The research of heating efficiency of different induction heating systems

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Abstract. Computer models of tape and coil inductors are described, and a comparison of the heating efficiency depending on various parameters is made. The developed computer model was made in the ELCUT 6.0. As a result of the simulation, data on the heating characteristics (depending on the various parameters of the heating elements) are obtained. The average statistical data of a series of experiments with a tape inductor are given. It is shown that for the same parameters (values of inductance and number of wires), the tape version inductor heats up a pipe to a higher temperature (by 5.08%) than the inductor in the coil version in 10 minutes.

Introduction

The oil and gas industry requires heating systems: in the extraction and transportation of high-viscosity oil, it is necessary to exert a thermal effect to reduce viscosity, facilitate of the pumping process, and reduce the load on pumps and drives [1, 2].

The authors conducted an analytical review of methods and devices for regulating the rheological properties of high-viscosity oil, as well as the use of induction technologies for heating pipelines in foreign articles with a depth of analysis of 10 years [3, 4]. In response to these problems, different technical solutions such as microwave heating [5] or solar water heating system have been proposed [6].

The most effective and the safest heating systems in this case are electrothermal systems (ETS) [7, 8]. These systems include cable (resistive) systems, inductive-resistive systems to contact temperature maintenance, as well as the induction heating systems operating at industrial and medium-high frequencies [9-12]. Advantages of using such systems are high energy efficiency, the possibility of localizing the area of heating, simplification of installation and exploitation [13-15].

Leading countries in the development and patenting of methods and devices for influencing the rheological properties of viscous, high-viscosity and bituminous oil have been identified [16, 17].

An analysis of the patenting dynamics of methods and devices for regulation of the rheological properties of high-viscosity oil based on international patented bases and patent bases of Russia showed the interest of leading world companies in the implementation of new technologies and devices such as induction heating for regulating the rheological properties of anomalous oils

[18, 19]. This interest is due to the development of the deposits with viscous, high-viscosity and bituminous oil against the background of depleted reserves of exploited deposits [20].

The paper presents an analytical comparison of the heating efficiency of various induction systems, such as multi-functional integrated electromagnetic component [21] and the classical inductor in coil design. The results for the analysis were obtained during computer simulation and were confirmed experimentally on laboratory samples.

1 Electrothermal systems based on induction heating

The following requirements are imposed on electrothermal systems (ETS) used at oil and gas facilities:

- providing two modes: maintaining temperature and emergency heating;
- power regulation;
- process automation and staff reduction;
- the operating of the ETS while limiting power supply [22-24].

The application use of induction heating systems operating at medium-high frequencies (IHS) is preferable, since they have better controllability for the transfer of heat power, which is necessary under different conditions of oil transfer compared to systems operating at an industrial frequency [25-28].

Induction heating systems consist of an inductor and a power source with a link of increased frequency [29-31]. By varying the frequency of commutations, it is possible to regulate the power of the IHS, and consequently the temperature and volume of the pumped liquid [32-34].

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Using of IHS allows implementing the following basic methods of pipelines heating: local, associated, locally-associated, locally-stepped.

2 Realization of locally-stepped heating on the basis of multi-functional integrated electromagnetic components

The method of locally-stepped heating, which consists in several intensive heatings of viscous fluid at short sections of the pipeline is the most effective in terms of reliability and simplicity of installation [35, 36].

This method is implemented using the system (device) of locally-stepped heating proposed by the authors, which contains a power source, control system, heating elements placed on the pipeline at intervals determined by the temperature mode and the technological process of pumping.

The heating elements are made in the form of multi-functional integrated electromagnetic components (MIEC) [21] and placed on the pipeline at intervals determined by the temperature mode and the technological process of pumping (the experimental layout is shown in Figure 1). Conductive membranes of MIEC fulfill the role of inductor, so that MIEC can be represented as a tape inductor.

The device works with an accompanying network and can receive power from two wires from the positive and negative poles of the power supply. The positive pole of the power source is connected to beginning of the first winding of the heating element; the negative pole of the power supply is connected to the second winding of the heating element. There is a switch added for each heating element. Switch is connected to the end of the first and to the beginning of the second winding of the heating element. One embodiment is a device in which the negative pole of the power source and the end of the heating element second winding are electrically connected to the pipeline [37].

