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EQUIPMENT

MODERNIZATION OF THE VACUUM TOWER IN THE AVT-6 UNIT

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An engineering solution to the problem of improving the economic and environmental indexes of the AVT-6 unit at Moscow Refinery Open Joint Stock Company without significant reconstruction is described.

The vacuum tower in this unit was equipped with valve and sieve straight-through trays before modernization (Fig. 1a). Atmospheric resid was delivered to it after heating in a furnace to 390°C. Steam was fed in underneath the tower and into the furnace for heating the atmospheric resid. The vapors above the tower were sent to three water condensers and then pumped out by one of the two three-stage vapor ejector units. The condensed vapors of the solar (diesel) cut were sent together with water vapors to a barometric condenser and then to separation. The tower had two circulating refluxes: upper (UCR) and middle (MCR). The following were the distillation products: <360°C cut, light and heavy vacuum gasoils (LVG and HVG), and vacuum resid. The temperature at the top of the tower was 130 – 135°C and the pressure was 11.97 – 12.64 kPa. The gases coming out of the condensers had a temperature of 50°C.

The depth of the vacuum created by the vapor ejector units is a function of the amount of vapors pumped out. The typical curve of the inlet pressure p_{in} as a function of vapor flow G_v — the basic characteristic of the ejector pumps, is shown in Fig. 2. This curve has two segments: gently sloping segment I — working, and steep segment II — overload. Important changes in the load have little effect on p_{in} on segment I; on segment II, small changes cause a sharp increase in p_{in}. Point G_w of inflection of the curve in the working segment, corresponding to maximum output, will be called the working point. For the three-stage ejector in the AVT-6 unit, it corresponds to p_{in} = 5.32 kPa and the following loads in evacuated gases: 900 kg/h in air and 400 kg/h in water vapors. The measured vacuum pump pressure was 11.97 – 12.64 kPa, i.e., the existing ejector operated in the overload zone (segment II).

Based on Fig. 2, the ejector overload at p_{in} = 11.97 kPa is 60% (or total load on the injector of 160% if the output of the ejector at the working point is set at 100%). In examining the operation of the heat-exchange equipment together with the vacuum-creating system, we find a direct correlation between the temperature at the outlet of the water condensers (see Fig. 1a) and pressure p_{in} at the inlet into the ejector. In other words, at 50°C, the amount of uncondensed vapors and gases at the outlet from the condensers corresponds to a 160% load on the ejector. As a consequence, the vacuum in the existing vacuum-creating system can only be deepened by reducing the temperature at the outlet from the condensers.

Testing the operation of the corresponding condensers showed:

- their efficiency is very low, despite the significant heat-exchange area (1500 m^2);
- the low heat transfer coefficient is due to the high degree of contamination of the heat-exchange surface to a significant degree according to the calculations;
- the cooling water temperature reaches 27°C in summer;
- the temperature of the pipe walls (40 – 50°C) and the low flow rate of water in the pipes (0.2 – 0.3 m/sec) cause an increase in sludge inside the pipes.

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It is difficult to reduce the temperature at the outlet of the condensers by ordinary methods, since a separate water preparation system which is very expensive to build is required for decreasing the temperature, increasing the flow rate and alkalization (to prevent sludge deposits) of the cooling water.

A new method of decreasing the load on the vacuum ejectors was proposed by PIRO Co.

In operating a vacuum tower with water vapor, water vapors and the diesel cut mixed with uncondensed gases (primarily nitrogen, hydrogen, and $C_1 - C_5$ hydrocarbons) enter the condenser coolers.

Consider the vapor condensation curves (Fig. 3) in vacuum tower condensers operating with water vapor.

