Petroleum and Coal

Article Open Access

ESTIMATION OF TECHNOLOGICAL PARAMETERS INFLUENCE ON THE COLD FLOW PROPERTIES AND YIELD OF DIESEL FUEL IN THE PROCESS OF CATALYTIC DEWAXING

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Received October 6, 2017; Accepted December 23, 2017

Abstract

The aim of this work is to study the process of catalytic dewaxing by the method of mathematical modelling. The influence of temperature and feedstock flow rate on the cold flow properties and yield of the product (diesel fuel) was studied depending on the feedstock composition. The temperature mode of the process was optimized depending on the composition and feedstock flow rate.

Keywords: : catalytic dewaxing; diesel fuel, cold flow properties; cold filter plugging point; the method of mathematical modelling.

1. Introduction

Diesel fuel is one of the most demanded product of oil refining industry. The demand for diesel fuel is constantly increasing all over the world [1-5]. Currently, the tendency towards increasing the demand for diesel fuel of winter and arctic grades, meeting EURO standards, is observed [6-8]. This is mostly due to exploration of the North territories, including Arctic regions [9-10]. The main quality indicators of diesel fuel of winter and arctic grades are cold flow properties, such as cloud point, cold filter plugging point, freezing point, which depend on the content of normal paraffins [11-13].

Under the conditions of decreasing the resource of "light" oil and domination of "heavy" paraffinic oil within oil extraction [14-16], hydroconversion processes assume greater and greater importance in oil refining industry [17-21], including the process of catalytic dewaxing of diesel fuels [22-24]. The studies on oil refining processes using the method of mathematical modelling are relevant these days. The models, developed based on the thermodynamic and kinetic regularities of the processes, allows making recommendations for control of the technological parameters of industrial processes, which ensures meeting specifications for product quality and achieving optimal yield of the product in the conditions of constantly changing composition of the feedstock [25-29]. The aim of this work is to study the process of catalytic dewaxing by the method of mathematical modelling.

2. Object and method of research

The object of the current research is the industrial process of catalytic dewaxing, which is aimed to produce diesel fuel of summer, winter and arctic grades.

The feedstock for the process of catalytic dewaxing is the mixture of the following components in different ratios: straight run diesel fraction, atmospheric gasoil and gasoline from visbreaking. Table 1 shows group composition and density of the components of catalytic dewaxing feedstock.

Table 1. Composition and density of the components of catalytic dewaxing feeds

Hydrocarbon group	Straight run diesel fraction	Atmospheric gasoil	Gasoline from visbreaking
		%wt.	
N-paraffins C_{10}-C_{27}	19.98	15.99	21.60
Olefins	3.75	6.52	19.20
Naphthenes	18.85	16.58	12.80
I-paraffins	32.02	29.01	27.40
Monoaromatics	17.30	19.10	19.00
Polyaromatics	8.10	12.80	0.00
Density, kg/m^3	845	870	727

Depending on the type of feedstock the firm-developer provides two variants of operation of catalytic dewaxing unit (Fig. 1).

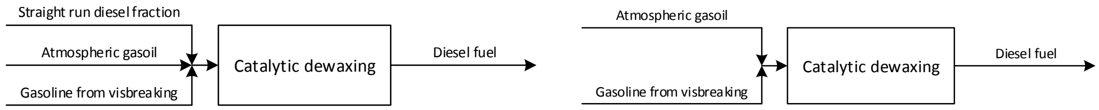

Fig. 1. Variants of catalytic dewaxing unit operation in terms of feedstock

Table 2 presents the ratios of fractions in the mixture of feedstock of the catalytic dewaxing process for the two variants of the unit operation.

Table 2. The ratios of fractions in the mixture of feedstock of the catalytic dewaxing process

Component of feedstock	Designed variants of the catalytic dewaxing unit operation	
	Variant 1	Variant 2
	%	
Straight run diesel fraction	75	0
Atmospheric gasoil	21	93
Gasoline from visbreaking	4	7

On the basis of compositions of feedstock components and their proportions in the feedstock mixture, the compositions and density of the mixed feedstock were calculated for the two variants of the dewaxing unit operation, presented in Table 3.

