbers of narrow fractions entering the reactor R-1 increase.

Similar dependences for the reactor R-2 are somewhat paradoxical, since with the increasing weight of the wide fraction entering R-2, the required catalyst loading decreases (Figure4),

but they can be explained when taking into account the change in the mass of the diesel fuel flow purified in the reactor. For example, comparing the results of hydrotreating in R-2 on a lightweight wide fraction at M = 4 and a weighted wide fraction at M = 8 (Table 2), it can be noted that when the reactor is operating on both types of incoming feedstock at the outlet of the equipment, the residual concentration of the most difficult-to-hydrogenate pseudo-component of the sixteenth narrow fraction is 10s of ppm, while the specified purity of the catalyzate in terms of total sulfur of 10 ppm is ensured by almost complete removal of sulfur from the lighter narrow fractions.
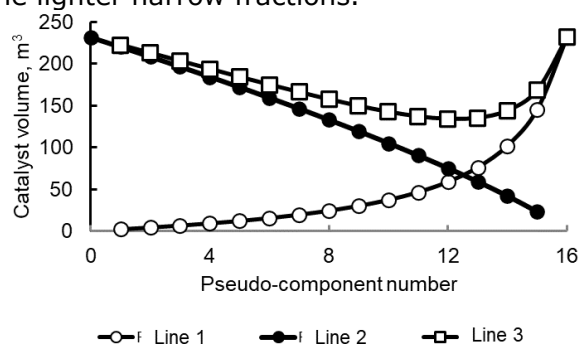

Fig. 4. Dependence of the volume of catalyst loaded into the reactor block on the number of pseudo-component M at the fission boundary light and heavy fractions for reactors, respectively R-1 (line 1), R-2 (line 2) and R-1+R-2 (line 3)

The combined operation of two reactors of the reaction unit at any value of M is ensured when the catalyst loading is less than that required for the operation of a single reactor and equal to 231.7 m^3 (Figure 4).

The minimum catalyst loading for a two-reactor hydrotreater is 134.2 m^3 at M = 12 (loading in R-1 is equal to 59.0 m^3 at a wide light fraction flow rate of 75 m^3/h and that in R-2 is 75.2 m^3 at a wide heavy fraction flow rate of 25 m^3/h. In addition, it follows from Fig. 4 that when the catalyst loading is slightly higher than the minimum one, the temperature boundary between wide light and heavy fractions can be changed, which does not require a clear fractionation of the feedstock in the rectification column (Fig.3).

Separate hydrogenation of feedstock in two reactors, in comparison with single-flow hydrotreatment, makes it possible to reduce the loading of an expensive catalyst per unit by 42.1% or 97.5 m^3 (from 231.7 to 134.2 m^3).

Since calculations have shown that the efficiency of hydrotreating is largely negatively affected by the overloading of the reactor R-1 with heavy narrow fractions, and the reactor R-2 with light narrow fractions (Table 2), there is no doubt that it is expedient to combine a part of these fractions into the third stream of the medium wide fraction subjected to hydrotreating in a separate third reactor R-3. This fraction can be obtained in the distillation column of the hydrotreater plant (Figure 3) as a side stream. The reactor R-3 becomes additional equipment of the unit.

Mathematical modeling of a three-reactor scheme of a hydrotreating unit, all other things being equal, showed that when a set of narrow fractions forming a medium narrow fraction sent to the reactor R-3 is formed, a rather diverse variability of solutions appears on the selection of temperature boundaries for the beginning and end of boiling of the middle fraction. It is characteristic that the transition from a two-reactor to a three-reactor hydrotreating scheme is accompanied by an additional decrease in the total volume of catalyst loading into the reactor unit due to the elimination of the previously discussed factors that negatively affect the operation of the reactors R-1 and R-2 of the two-reactor scheme.

