The separation of heavy crude oil by spray evaporation

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Abstract. Studies have shown a significant intensification of the process of flash evaporation by spraying heavy oil through a nozzle. By changing the temperature in the apparatus and the pressure gradient, the carryover of the liquid phase by the distillate was set within the required limits. Results on flash evaporation of heavy crude oil at 200, 250, 300 and 350°C without spraying and with spraying through nozzles showed a significant intensification of the process with an increase in the yield of the distillate product from 22 to 67 wt %. Upon reaching a moderate degree of entrainment of 6 wt % with an increase in the yield of distillate to 43 wt % at 300°C, the viscosity of the distillate at 20°C does not exceed 15 sSt, density 0.8199 g/cm³, sulfur content no more than 2 wt %. Intensive flash evaporation process can be successfully used for the primary refinement of heavy high-viscosity oils. As a result of the process, two products from heavy oil are produced: high-quality light distillate, enriched in fuel fractions, and the residue, which can serve as raw material for the bitumen production.

1. Introduction

Due to the depletion of conventional oil deposits at present, Russian oil and gas companies are paying increasing attention to the development of deposits of heavy oil. Reserves of heavy hydrocarbon resources are among the main alternative energy resources of the XXI century. Based on their physical and chemical properties, super-viscous oil and natural bitumen significantly differ from conventional oil. Their main differences are associated with a low content of fractions boiling up to 350°C, a high content of sulfur compounds, resins, asphaltenes in their composition, which leads to their abnormally high viscosity and lower thermal stability, and, therefore, their processing is very difficult, energy intensive and low profitable or unprofitable [1-6].

The development of heavy hydrocarbon resources seems possible due to the evolution of processing technologies. At present, leading scientists and experts in the field of the development of heavy hydrocarbon resources have come to the conclusion that the primary crude processing should be carried out directly at production units. For this purpose, it is advisable to use energy-saving technology of separating oil into light and heavy parts, based on the principles of flash evaporation. Flash evaporation of super-viscous oil proceeds in a sprayed mode [7, 8]. The separation efficiency will be determined by the equilibrium state between the liquid and vapor phases, and will depend on the residence time of the raw material in the column and the surface area of the interface. There is a high probability of hydrodynamic equilibrium, when the number of molecules passing from the liquid phase to the vapor
phase and vice versa increases with time. The composition of the distillate can be varied over a wide range by controlling droplet carryover by the vapor phase, which depends on the nozzle design, its location in the apparatus, and hydrodynamic conditions in the apparatus [9]. Thus, it is possible to provide the maximum possible yield of distillate with desired characteristics.

The present study is devoted to the creation of a simple method for the separation of heavy hydrocarbon feedstocks, based on the multiple increase in the working surface of the liquid phase during its intensive evaporation due to spraying the latter.

Despite the huge interest of scientists in heavy, highly viscous oils capable of replenishing the reserves of light conventional oils, the most important unsolved problem is the lack of an experimental data on their refinement and separation in relation to various technological factors.

2. Methodology

The object of the study was the heavy oil of the Romashkinskoye field of the Republic of Tatarstan lying in terrigenous deposits of the Carboniferous period of the Tournaisian stage of the central part of the South Tatar arch, characterized by a density of 0.9127 g/cm³ and a viscosity of 140 sSt at 20°C, a content of saturated and aromatic hydrocarbons of 35.6 and 36 wt %, resins - 23 wt %, asphaltenes - 5.4 wt %, light fractions boiling up to 350°C - 37 vol. %, sulfur - 3.4 wt %.

The studied process of flash evaporation occurs when heated heavy oil is poured under pressure and sprayed in a hollow reactor using a nozzle [10]. A centrifugal nozzle with a tangential supply of oil to the chamber was selected to spray heavy oil and obtain a compact torch of swirling boiling liquid (Figure 1). Experiments were carried out in a cylindrical vertical apparatus R-102, operating at a pressure of 0.3 MPa, with the spraying of raw materials in the upward direction and equipped with an N-102 furnace with feed lines for feeding raw materials, output of the distillate vapor-liquid mixture (“light”) and removal of residual fractions (“heavy”) (Figure 2). The light fraction was then condensed in the refrigerator and discharged as distillate. The heavy residual fraction (bottoms) is also cooled and collected. Spraying of raw materials in the direction from the bottom upwards allows low-boiling components enclosed in drops to diffuse to their surface and evaporate. Evaporation from the surface of the droplet is also facilitated by blowing of lighter fractions rising from the bottom upwards, whereby droplet entrainment of higher boiling components occurs, which remain in the residue during conventional evaporation.

