Experimental determination of parameters and characteristics of the oil separation unit of combined design

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Abstract. The article deals with the oil separation unit based on engine-separator. The paper presents data of experimental observation of the most important characteristic of the "hot cycle" separator, i.e. heat-conductivity coefficient. It shows the method of measurement and subsequent data processing.

1. Introduction

Oil is one of the world's most important mineral resources. It is the raw material for producing fuel and lubricants and other materials. Oil is called black gold due to its distinctive dark color and great significance for the world economy. Extracted from wells oil is a mixture of approximately 1,000 substances of different nature. Main components are:

- liquid hydrocarbons (80-90% by mass);
- organic heteroatomic compounds (4-5%);
- organometallic compounds (mainly nickel and vanadium);
- dissolved gases of hydrocarbon type (C1-C4, from a few tenths to 4 per cent);
- water (from traces to 10%);
- mineral salts; for the most part it is chlorides (0.1 to 4,000 mg/l and above);
- solutions of salts, organic acids and mechanical impurities (particles of clay, limestone, sand) [1].

Before transporting oil is refined by applying separation from gas, water, salts and other impurities. To obtain oil of the required quality at one of the separation stages oil is heated, the separation is called hot [2]. At a temperature of about 120°C and in the presence of demulsifiers water and mineral salts content is reduced and gas of the third stage of separation is produced [3].

2. Results and Discussion

In "Kuban State Technological University" at the Department of Electrical Engineering and Electrical Machines within the scope of research on optimization of energy consumption by electric machines at oil and gas fields an oil separation unit has been created [4-6] based on the engine-separator (D-C), shown in Fig. 1. Since conventionally hot separation stage can be presented as technological chain: oil-water-gas mixture – heater – separator – refined oil, the present unit for oil separation assumes part of the task on oil preheating using the heat energy generated in the windings and magnetic core of the stator and rotor drum.
Figure 1. Oil separation unit based on engine-separator

Oil separation unit based on D-C includes housing 1 of the separator, mounted therein stator of the electric motor, consisting of two parts (cylindrical part 2-1, axial part 2-2), with winding 3 of two parts of the stator, around the frontal parts of which there are tubes 4, with compound 5, separator drum 6, which at the same time is the rotor of the electric motor rigidly connected with shaft 7, oil heater 15, connecting tubes 16 and 17. Shaft 7 is mounted in bearings 8 and 9. Separator drum 6 consists of base 10 with a central tube, dividing plates 11, cover 12, plate carrier 13, tightening ring 14. Connecting tube 16 connects oil heater 15 with input of tubes 4 and connecting tube 17 connects output of tubes 4 with the inside of the separator drum 6.

[6] presents a mathematical model of the engine-separator in order to build temperature field. To implement this model and build a temperature field of the unit, it is necessary to define heat transfer coefficients of the elements of the unit design. In this regard an approximate physical model of the engine-separator was composed (Fig. 2), where the smooth solid rotor is a working body, in its channels the separation product flows, being at the same time a refrigerant. Frontal parts of the stator winding and outer part of stator core are covered with the pipeline, through which the product (refrigerant) flows, in Fig. 2 arrows
schematically show its movement. Dot marks indicate the points for installation of the temperature sensors.

**Figure 2.** Model of oil separation unit of combined design to study thermal processes

It is commonly known that, heat transfer coefficients can be defined as local (differential), and integrated ones. To determine the local heat transfer coefficients, we use the method [7] based on using as the measuring element $ℒ$-sensors (Fig. 3), which are multilayer plate, glued on the test surface.

**Figure 3.** Device for determining heat transfer coefficients
In the plate (Fig. 3) two heaters are mounted – working heater 1 facing cooling medium, and the compensative heater 2 located on the surface being studied, three thermocouples 4, 5, 6. Chromel-Copel thermocouples are used as thermocouples. Heater 1 defines the power dissipated from the surface 3, thermocouple 4 measures the average temperature of the surface. The heater screens, and thermocouples 5, 6 measure heat flows from the heater 1 for more accurate determination of the power of dissipated from the surface into cooling medium. The heaters are separated by heat-insulating plate 3. Fig.2 shows the installation points of 𝓁 - sensors (points -10-22). In order to prevent the ℓ - sensors from affecting the aerodynamics of the air gap δ, at points 10, 12, 18, 19, 20 small holes were made (up to 1 mm).

According to [8-10], the local heat transfer coefficients were determined using the formula

\[ ℓ = \frac{1}{2} \frac{K_g}{(t_s-t_0)}, \]  

where \( i_g \) is the current flowing along the heater 1;
\( K_g = K' \frac{r_g}{s_1} \) sensor coefficient which is its setting;
\( K' \) is calibration factor taking into account the deviation of specific sensors’ readings from a model sensor;
\( r_g \) – resistance of heater 1;
\( t_s, t_0 \)– temperatures of the surface and ambient environment, respectively.

![Figure 4. Dependence \( ℓ = f(G) \) on the surface of the stator](image)

Average heat transfer coefficients can be determined on the basis of local coefficient measurements using the formula

\[ ℓ_{av} = \frac{\sum_i \ell_i \xi_i}{\sum_i \xi_i}, \]  

where \( \ell_i \) - local heat transfer coefficient in i- point on the surface S.
Fig. 4 shows the dependence of the local (for point 14), average (on stator surface) and the calculated [6] coefficients of heat transfer on the liquid supply rate. At the same time $\mathcal{L}_{av}$ calculated using (2) are given in comparison $\mathcal{L}_{av, cal}$ calculated by the formula

$$\mathcal{L}_{av, cal} = \frac{G \cdot C_A (t_{output.liquid} - t_{input.liquid})}{S(t_w - t_l)},$$

(3)

Where $t_{output.liquid}$, $t_{input.liquid}$ - temperature of output and input liquid;
$t_w$ - wall’s temperature;
$t_l$ - average temperature of the liquid in plane of measurement of the wall’s temperature;
$G$ - amount of liquid supply;
$C_A$ - specific heat capacity of air;
$S$ - surface of contact between the liquid and the wall.

The liquid’s temperature was measured with a type TPK thermometer.

Fig. 5, 6 show the heat transfer coefficients in the air gap of the unit.

![Graph](image)

**Figure 5.** The dependence of heat transfer coefficient in the air gap of the oil separation unit of combined design on the rotor rotational frequency.
Figure 6. The dependence of heat transfer coefficient in the air gap of oil separation unit of combined design on rotor size

3. Conclusion
The analysis of the curves in Fig. 4, 5, 6 allows us to conclude that certain coefficients of heat transfer according to (1, 2) are closest to calculated values [6] compared to heat transfer coefficients, defined by (3) for Fig.4. For other sections of the machine the same pattern is observed, and this is the reason why the curves of heat transfer coefficients are not given.

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