When selecting the temperature limits of the medium wide fraction, the adopted set of narrow fractions provides a monotonic change in the volume of the catalyst loaded into the reactor R-3 (Figure 5), while the calculated volume of the total load in all three reactors also has a minimum (Figure 6), like for a two-reactor scheme. However, if a two-reactor unit has a single minimum of catalyst loading, many local extrema of the minimum type are formed-when calculating a three-reactor unit, and when searching for a global extremum, it is necessary to use a scanning method with a sequential change in the range of narrow fractions that form a wide medium fraction for the new reactorR-3.
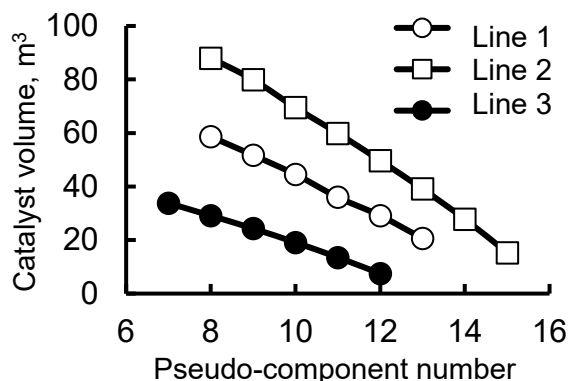
Fig. 5. Dependence of the volume of catalyst loaded into the R-3 reactor on the numbers of narrow fractions that form its raw material:
line 1 - narrow fractions 11 ... 14,
line 2 - narrow fractions 12 ... 15,
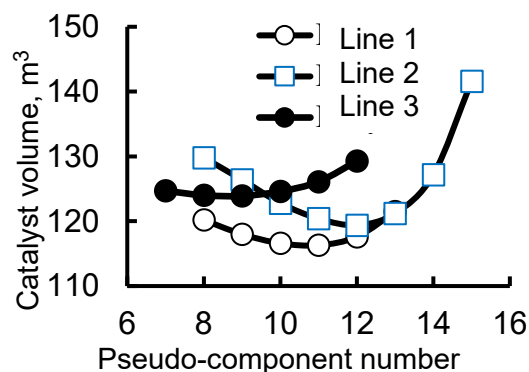line 3 - narrow fractions 9 ... 12.

Fig. 6. Dependence of the volume of catalyst loaded into the block on the numbers of narrow fractions, feedstock of the R-3 reactor:
line 1 - narrow fractions 11 ... 14,   line 2 - narrow fractions 12 ... 15, line 3 - narrow fractions 9 ... 12.

As an example of mathematical modeling of the hydrotreating process in a three-reactor scheme, Figure 7 shows the distribution of total sulfur concentrations by pseudo-components in reactors and the kinetics of the process as a whole.
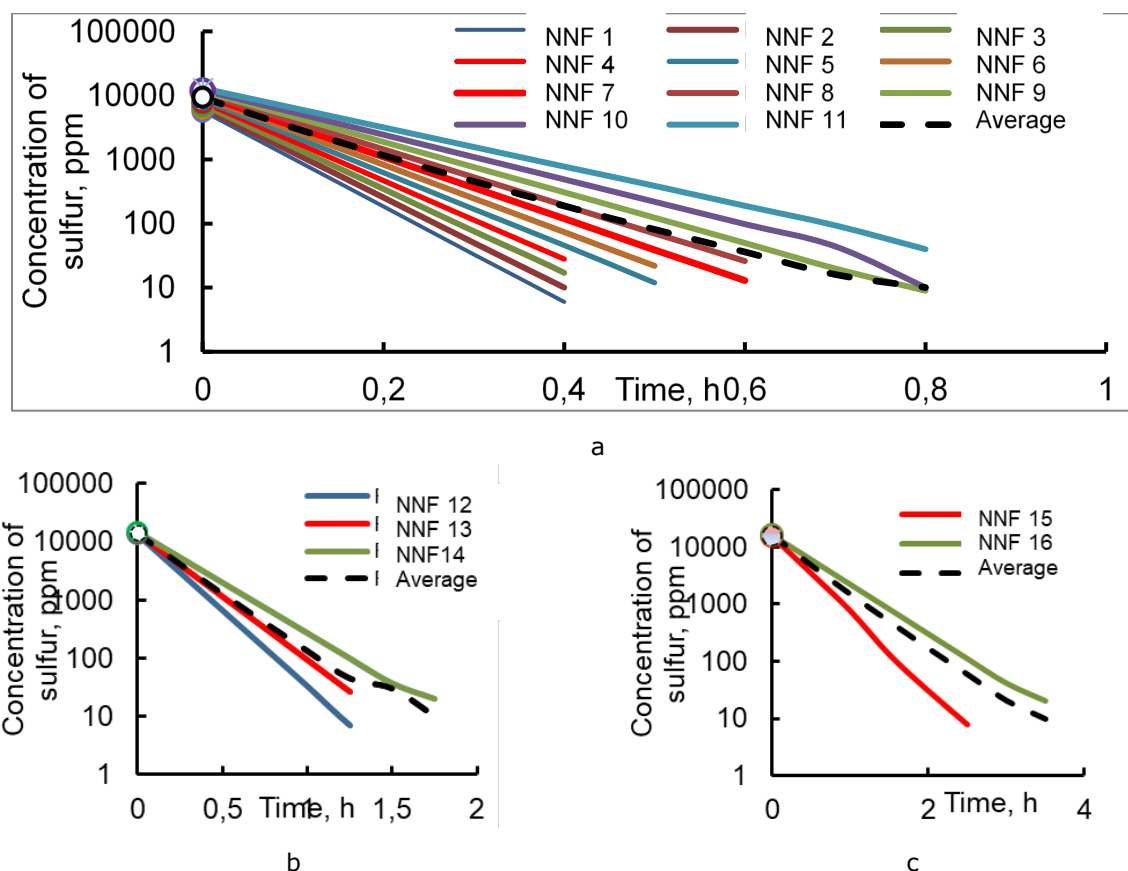