Fig. 1. Coil and tape inductor experimental models (1 – the coil inductor, 2 – the tape inductor, 3 – control system).

To evaluate the effectiveness of the high-viscosity oil rheological properties regulating method, it is necessary to study the thermal, electrodynamic and mechanical

processes occurring in IHS heating elements of local-step heating.

The tape inductor is structurally constituted by two layers of copper foil stacked one on top of the other, separated by polyimide film insulation. Inductor is made in the form of a cylinder placed on the pipeline. The sizes of copper foil and polyimide insulation used during the experiment are shown in Table 1. Figure 2 shows images of coil and tape inductors. Figure 3 shows the structure of the tape inductor.

Table 1. Characteristics of copper film and polyimide insulation used during the experiment

	Thickness, μm	Width, cm
Copper film	20	12
Polyimide insulation	10	11

Fig. 2. Coil inductor.

Fig. 3. Tape inductor structure (1 – copper film, 2 – polyimide insulation).

The actual task is to analyze the heating efficiency of single inductors in the coil and tape design, used as the parts for constructing a locally-stepped heating system.

3 Results of experimental and computer modelling

The authors have developed computer models of tape and coil inductors (Fig. 4) and compared their heating efficiency depending on various parameters. Computer model was made in the ELCUT 6.0 program.

For modeling in the program ELCUT 6.0 it is necessary to specify the geometric data of the inductors.

The winding of the inductor in the tape version is made of a copper film with a thickness of 20 μm , a width of 10 cm; a polyimide film with a thickness of 12 μm and a width of 11 cm was used as the insulation. The winding of the coil inductor is made of a copper wire of 2 mm² cross section. Figure 4 shows the inductor model in the ELCUT 6.0, and Figure 5 presents the thermogram of the inductor covered by a cover.

Fig. 4. Tape inductor model in ELCUT 6.0 (1 – tape inductor, 2 – plastic frame, 3 – pipe wall, 4 – empty pipe cavity).

Fig. 5. The thermogram of the tape inductor covered by a cover.

4 The discussion of the results

Table 2 shows the pipe temperature values obtained during the simulation for the given parameters ($U = 40$ V, $f = 100$ kHz (for the tape inductor), $f = 50$ Hz (for the coil inductor), number of turns = 23).

Table 2. Comparison of the data obtained during the simulation at $U = 40$ V, $f = 100$ kHz, $n = 23$.

Time, min	Heating temperature of the pipe under the inductor, °C		
	Coil inductor model	Tape inductor model	Experiment with tape inductor
0	29	29	29
1	36,78	37,19	35,06
2	43,37	44,16	43,25
3	48,99	50,14	49,13
4	53,79	55,31	53,63
5	57,92	59,82	56,88
6	61,49	63,77	60,13
7	64,59	67,25	63,19
8	67,29	70,35	66,19
9	69,67	73,12	68,56
10	71,76	75,6	71,56

As a result of the simulation, data on the heating characteristics for the coil and tape inductors are obtained (Fig. 6 – 8).

The adequacy of the obtained model was confirmed experimentally. The temperature was derived by the digital dht22 type sensors, located on the tube in the center of each inductor. Data from the sensors were taken within ten minutes. The highest value difference between the results obtained in the experiments compared with the results obtained during the simulation was 6.2%. The experiments were carried out on the prototype IHS pipeline, which is a pipe section with a tape inductor and coil inductor placed on it. Table 2 shows the average statistical data of a series of experiments with a tape inductor.

Fig. 6. The results of the efficiency of tube heating, obtained for coil inductor model.

Fig. 7. The results of the efficiency of tube heating, obtained for tape inductor model.

Fig. 8. The results of the efficiency of tube heating, obtained for experiment with tape inductor.

5 Conclusion

With the help of the obtained model, the character of the pipe heating with the tape and coil inductors (depending on various inductors parameters) was evaluated. It is shown that for the same parameters (inductance value, number of turns), the tape inductor made in the form of

MIEK is heated to a higher temperature (by 5.08%) for 10 minutes than the coil version inductor.

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