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Improvement of energy efficiency of motor fuel production at oil refinery

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Abstract. This work presents a complex of technological solutions aimed at possible improvement of performance efficiency of oil refinery plants. These technological solutions are based on the control mechanisms of consumer material-heat balance for obtaining an optimum balance between fractionating accuracy of the obtained distillates, process energy characteristics and increase of the thermal energy integration at the plant. At this the proposed solutions do not provide the changes of the basic plant equipment, and no significant capital investments should be made for its implementation.

1. Introduction

Nowadays the issues concerning energy-efficiency and environmental sustainability are of vital importance for every area of human activities, and power engineering sector of industry is one of the highest-developing [1–11]. Oil refinery industry is one of the branches of huge fuel-and-energy complex, which also includes fuel extraction and production, energy distribution, as well as energy supply, etc. The major unfavorable external factors, which have a negative impact on oil refinery plant (ORP) efficiency, are instabilities of regional oil-energy balances and power supply [12–14]. The internal factors are the following: efficiency of energy-consuming and energy-generating equipment, energy capacity of technological processes, technological stream heat recuperation and regeneration degree. Energy-efficient and environmentally-friendly technologies are to be used here. Drastic economy of energy-resources may be obtained through implementation of energy-saving measures and advanced technologies into the most energy-consuming processes, as well as improvement of equipment and unit efficiencies[15–21]. At oil refinery plants the most energy-consuming are the processes of rectification, which consume a large amount of thermal energy in the form of steam, and electrical energy for cooling processes (Figure 1). To the greater extent rectification process is implemented at preliminary oil distillation units [22]. The example of this installation was used to study ways for improvement of energy-efficiency.

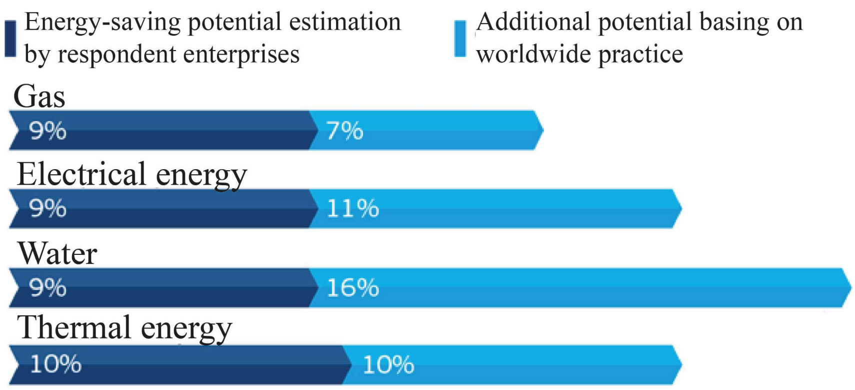

Figure 1. Estimation of energy-savings at modern oil refinery plants.

2. Physical-chemical basis of rectification process

The preliminary oil distillation units, in Russia known as ELOY-AVT (electric desalter unit with atmospheric-vacuum distillation) serve for removal of residual humidity and salts from oil with its further fractionation for obtaining of targeted product assortment (Figure 2).

The basic products which are obtained during oil division at AVT units are light distillates: straight-run gasoline (boiling range is 180 °C), jet fuel (150-220 °C), diesel fuel (180-360 °C), hydrocarbon gas and vacuum distillates (light and heavy vacuum gas oil) and vacuum distillation residue (gudron). Petroleum division for products is performed via rectification.

Rectification process can be organized periodically and continuously. Preliminary oil distillation units at oil refinery plants use nothing else but continuous rectification at various pressures: increased pressure is used for division of low-boiling hydro-carbons (crude oil stripping), near-atmospheric pressure is used for atmospheric distillation, vacuum is used for division of high-boiling hydrocarbons (vacuum distillation) [23].