Table 3. Compositions of feedstock of catalytic dewaxing unit

Hydrocarbon group	Variant 1	Variant 2
	%wt.	
N-paraffins C_{10}-C_{27}	19.21	16.38
Olefins	4.95	7.41
Naphthenes	18.31	16.32
I-paraffins	31.20	28.90
Monoaromatics	17.75	19.09
Polyaromatics	8.76	11.90
Density, kg/m^3	846	860

Thus, when the compositions and ratios of feedstock component change, the composition of the feedstock of catalytic dewaxing unit changes significantly. In such a way, the content of n-paraffins, which influence the cold flow properties of diesel fuel the most, changes by3 %wt. The content of monoaromatics, which influences the cold flow properties of diesel fuels being the solvent of n-paraffins, changes by 2 %wt.

Such change in the feedstock composition requires constant correction of the mode of the dewaxing reactor operation, determination and maintenance of optimal technological parameters for the exact feedstock composition in order to obtain maximum yield of the product meeting required quality in terms of cold flow properties. In this work, the influence of temperature and feedstock flow rate on the yield and cold filter plugging point of the product was studied, as well as technological mode for the two variants of unit operation was optimized using the developed mathematical model [30].

The model is written as a system of material and heat balances as follows:

$$\begin{cases} G\cdot\dfrac{\partial C_i}{\partial z}+G\cdot\dfrac{\partial C_i}{\partial V}=\sum\limits_{j=1}^{m}a_j\cdot W_j \\ G\cdot\dfrac{\partial T}{\partial z}+G\cdot\dfrac{\partial T}{\partial V}=\dfrac{1}{\rho\cdot C_p^m}\sum\limits_{j=1}^{m}Q_j\cdot a_j\cdot W_j \end{cases} \quad (1)$$

Initial and boundary conditions are as follows: z=0: C_i=$C_{i,0}$; T=T_0; V=0: C_i=$C_{i,0}$; T=T_0, where z is the volume of refined feedstock from the moment of fresh catalyst load, m^3; G is the feedstock flow rate, m^3/h; $z = G\cdot t$ (t is the catalyst operating time from the moment of fresh catalyst load, h); C_i is the content of i^{th} component, mol/l; V is the catalyst bed volume, m^3; a_j is the catalyst activity in j^{th} reaction; ρ is the density of mixture, kg/m^3; C_p^{mix} is the specific heat capacity of the mixture, J/(kg·K); Q_j is the heat effect of j^{th} reaction, J/mol; T is the temperature, K; W_j is the rate of j^{th} reaction, mol/(l·s); m is the number of reactions.

3. Experimental

3.1. Studying the influence of temperature on the dewaxing process

The influence of temperature on the content of n-paraffins in the product (diesel fuel), product cold filter plugging point and product yield in the process of catalytic dewaxing was studied in the range from 320°C to 360°C. Feedstock flow rate is equal to 320 m^3/h, hydrogen-containing gas flow rate is equal 15000 m^3/h, pressure is equal to 6.9 MPa. The calculation results are presented in Fig. 2-4.

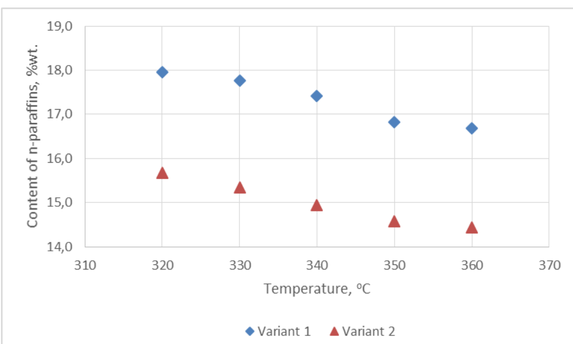

Fig. 2. Dependence of n-paraffins content in the product on the process temperature

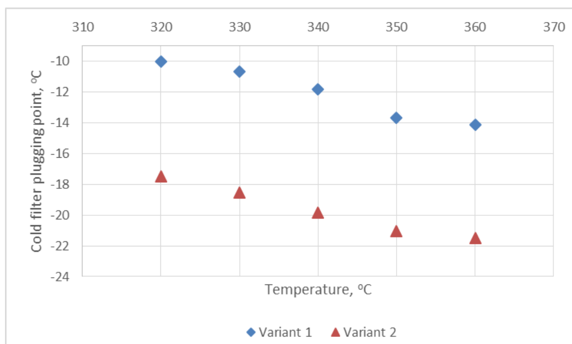

Fig. 3. Dependence of cold filter plugging point of the product on the process temperature

