Distillation of vacuum gas oil in a column with new packings

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Abstract. A description of the technological scheme of the unit for separating the fraction of vacuum gas oil (FVG) is given, where the process of separation of heavy gas oil from FVG takes place in the column. The main focus of the work is on the design of a distillation column using the new structured roll packing. The fractional composition of the feedstock, by-product, light gas oil, and the target product, which is heavy gas oil, is presented. Requirements for the design of a structured packing in terms of pressure drop and separation efficiency are formulated. A structured roll packing with corrugations and rough surface having specific surface area of 300 m²/m³ is chosen. The diagram and photograph of the packing are presented. Comparative values of specific pressure drop for several structured packings are given. It is shown that the selected packing provides the lowest hydraulic resistance. For mathematical modeling and calculation of the multicomponent distillation process, a system of mass transfer equations with interfacial bulk sources of transfer components is used. In this case, for the conditional component, a fraction at the specified boiling points is used. As a result of solving the system of equations with boundary conditions, the profiles of the fractions along the height of the packed bed are found and the structural characteristics of the structured packing are selected that meet the requirements for the top and bottom of the column. Calculations of a vacuum distillation column with this packing are carried out and it is found that the bed height of 6 meters is sufficient to meet the requirements for the fractional composition of the upper and lower products, while meeting the pressure drop requirements. The developed scientific and technical solutions have been implemented at a refinery in Malaysia and correspond to the technical specifications for the design of the unit.

1. Introduction
Mathematical modeling and selection of instrumentation for the separation of oil mixtures by distillation are relevant for both fundamental science and applied research for oil and gas refining [1-3]. It is known that distillation is one of the most energy-intensive processes, and mass transfer columns have a complex design and increased metal consumption [4-5]. Depending on the conditions of the process of separating mixtures in the columns, bubbling, jet, packed or combined gas-liquid contact devices are used [6-8]. If the column operates at reduced pressure, the columns are called vacuum columns and are used mainly for the distillation of heavy hydrocarbon mixtures [9-12].

2. Materials and methods
The unit for separating the fraction of vacuum gas oil (FVG) is intended to separate heavy gas oil from the broad FVG in order to provide the extract normalization unit with raw materials. The feed capacity of the unit is 65 thousand tons per year.
The FVG separation unit consists of the following modules (figure 1).

- Module for separation of FVG by vacuum distillation in a packed column K-1;
- Module for distillate condensation and cooling in air heat exchanger T-1 with distillate collection tank E-1;
- Module for cooling the finished product in the heat exchanger-recuperator T-2 and in the air heat exchanger T-3;
- Module for heating the bottom liquid in the Π-1 furnace;
- Vacuum creating system.

The purpose of the present work is to design the K-1 vacuum distillation column with a scientifically grounded choice of a high-efficiency packing of a structured type, as well as to use a plate heat exchanger with a high specific surface area developed by the authors as a heat exchanger-recuperator T-2.

According to the design, the vacuum distillation unit with the K-1 column has a feed capacity of 194.3 tons per day, i.e. 8.1 tons per hour. Column diameter is 1200 mm; column height is 16336 mm.

The commissioning of this unit will ensure the release of light fraction of FVG and heavy fraction of FVG (fractional composition of the mixtures is given in table 1):

- Target bottom product is a heavy FVG with a boiling point of 380–540 °C, which is a feed for a unit for the oil extracts normalization;
- Top by-product is a light FVG with a boiling point of 300–420 °C, which is used as a feed for petrochemical processes.

The initial raw material with an initial temperature of 60 °C is pumped into the heat exchanger-recuperator T-2, where it is heated by the heat of the finished product to the required temperature of 220-280 °C, i.e. close to the initial boiling point of the initial mixture under vacuum. Then the mixture is fed through the throttle to the upper part of the K-1 vacuum column through the flow distributor.

The temperature regime of the feed supply at the inlet to the column is maintained by controlling the flowrate of the hot heat carrier (heavy FVG).

At the entrance to the column K-1, partial evaporation of the lightest fractions of the feedstock occurs due to heat when the pressure is reduced to vacuum. The unevaporated liquid phase of the
feedstock enters the section with packing and flows in the form of a film over its surface into the column bottom, interacting with the vapor flow that rises from the column bottom after the Π-1 furnace. The process of vacuum distillation takes place on the structured packing of height H1. To separate the droplet liquid that can be carried away by the rising vapor, a separating section of the packing of height H2 is provided in the upper part of the column.

Table 1. Fractional composition of gas oil.

| Fractional composition, % | Feedstock, °C | By-product - light gas oil, °C | Target product - heavy gas oil, °C |
|---------------------------|---------------|-------------------------------|----------------------------------|
| 5                         | 351.76        | 302.86                        | 384.74                           |
| 10                        | 368.43        | 319.90                        | 398.17                           |
| 15                        | 380.92        | 331.44                        | 407.64                           |
| 20                        | 391.36        | 339.95                        | 415.16                           |
| 25                        | 399.87        | 346.82                        | 421.59                           |
| 30                        | 407.28        | 352.44                        | 427.59                           |
| 35                        | 414.30        | 357.56                        | 433.61                           |
| 40                        | 421.26        | 362.17                        | 439.80                           |
| 45                        | 427.99        | 366.69                        | 445.97                           |
| 50                        | 434.73        | 371.14                        | 452.21                           |
| 55                        | 441.63        | 375.40                        | 458.63                           |
| 60                        | 448.87        | 379.85                        | 465.38                           |
| 65                        | 456.48        | 384.38                        | 471.81                           |
| 70                        | 464.66        | 389.09                        | 478.51                           |
| 75                        | 473.22        | 394.33                        | 486.21                           |
| 80                        | 482.42        | 399.92                        | 494.97                           |
| 85                        | 492.99        | 406.31                        | 504.98                           |
| 90                        | 505.84        | 414.19                        | 516.92                           |
| 95                        | 522.44        | 424.88                        | 533.39                           |