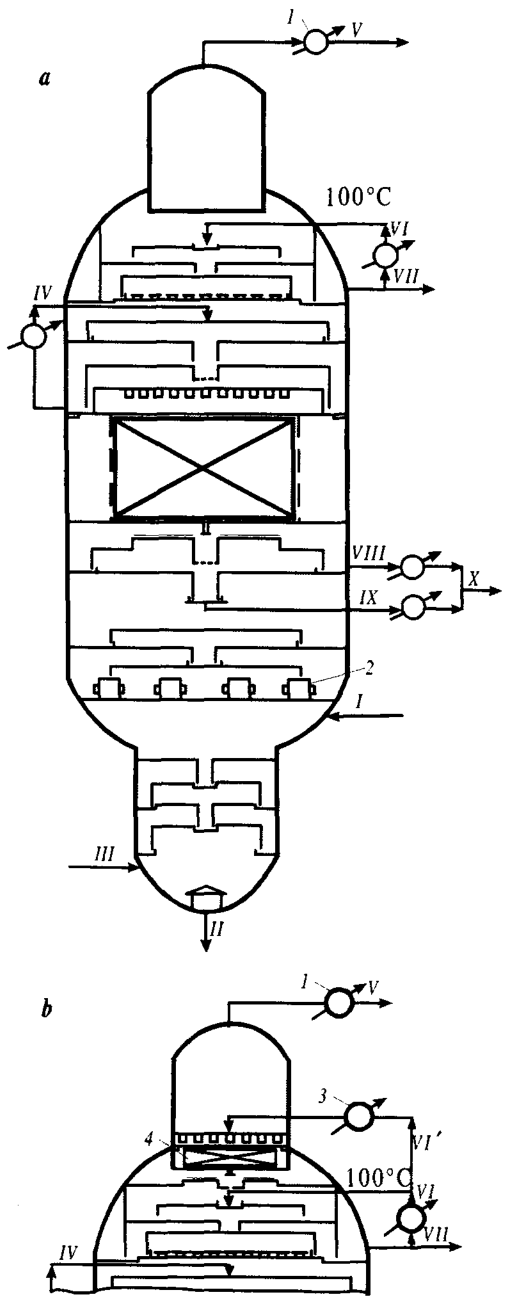

Fig. 1. Diagram of the vacuum tower in the AVT-6 unit: a) before modernization; b) after modernization; 1, 3) water condensers; 2) jet separator; I) atmospheric resid; II) vacuum resid; III) water vapor; IV, VI) middle and upper circulating refluxes; V) to the vacuum-creating system; VI′) additional reflux; VII) cut under 360°C; VIII, IX) light and heavy vacuum gasoils; X) broad vacuum cut.

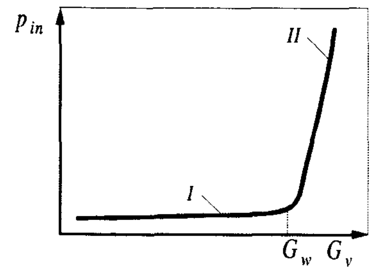

Fig. 2. Characterization of the vapor ejector pump.

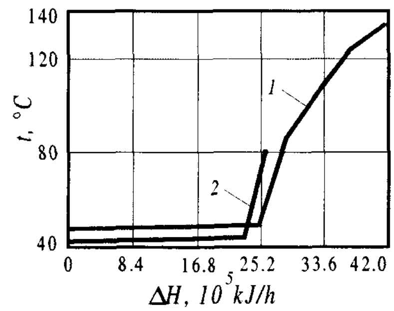

Fig. 3. Curve of vapor condensation in vacuum tower condensers (t, ΔH: temperature and heat of condensation, respectively): 1) at a temperature above the tower of t_a = 135°C, pressure p = 11.97 kPa; 2) for t_a = 80°C, p = 9.31 kPa.

Before reconstruction, the temperature of the vapors at the outlet of the tower was 135°C (curve 1). The condensation curve can be divided into two segments. The first segment corresponds to condensation of vapors of the diesel cut and the second, more gently sloping segment, corresponds to combined condensation of solar and water vapors. The diesel cut vapors should obviously be condensed in the vacuum tower to prevent their entrainment into the condensers together with the water vapors. For this purpose, it was suggested that the temperature of the vapors coming out of the tower be decreased to 80°C.

The calculations showed that for a vacuum tower load in atmospheric resid of 450 t/h, entrainment of the diesel cut decreases from 8.5 to 0.5 ton/h simultaneously with a decrease in the temperature of the vapors at the tower outlet from 135 to 80°C, and this allows decreasing the load on the condensers (see Fig. 3, curve 2) and amount of vapors entering the vapor ejector unit.

Decreasing the amount of diesel cut entrained with the water vapors is also expedient from an environmental point of view.

In "dry" distillation of atmospheric resid (with no water vapor), the effect of the temperature at the top of the tower on entrainment of the diesel cut is also large. The dependence of the amount of diesel cut entrained with uncondensed gases on the amount of uncondensed gases for different temperatures at the top of the tower is shown in Fig. 4. The calculation shows that when this temperature is decreased from 135 to 80°C, not only does entrainment of the diesel cut decrease but also its dependence on the amount of uncondensed gases.