Fig. 7. Kinetics of hydrodesulfurization of pseudo-components contained in narrow fractions forming reactor feedstock: R-1 (a), R-3 (b) and R-2 (c) (NNF - number of narrow fraction)

An additional feature of the variability of the problems being solved for optimizing a three-reactor hydrotreatment scheme is the possibility of not only minimizing the catalyst load in a separate variant of the distribution of narrow fractions of diesel fuel over light, medium and

heavy wide fractions, but also selecting such a variant of the simulated scheme, so that at a volume sufficiently close to the global minimum for the total loading of the catalyst, the scheme included similar volumes of catalyst in all three reactors of the scheme, which makes it possible to develop the designed reactors as identical equipment (for example, option 1 in Figure 8).

Considering the required volume of loading an expensive catalyst into the reactor unit as an optimality criterion R, we can assume that each calculation option allows us to determine the local optimum, and their comparison allows us to identify the global optimum for solving the problem (Table 3).

Table 3. Comparison of the characteristics of one-, two- and three-reactor units of plants for differentiated hydrotreatment of diesel fuel

| Characteristics of the reactor block	Reactors		
	R-1	R-3	R-2
One-reactor block (R= 231.7 m^3)			
Distribution of pseudo-components	1…16		
Raw material consumption, m^3/h	100		
The duration of contact of raw materials with the catalyst, h	2.31		
Catalyst volume in the reactor, m^3	231.7		
Two-reactor block (R= 134.2 m^3)			
Temperature limits of boiling of wide fractions, °C	180-315		315-360
Distribution of pseudo-components	1…12		13…16
Raw material consumption, m^3/h	75		25
The duration of contact of raw materials with the catalyst, h	0.78		3.00
Catalyst volume in the reactor, m^3	59.0		75.2
Optimal three-reactor block (option No. 1 - global optimum; R= 116.3 m^3)			
Temperature limits of boiling of wide fractions, °C	180-292.5	292.5-337.5	337.5-360
Distribution of pseudo-components	1…10	11…14	15…16
Raw material consumption, m^3/h	62.5	25	12.5
The duration of contact of raw materials with the catalyst, h	0.60	1.48	3.35
Catalyst volume in the reactor, m^3	37.4	41.9	32.0
Optimal three-reactor block (option No. 2 - local optimum; R= 119.4 m^3)			
Temperature limits of boiling of wide fractions, °C	180-303.7	303.7-348.7	348.7-360
Distribution of pseudo-components	1…11	12…15	16
Raw material consumption, m^3/h	68.75	25	6.25
The duration of contact of raw materials with the catalyst, h	0.68	2.00	3.70
Catalyst volume in the reactor, m^3	46.6	23.1	49.7
Optimal three-reactor block (option No. 3 - local optimum; R= 123.9 m^3)			
Temperature limits of boiling of wide fractions, °C	180-270	270-315	315-360