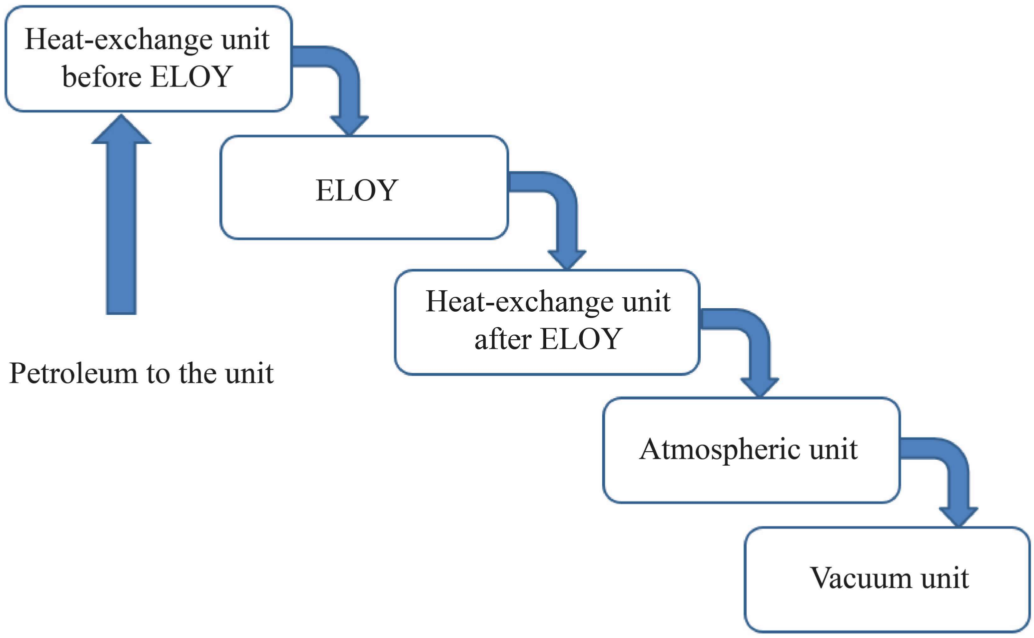

Figure 2. A schematic diagram for ELOY-AVT unit.

The quality of components, obtained at initial mixture division, is governed by its relative volatility (difference in boiling temperatures), relation between liquid and gas phases, and number of contact steps. The major technological parameters of rectification process are temperature mode, pressure, flow rates. Temperature of the rectifying column top defines rectification quality and is automatically maintained by upper delivery (reflux). Bottom temperature defines stripping degree from light-boiling components and is maintained by heat supply from pipe furnace. As for pressure, at its increase the fractionating accuracy deteriorates, as the relative volatility of the divided components is decreased.

Reflux supply to the upper part of the column is altered gradually in order not to cause reduction of its liquid level (flooding mode). At insufficient reflux supply, the top column temperature increases, and rectificate end-boiling temperature increases significantly. At excess reflux, the top column temperature decreases, rectificate end-boiling temperature decreases, its high-boiling components transform into residual. Increasing of reflux amount at relevant temperature raise of column bottom improves rectification sharpness.

3. Usage of energy potential of secondary energy-resources

The waste thermal energy is usually classified according to three temperature ranges: high-temperature (higher than 650 °C); medium-temperature (230÷650 °C); low-temperature (less than 230 °C). High- and medium-temperature thermal energies are used at oil refinery for steam generation of technological parameters, electrical energy, warming of air supplied at burner devices. Low-temperature thermal energy is used for heating of buildings, water and air. The main sources for thermal secondary energy-resources (SER) at oil refinery are the following;

- Flue gases of heating furnaces (300÷500 °C);
- Hot flows of liquid and gaseous oil products (125÷385 °C). After its' usage at technological cycle, the heat is removed at compressor-refrigerator (40÷90 °C);
- Thermal resources of light-fractions overhead (102÷125 °C), which are not used at Russian ORP.
- Thermal resources of combustion products, which are obtained during decoking of the catalyst processes (580÷600 °C), as well as whose failing to find complete usage for additional electrical energy generation at Russian installations of catalytic cracking;
- Thermal resources of condensate (70÷85 °C), exhaust steam (139 °C at P = 0.3 MPa) and hot water (45÷110 °C).
- The methods for waste heat utilization at ORP are the following:
- Direct utilization for heating of raw materials at the absence of heat-exchangers (so-called "heat tracers");
- Heat recuperation of production flows or exhaust gases at heat-exchangers or exhaust-heat boilers (EHB) for production of process steam or hot water;
- Regeneration of exhaust gases at air heaters or heat of product flows at combined units;
- Cogeneration with generation of electrical and thermal energies.

Regeneration of heat of warmed product flows is rather widely used at technological schemes at oil refineries. Excess heat of hot petroleum products at temperature 110÷160 °C and consumption more than 20 m^3/h is usually used for warming of chemically purified water (feeding of exhaust-heat boilers and water of industrial cogeneration), obtaining of freeze at absorption refrigeration units; while at temperature more than 160 °C it is used for steam obtaining. In order to cool-down the petroleum product flows with steam obtaining one use evaporators with steam chambers which are fed by condensate, collected at the unit. The majority steam consumers use only steam condensation heat and distribute condensate at saturation temperature [24,25].

Regenerative and recuperative air heaters and exhaust-heat boilers are widely used for utilization of flue gases thermal energy. It's a common practice to utilize heat of furnaces of efficiency more than 25 GJ/h at exhaust gases temperature higher than 220 °C. It should be noted that due to mismatch between real and design temperatures of exhaust gases at operating units, the exhaust-heat boiler efficiency is less than passport one. Special aspect of exhaust-heat boiler exploitation at ORP is instability of heating gas consumption, which leads to significant load fluctuations at exhaust-heat boilers [25,26].