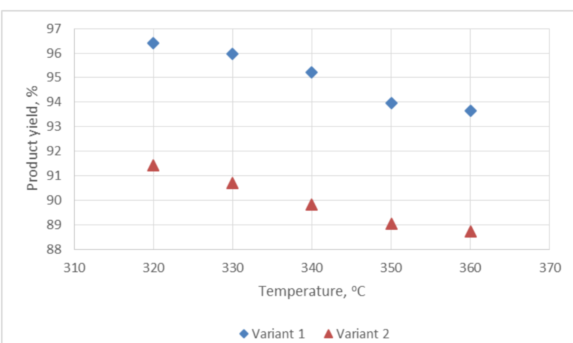

Fig. 4. Dependence of the product yield on the process temperature

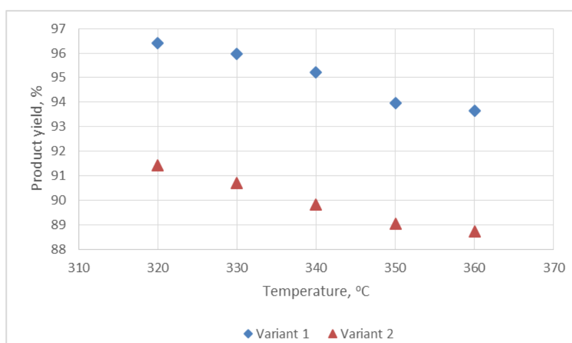

Fig. 5. Dependence of n-paraffins content in the product on the feedstock flow rate

As it can be seen in Fig. 2, the increase in process temperature by 40°C (from 320°C to 360°C) the content of n-paraffins in the product decreases by 7.2 % (from 18.0 %wt. to 16.7 %wt.) when the unit operates according to "Variant 1", and by 7.9 % (from 15.7 %wt. to 14.4 %wt.) when the unit operates according to "Variant 2". This is due to intensification of the target reaction of hydrocracking, which leads to the higher conversion of n-paraffins in this reaction during the time of contact of feedstock with catalyst. Due to the decrease in the content of n-paraffins the cold filter plugging point of the product decreases by 41 % (from –10°C to –14°C) when the unit operates according to "Variant 1", and by 23 % (from –17°C to –21°C) when the unit operates according to "Variant 2" (Fig. 3). The yield of the product decreases by 2.8 % (from 96.4 % to 93.6 %) when the unit operates according to "Variant 1", and by 2.7 % (from 91.4 % to 88.7 %) when the unit operates according to "Variant 2" (Fig. 4).

3.2. Studying the influence of feedstock flow rate on the dewaxing process

The influence of feedstock flow rate on the content of n-paraffins in the product (diesel fuel), product cold filter plugging point and product yield in the process of catalytic dewaxing was studied in the range from 290 m^3/h to 320 m^3/h. Temperature is equal to 350°C, hydrogen-containing gas flow rate is equal 15000 m^3/h, pressure is equal to 6.9 MPa. The calculation results are presented in Fig. 5-7.

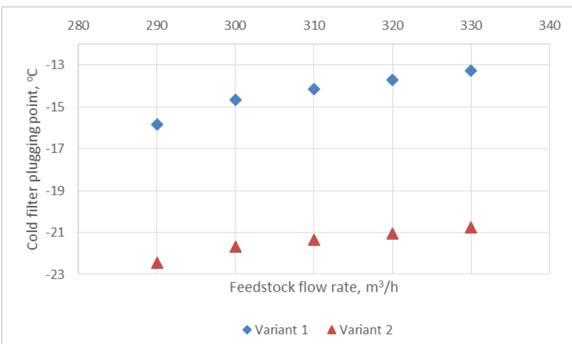

Fig. 6. Dependence of cold filter plugging point of the product on the feedstock flow rate

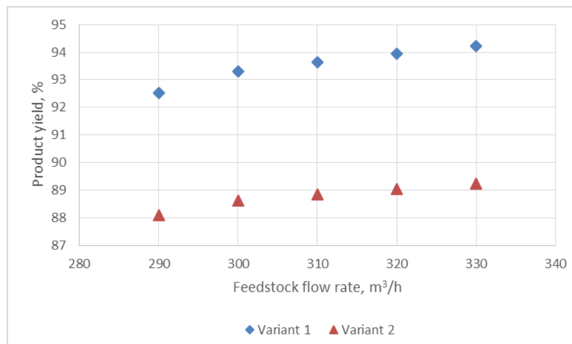

Fig. 7. Dependence of cold filter plugging point of the product on the feedstock flow rate

Increase in the feedstock flow rate by 40 m^3/h (from 290 m^3/h to 330 m^3/h) leads to insignificant increase in the content of n-paraffins in the product by 4.9 % (from 16.2 %wt. to 17 %wt.) when the unit operates according to "Variant 1", and by 3.7 % (from 14.1 %wt. to 14.7 %wt.) when the unit operates according to "Variant 2" (Fig. 5). Due to this the cold filter plugging point increases by 16 % (from –16°C to –13°C) when the unit operates according to "Variant 1", and by 8 % (from –22°C to –21°C) when the unit operates according to "Variant 2" (Fig. 6). Meanwhile, the product yield increases by 1.7 % (from 92.5 % to 94.2 %) when the unit operates according to "Variant 1", and by 1.1 % (from 88.1 % to 89.2 %) when the unit operates according to "Variant 2" (Fig. 7).