Distribution of pseudo-components	1…8	9…12	13…16
Raw material consumption, m^3/h	50	25	25
The duration of contact of raw materials with the catalyst, h	0.49	0.97	3.00
Catalyst volume in the reactor, m^3	24.4	24.3	75.2
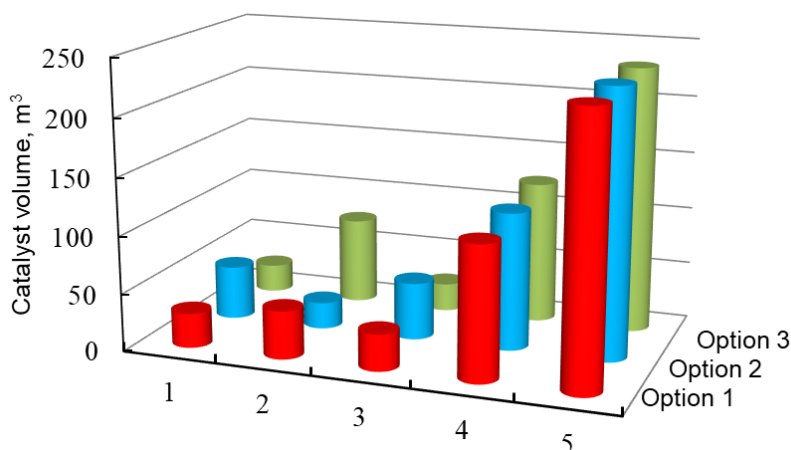
Fig. 8. Dependence of the volume of the catalyst loaded into the reactors R-1 (1),R-2 (2), R-3 (3), into a three-reactor block (4) and a reactor unit of a typical diesel fuel hydrotreatment industrial unit (5) from the numbers of narrow fractions that form the raw material of the R-3 reactor: option 1 - narrow fractions 11 ... 14, option 2 - narrow fractions 12 ... 15, option 3 - narrow fractions 9 ... 12
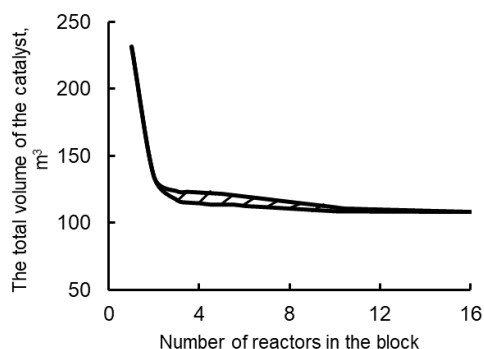

Figure 9. Dependence of the total catalyst volume in the reactor block of the diesel fuel hydrotreater on the number of reactors. (The area of local extremums from the condition of the minimum of the optimality criterion R is shaded)

It can be assumed that a further increase in the number of hydrotreating reactors to the limit of the number of narrow fractions will lead to a further decrease in the required catalyst load in the reactor unit, but this will most likely be inefficient from an economic standpoint due to an increase in the cost of numerous non-standard equipment (Figure 9). For example, with 16 narrow fractions and their separate hydrogenation in 16 reactors, the reactor loading will vary from 2.3 m^3 in the first reactor to 23.1 m^3 in the sixteenth reactor, totaling 108.5 m^3, which is only 9.8 m^3 achieved global optimum of 116.3 m^3 (Table 3).

The three-reactor scheme, compared with the two-reactor scheme, makes it possible to reduce the catalyst loading, depending on the option of forming the medium wide fraction, from 7 to 13% and bring the reduction in catalyst loading to 50% from the currently used "one-reactor" variant of diesel fuel hydrotreatment.

A feature of the process scheme of differentiated hydrotreatment is the need for computer control of the process of distribution of wide fractions in reactors with a change in the flow rate and composition of the feedstock.

4. Conclusion

It has been shown by mathematical modeling that the reactor units of industrial diesel fuel hydrotreatment units are equivalent to a single reactor, on the basis of which series or parallel reactor piping schemes with the same total catalyst load are formed. It has been substantiated that in case of differentiated hydrotreatment, when the feedstock is pre-fractionated into two or three wide, separately hydrogenated narrow fractions, it is possible to reduce the loading of an expensive catalyst by 40-50% as compared to traditional schemes of reactor units of industrial hydrotreatment plants.

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