The vapor flow from the top of the column K-1 enters the air cooler-condenser T-1, where it is condensed and cooled to 70 °C. The fraction of waste is 11.68 wt.%. The cooled condensate is collected in tank E-1 and then pumped to the storage vessel.

The vapor flow at the bottom of the column is created by intensively heating part of the bottom liquid in the Π-1 furnace. Evaporation in the column occurs only due to the heat of heating the flow (up to 310 °C) when the pressure is reduced to vacuum.

Part of the bottom liquid from the Π-1 furnace enters the heat exchanger-recuporator T-2, in which it gives off heat to the feedstock, after which it is additionally cooled in the air cooler T-3 and then fed to the storage vessel.

The vacuum in the column is created using a vacuum creating system based on a vacuum pump. The vacuum line is connected to the E-1 tank (the line is not shown in the scheme).

3. Selecting the packing design

For a vacuum distillation column, the packing, in addition to its high separation capacity, must provide a low hydraulic resistance due to restrictions on the pressure drop in the upper and lower parts of the apparatus. Therefore, the choice of packing type is limited to structured roll or plate type designs. During distillation, the resistance to mass transfer is concentrated both in the liquid and in the vapor phases (somewhat more in the vapor phase), and then the packing should provide a turbulent regime of vapor movement and wave flow of the film. This mode is ensured by corrugated metal sheets, with the corrugations at an angle to the horizon (30-45°), and an artificially rough surface. The roughness ensures the wave flow of the film even at low Reynolds numbers.
These requirements are met by a structured roll corrugated packing with an applied roughness on the surface (protrusions with a height of about 1 mm and with a pitch of 3 mm). A structured packing is shown in figure 2, and a photograph of the manufactured packing for an industrial column is shown in figure 3 [11].

Depending on the height of the corrugation, the packing can be manufactured with a specific surface area of 200 to 350 m²/m³ and has a free volume of 0.95 m³/m³ [11].

\[
\frac{\Delta p_{\text{irrigated}}}{H} \text{, Pa/m} \tag{1}
\]

Figure 4 shows comparative values of the specific pressure drop for structured packings for the air-water system under normal conditions. As follows from the data presented, the selected design of the structured packing has the lowest hydraulic resistance.

4. Conclusion
To calculate the process of separating vacuum gas oil into specified fractions, a system of differential equations of the diffusion model of the flow structure is used [11]. The one-dimensional equations of the diffusion model are written for the liquid and vapor phases, where mass transfer is considered due to volumetric interfacial sources, together with the conditions of thermodynamic equilibrium. As a result of calculations, it is found that six meters of the packing height is sufficient for a given quality
of separation of the FVG (table 1). The considered design of the packing can be used in the modernization or design of industrial distillation apparatus.

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References
[1] Golubeva I A, Khudyakov D S and Rodina E V 2020 Chemistry and Technology of Fuels and Oils 56.3 395-404
[2] Ledenev S M, Shubitova N V and Zhirmov V V 2020 Chemistry and Technology of Fuels and Oils 56.1 9-11
[3] Kulov N N, Maksimov V V, Maljusov V A and Zavoronkov N M 1979 The Chemical Engineering Journal 18.3 183-8
[4] Ivanov I V, Lotkhov V A, Kulov N N and Moiseeva K A 2016 Theoretical Foundations of Chemical Engineering 50.5 667-77
[5] Kagan A M, Pushnov A S and Ryabushenko A S 2007 Khimicheskaia Tekhnologiya 8.5 232-40
[6] Gorodilov A A, Pushnov A S and Berengarten M G 2014 Chemical and Petroleum Engineering 50.1-2 84-90
[7] Dmitrieva G B, Berengarten M G, Kagan A M, Pushnov A S and Klimov A G 2007 Chemical and Petroleum Engineering 1 11-4
[8] Komissarov Y A, Ravichev L V and Kiselev M S 2019 Theoretical Foundations of Chemical Engineering 53.5 747-59
[9] Telyakov E S, Ponikarov A S and Osipova L E 2018 Theoretical Foundations of Chemical Engineering 52.1 11-23
[10] Telyakov E S, Osipova L E and Ponikarov A S 2018 Teoreticheskie Osnovy Khimicheskoi Tekhnologii 52.1 13-25
[11] Laptev A G, Basharov M M, Lapteva E A and Farakhov T M 2020 Models of interphase transport and calculation of process efficiency. Part 2. Heat and mass transfer processes (Kazan: Center for innovative technology) 565
[12] Babiev V A, Korovin P I, Lagutkin M G, Generalov M B and Sidelnikov I I 2018 Chemical Industry Today 5 26-9