4. Development of ELOY-AVT model

Computer model development was performed at Aspen HYSYS environment, which is widely used for various technological process modeling [27,28]. In order to calculate physical-chemical properties of petroleum we used design data on composition and properties of narrow fractions for typical Russian installation ELOY-AVT-7 (annual production of crude oil is 7 mln tones per year). As a thermodynamic package we chose Peng-Robinson equation of state. It allows one to calculate with high accuracy equilibrium and thermodynamic parameters of hydrocarbon systems at pressures lower than 30 MPa [29].

It was established that atmospheric column furnaces H0801A/B set limits for unit efficiency improvement. When they are loaded for 120%, temperature of pipe coil walls is close to maximum allowable one (650 °C), flue gases temperature is more than 300 °C, which states for low thermal efficiency of the furnace.

In order to reduce thermal load at H0801A/B/C furnaces, we suggest to warm up stripped oil, supplied from C0401 column cube by high-potential gudron flow from vacuum column C0501 (Figure 3). Gudron flow is the highest-potential technological flow at this installation, its temperature is 362 °C. We chose gudron for oil warming up as it has rather high ratio of hot/cold coolant due to its high content in petroleum (about 25%). For implementation of this solution we suggest to use the existing heat-exchanger for oil warming up before ELOY E-104A with surface area of 427.4 m^2.

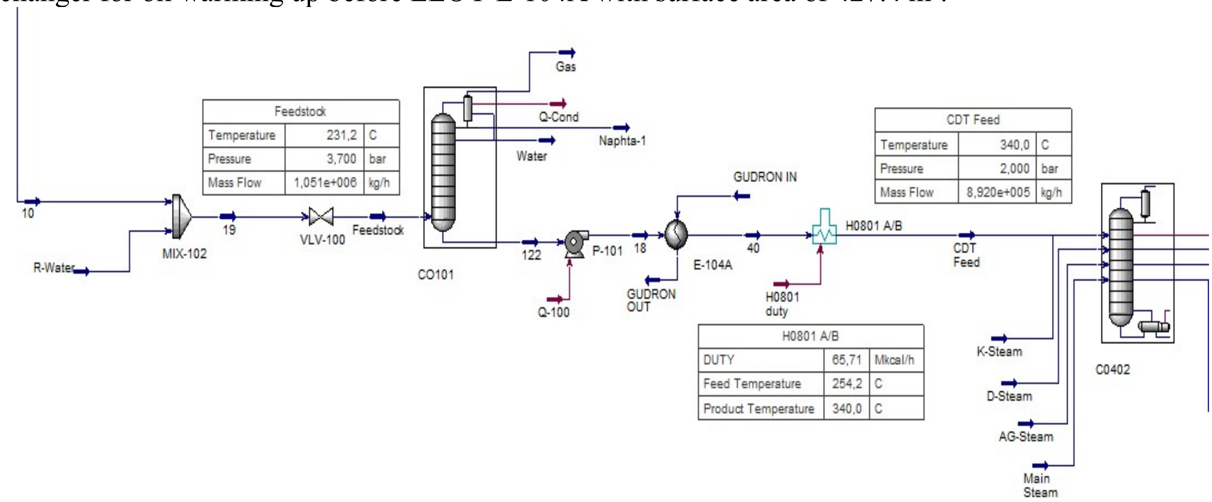

Figure 3. ELOY-AVT unit modeling in Aspen HYSYS environment.

After stripped oil warming up by gudron, its temperature before the furnace H0801 A/B increased from 230 to 254 °C, while thermal load decreased from 79.36 to 65.71 Gcal, which is 17%.

After stripped oil warming before the atmospheric furnaces H0801 A/B/C a drastic reduction of gudron temperature took place (up to 280 °C). To compensate heat, directed at reduction of H0801A/B/C furnaces load, one should increase heat recuperation degree at heat-exchange unit before and after ELOY. For this purpose we redistributed heat balance of the main atmospheric column C0402: recovery of higher-potential 2nd and 3rd pumparound (PA) was increased, recovery of low-potential 1st PA was decreased. This resulted in 1st PA load reduction from 21.82 to15.42 Gcal/h, 2nd and 3rd PA load increase, which allows increasing of recuperation degree at oil warming unit after ELOY. Load redistribution between pumparounds was performed in such a way that provided maximum recovery increase of high-potential 2nd and 3rd PA. At this the quality indicators were maintained within the specification limits.

5. Conclusions

This work presents a variant for ELOY-AVT unit modernization. Here we suggest warming up of a stripped oil flow part before the H0801A/B furnace by gudrone from vacuum column C0501. Using the computer modeling we obtained the following results:

- Change of configuration and connection circuit of the heat-consuming equipment allowed reducing natural gas consumption by H0801 A/B furnace for 15%.
- In order to increase heat recuperation degree we redistributed heat balance at atmospheric column C0402 and changed the arrangement of material warming up unit.
- During material flow optimization we succeeded in improvement of thermal energy recuperation degree at the unit and maintaining of normative oil temperature before the atmospheric block.

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