![Figure 1. Nozzle design](image1.png)  
![Figure 2. Reactor schematic](image2.png)
On entering the hollow apparatus, where the pressure is lower than in the nozzle, the sprayed heavy oil boils. On a first approximation, the mass transfer process is controlled by aerodynamic parameters of the reactor, which depend on the droplets dispersion, their speed, spray angle, and contact time of the vapor and liquid phases [11]. The residence time of the liquid phase in the sprayed state after exiting the nozzle ensures the evaporation of droplets; for large droplets, the evaporation process is delayed due to poor heating. With an increase in droplet size, the heating time also increases, the course of the evaporation process drops, the range and diameter of the torch increase.

For the initial heavy oil, the light product (distillate) and the residual heavy fraction (bottoms), the fractional composition was determined up to 350°C in accordance with GOST 2177, density - according to GOST 3900, viscosity at temperatures of 20 and 50°C - GOST 33, sulfur content according to GOST 1437.

3. Results and discussion

The main technological parameters of heavy oil separation, in addition to product output, are the amount of high-boiling and low-boiling compounds characterizing the deviation from the fractional composition, density, viscosity and sulfur content, which determine the possibility of their transportation through existing oil pipelines. Figure 3 shows the quantitative yield of light and heavy products obtained by separating heavy oil by a flash evaporation method without spraying and with spraying; Figures 5-7 show their main characteristics. Flash evaporation of heavy crude oil at 200°C without spraying and with spraying through a nozzle indicates a significant intensification of the process with an increase in the yield of distillate fractions from 22 to 39 vol. % (Figure 3). The separation of heavy crude oil by spray evaporation process is non-equilibrium, a shift from phase equilibrium occurs in the direction of increasing the yield of the distillate due to its enrichment with heavy boiling components (Figure 4). A significant effect is achieved with increasing process temperature.

Figure 3. The output of the distillate vapor-liquid mixture of "light" and residual fractions of "heavy"

Figure 4. Deviation from the potential content of light and heavy products to light fractions up to 350°C and dark fractions above 350°C (entrainment)
As temperature rises to 350°C, the yield of light fractions during spraying increases from 35 to 55 vol. %, considering a potential content of light low boiling fraction (boiling up to 350°C) in the initial heavy oil 37 vol. %, an increase of 18 vol. % occurs due to the droplet entrainment of heavy components from the heavy residual fraction (bottom). As a result, an increase in the process temperature leads to a significant entrainment of high-boiling compounds of heavy oil with boiling points above 350°C.

Based on the experimental data, it is necessary to avoid short residence time of sprayed droplets in the reactor at temperatures less than 300°C, due to incomplete extraction of the distillate fractions from heavy oil. When a high degree of separation is achieved at 350°C with an increase in the yield of distillate to 35 wt. %, its viscosity at 20°C does not exceed 13 sSt, on the contrary, at similar thermodynamic process carried out with spraying, the viscosity of the upper product increases to 22.5 sSt with an increase in density from 0.8028 to 0.8446 g/cm³. With an increase in the yield of distillate from 32 to 43 vol. %, when the temperature of a flash evaporation process with spraying is increased from 250 to 300°C, the viscosity of the light fraction at 20 °C does not exceed 15 sSt, which abides light commercial oils standards.

As a result of a flash evaporation of heavy oil, sulfur compounds are concentrated in the bottom residue. The spraying of heavy oil during flash evaporation process intensifies this process (Figure 7).
Figure 7. Sulfur content of light and heavy products

With increasing temperature of flash evaporation from 200 to 350°C, with the spraying of heavy oil, the sulfur content in the distilled product increases from 0.95 to 2.34 wt %, versus 3.5 wt % in the original heavy oil. It is worth noting that during flash evaporation of heavy oil without spraying with an increase in the process temperature from 200 to 350°C, the sulfur content light fractions does not exceed 1.6 wt %.

Heavy residues, resulting from flash evaporation process with the spraying of heavy oil, contain a significant amount of resin from 37 to 63 wt % and asphaltenes from 7 to 12 wt %. The absence of saturated and light aromatic hydrocarbons makes them an attractive raw material for obtaining high-quality bitumen materials with high adhesive properties to mineral fillers.

4. Conclusion

Studies have shown a significant intensification of the process of flash evaporation by spraying heavy oil through a nozzle. By changing the temperature in the apparatus and the pressure gradient, the carryover of the liquid phase by the distillate was set within the required limits. Results on flash evaporation of heavy crude oil at 200, 250, 300 and 350°C without spraying and with spraying through nozzles showed a significant intensification of the process with an increase in the yield of the distillate product from 22 to 67 wt %. Upon reaching a moderate degree of entrainment of 6 wt % with an increase in the yield of distillate to 43 wt % at 300°C, the viscosity of the distillate at 20°C does not exceed 15 sSt, density 0.8199 g/cm³, sulfur content no more than 2 wt %. Intensive flash evaporation process can be successfully used for the primary refinement of heavy high-viscosity oils. As a result of the process, two products from heavy oil are produced: high-quality light distillate, enriched in fuel fractions, and the residue, which can serve as raw material for the bitumen production.

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