A problem with estimating the amount of uncondensed gases arose in the calculation. Simulation Sciences Inc. (USA) reports the following dependences for this estimation in the documentation for the PRO/II modeling system:

$$G_1 = 2.86 \cdot 0.15 exp[0.495 \times (t_c - 385)]F_m$$

$$G_2 = 2.72(0.151 F_m)^{0.5}$$

where G_1, G_2 are the flow rates of the decomposition and influx gases, kg/h; tc is the temperature at the outlet from the furnace, °C; F_m is the vacuum tower feed flow rate, m^3/h.

According to the calculations with these equations, the gas flow rate should be 260 – 370 kg/h.

We suggested graphic evaluation of the effect of reducing the temperature at the top of the tower on the pressure drop in the system. The vapor-ejector pump overload line is designated by the solid line in Fig. 5. Its output is expressed in percentage of the load in vapors at the operating point of the pump. The calculated amount of vapors at the outlet from the condensers as a function of the pressure at the top of the tower is indicated by the dashed lines. The calculations were performed for a temperature at the top of the tower of 80°C and different amounts of uncondensed gases. The intersection of the flow rate curves of vapors from the condenser with the vacuum pump load curve shows the pressure change sought.

It will be shown below that in practice, the vacuum was deepened by 2.26 – 2.66 kPa, i.e., the amount of

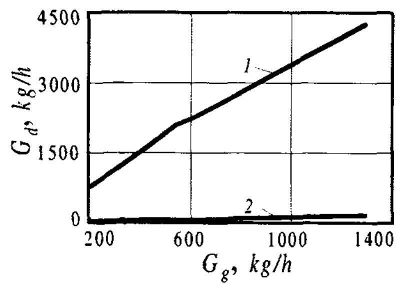

Fig. 4. Effect of the amount G_g of uncondensed gases on the amount G_d of diesel cut entrained with vapors in "dry" distillation of atmospheric resid: 1, 2) of a temperature at the top of the tower of 135 and 80°C.

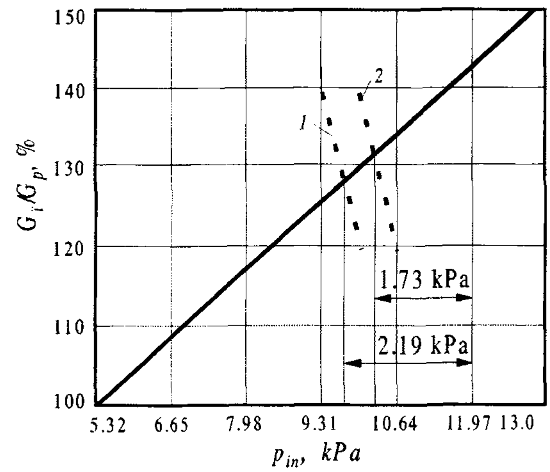

Fig. 5. Graphic evaluation of the effect of decreasing the temperature at the top of the vacuum tower on the pressure drop in the system: 1) p = 9.78 kPa, G_g = 200 kg/h, t_v = 70°C; 2) p = 10.24 kPa, G_g = 500 kg/h, t_v = 80°C.

TABLE 1

Indexes	Cut under 350°C (average value)	Solar cut vapors
Density at 20°C, kg/m^3	870.4	851
Viscosity at 50°C, mm^2/sec	4.3	–
Temperature, °C		
flash point	123	–
solid point	–2	–
Distillation, °C		
IBP	256	143
10%	281	220
20%	290	239
30%	297	251
40%	305	262
50%	312	269
60%	321	278
70%	332	286
80%	345	297
90%	368	309
EP (yield, %)	398 (97)	326 (96)
Yield of cuts vol. %		
under 350°C	83	–
under 360°C	87	–
Sulfur content, wt. %	1.32	1.15
Carbon residue, wt. %	0.0123	–

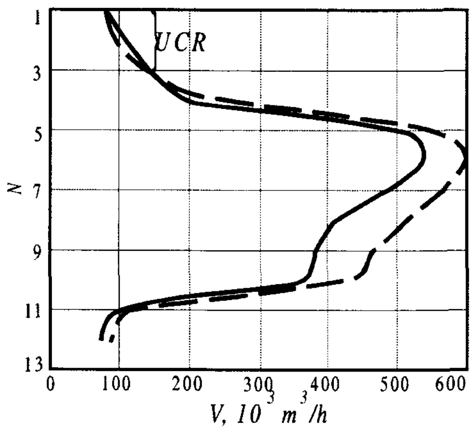

Fig. 6. Change in volume V of vapors over tower height (N is the number of theoretical plates): ———: before modernization (p = 11.97 kPa); — — —: after modernization (p = 9.31 kPa).

uncondensed gases was closer to 200 – 300 kg/h.