In spite of the fact that lower feedstock flow rate ensures higher conversion of the feedstock and improving the cold filter plugging point, the yield of the product is the lowest along with the lowest unit productivity.

3.3. Optimization of temperature mode in the reactor depending on the feedstock composition and flow rate

Studying of the influence of temperature and feedstock flow rate on the dewaxing process, allowed revealing that increase in temperature and decrease in feedstock flow rate provides improving cold flow properties of diesel fuel. However, the yield of diesel fuel decreases. Hence, the aim of optimization is to determine the process temperature, which ensure meeting the product specifications at the maximum yield.

Optimization of temperature mode in the dewaxing reactor was carried out for feedstock flow rates of 280 m^3/h, 300 m^3/h and 320 m^3/h. Flow rate of hydrogen-containing gas is equal to 15000 m^3/h, pressure is equal to 6.9 MPa.

For the first variant of unit operation the temperature of the process was optimized in order to obtain diesel fuel EURO interseasonal (grade E) [31] with cold filter plugging point equal to −15 °C. The results of optimal temperature determination are presented in Table 4.

Table 4. The results of optimization for the feedstock

Feedstock flow rate, m^3/h	Optimal temperature, °C	Content of n-paraffins in the product, % wt.	Cold filter plugging point of the product,°C	Diesel fuel yield,%wt.
	342	16,76	−14	93
280	**347**	**16,38**	**−15**	**92**
	352	16,06	−16	91
	348	16,65	−14	93
300	**353**	**16,40**	**−15**	**92**
	358	16,33	−15	92
	352	16,75	−14	93
320	**357**	**16,67**	**−15**	**93**
	362	16,71	−15	93

For the second variant of unit operation the temperature of the process was optimized in order to obtain diesel fuel EURO winter (grade 0) [31] with cold filter plugging point equal to −21°C. The results of optimal temperature determination are presented in Table 5.

Table 5. The results of optimization for the feedstock composition corresponding to operation of the dewaxing unit according to "Variant 2"

Feedstock flow rate, m^3/h	Optimal temperature, °C	Content of n-paraffins in the product, % wt.	Cold filter plugging point of the product,°C	Diesel fuel yield,%wt.
	330	15,1	−19	90
280	**335**	**14,85**	**−20**	**89**
	340	14,59	−21	88
	333	15,1	−19	90
300	**338**	**14,88**	**−20**	**89**
	343	14,64	−21	88
	337	15,07	−19	90
320	**342**	**14,85**	**−20**	**89**
	347	14,66	−21	88

According to the results of optimization the following conclusions were made:

1. When increasing the feedstock flow rate in the dewaxing process the maintaining optimal temperature allows obtaining diesel fuel with required cold flow properties (cold filter plugging point of −15°C and −20°C respectively for interseasonal and winter diesel fuel) while ensuring high product yield (93 % and 89 % respectively for interseasonal and winter diesel fuel).
2. In the range of feedstock flow rate from 280 m^3/h to 320 m^3/h the optimal temperature in the dewaxing reactor lies in the range from 347°C to 357°C for the feedstock, consisting of straight run diesel fraction, atmospheric gasoil and gasoline from visbreaking ("Variant 1"), and from 335°C to 342°C for the feedstock, consisting of atmospheric gasoil and gasoline from visbreaking ("Variant 2").

4. Conclusions

The influence of temperature and feedstock flow rate in the rages 320–360°C and 290–330 m^3/h respectively on the cold flow properties and yield of the product (diesel fuel) was studied depending on the feedstock composition. The temperature mode of the process was optimized depending on the composition and feedstock flow rate.

Acknowledgements

Ministry of Education and Science of the Russian Federation (10.8306.2017/6.7) supported the research. The research is carried out at National Research Tomsk Polytechnic University and within the framework of National Research Tomsk Polytechnic University Competitiveness Enhancement Program grant.

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