A decrease in the solid point of the diesel fuel was predicted simultaneously with deepening of the vacuum when the temperature at the top of the vacuum tower decreased. In fact, not the end point of the cut, but instead the content of low-boiling components affects the solid point of a petroleum product to a significant degree.

The quality indexes of the products of vacuum distillation before the tower was reconstructed are reported in Table 1. In this period, the amount of solar vapors entrained from the tower was significant: 8 – 10 m^3/h. The cut under 350°C from the tower was either returned to the crude oil or sent for preparation of furnace residual fuel oil. The wet diesel fuel cut from the barometric condenser was also returned to the crude oil.

The change in the quality indexes of the cut under 350°C after modernization of the vacuum tower will be discussed below. According to the calculations, as a result of modernization, takeoff of the cut under 350°C increased from 2 to 3% in crude oil.

Based on the above, it was decided to decrease the temperature at the top of the vacuum tower from 135 to 80°C. In this respect, PIRO CJSC was faced with the problem of practical implementation of this solution.

Due to a sharp decrease in the volume of vapors in the UCR zone of the tower (Fig. 6), when there was a significant amount of liquid on the trays in this zone, it was difficult to decrease the temperature at the top of the tower using the trays in the tower alone. For this reason, PIRO CJSC proposed installing a small reflux layer of packing above the upper tower tray (see Fig. 1b), equipped with a rectangular cap distributor and a blind tray with respect to liquid. According to the new scheme, part of the stream of UCR is directed to additional cooling in condenser 3 and is fed to the packing layer as reflux. At the same time the UCR scheme was modernized, the CR trays were restored. In addition, jet spray separators were replaced by spray separators of the rod type.

The results of testing the modernized column indicate the expediency of reducing the temperature in the top part. During the tests, the output in atmospheric resid was 450-530 m3/h, which corresponds to output of the AVT-6 unit in crude oil of 708-833 tons/h (800-950 m3/h).

The temperature at the top of the column was decreased to 80°C and lower, and the residual pressure was on average 8.65 kPa, i.e., 2.66 kPa lower than before modernization. The diesel fuel quality indexes obtained after modernization of the tower are reported in Table 2. The cut under 350°C contains more low-boiling components, and the content of cuts under 360°C is 96-98%, versus 60 – 80% before modernization. After modernization, the diesel cut obtained had a solid point of −10°C and lower, which allows including it (up to 3000 tons/day) in the mixture of 240 – 290 and 290 – 350°C cuts from the atmospheric tower (~7% in diesel fuel) with production of a product which meets the requirements of the company standard. The total takeoff of the cut under 350°C attains 3% in crude oil. Due to this alone, the economic effect of modernization is $3.6 million per year (in December 1998 prices) for a load in crude oil of 6 million tons a year.

At the same time, the savings of atmospheric resid due to elimination of circulation of the diesel fuel cut are 560 kg/h, which is expedient from both environmental and economic points of view.

TABLE 2

Cut, °C	Density at 20°C, kg/m^3	Temperature, °C		Viscosity at 50°C, mm^2/sec	Distillation (Engler), °C					
		flash point	solid point		IBP	10%	50%	90%	96%	EP
Under 350 (1)	870.6	127	-10	3.81	259	275	305	340	360	366
240 – 290 (2)	820.7	79	-32	1.57	202	219	238	259	270	281
290 – 350 (3)	835.7	91	-15	2.62	193	233	273	324	339	343
Mixture (1:5:8) of cuts 1, 2, and 3	835.7	83	-19	2.56	196	230	260	315	334	337
STOP 19906-401112–88	–	Minimum of 65	Minimum of – 8	–	Distills under 360°C, %, minimum: in summer: 92, in winter: 94					

The yield of the 350 – 500°C broad vacuum cut (vacuum gasoil) — feedstock for catalytic cracking, increased to 44.7 wt. % in atmospheric resid (22.8 wt. % in crude oil). The carbon content of the product decreased to 0.09 wt. % versus 0.3 – 0.4 wt. % before modernization, which can be attributed to replacement of the physically exhausted jet spray separator by a new rod separator. The content of cuts under 360°C varied from 5 to 12% for an average annual content before modernization of 15%.

After stabilization of the vacuum tower operating regime, the quality of the vacuum resid improved, where the content of the cut below 500°C on individual days attains 9 vol. % for an average value on the inspection days of 13.3 vol. %. Before modernization, the average content of the cut under 500°C was 16.5 – 19 vol. %, which unambiguously indicates improvement of the quality of the vacuum resid after modernization.