Development and research of an induction heating system for a long pipeline

R R Aflyatunov, R T Khazieva and P I Vasilyev

Ufa State Petroleum Technological University, 1, Kosmonavtov Ave., Ufa, 450062, Russia

E-mail: Radmir.afl@yandex.ru

Abstract. The authors proposed an induction heating system for an extended pipeline, which implements the technology of local-associated heating, using the methods of functional integration. The authors carried out a study of the technology of local-associated thermal effect on an extended pipeline. We have developed a technical solution for a system of local-associated induction heating of a long pipeline using functional integration methods. We also developed a computer model of the system in the ELCUT 6.4 software package. The authors evaluated the efficiency of the heating process and obtained the characteristics of the magnetic field of the system as a result of modeling. We have solved a thermal problem that demonstrates the efficiency of the local heating technology.

1. Introduction

It is important to maintain the temperature regime in the process of pumping high-viscosity oil and oil products with a high pour point, due to the risk of the formation of crystalline structures on the pipeline wall. This can lead to a narrowing of the working diameter of the oil pipeline and an increase in the load on the engines of main pumping units [1].

The simplest and most commonly used method is a combination of chemical and thermal exposure methods to reduce the viscosity of oil and oil products. Along with the addition of chemical reagents, oil is heated in order to prevent the formation of crystalline structures. The most common is the electrical method of electrothermal. In electrothermal, the source of thermal effect is the heating cable or the pipe itself in the case of using inductive-resistive and induction heating systems [2].

The authors proposed a solution to the described problem. We have developed and implemented an induction heating system. The peculiarity of the developed system lies in the application of functional integration methods. Functional integration improves equipment reliability and controllability of the heating process. It is proposed to increase the energy efficiency of heating an extended pipeline by using the technology of local-associated heating based on an induction heating system with the use of functional integration methods.

2. Advantages of induction heating systems

The use of a heating cable and resistive-inductive systems allows for partial or complete compensation of heat losses, without the possibility of emergency heating of a frozen pipeline. The main difference between the induction method of influencing an oil pipeline is the ability to provide
emergency heating after a complete stop and solidification of oil, in contrast to a heating cable and resistive-inductive systems. The important advantages of induction heating for the oil and gas industry are the fire safety of this technology, the provision of high efficiency and the degree of regulation of the heating process, as well as a high degree of maintainability [3-4].

3. Realization of local-passed induction heating using functional integration methods

The method of locally associated heating (Figure 1) is a combination of methods of local and associated heating. In a short section at the beginning of the pipeline, there is a local heating element (L₀-L₁) that heats up the pipeline to the temperature Tₙ required for pumping, the remaining length of the pipeline is heated by an associated heating element (L₁-L₂), which reduces heat losses and allows unloading the local heater in terms of power.

The technology of local associated heating allows for a smoother process of maintaining the oil temperature throughout the entire pipeline. This has a beneficial effect on the pumping process. This technology is energetically more efficient than local and associated heating methods. In addition, this technology allows to reduce the power of local heating elements by compensating for heat losses with associated heaters. This heating method over time does not significantly affect the quality of the electrical insulation of conductors due to the low temperature gradient [5].

The use of an induction heating system is possible as a system that implements the method of locally associated heating.

Multifunctional integrated electromagnetic component (MIEC) can be used as a local induction heater in order to increase reliability and improve weight and dimensions. MIEC consists of two conducting plates separated by a dielectric (Figure 2), thereby forming a capacitance and wound into a roll to increase inductance [6].
The concentration of the electromagnetic field in the area of the local heating element is higher in relation to the associated heater due to the density of the winding and the number of turns, for this reason, heating occurs more intensively in this area. The section of the pipeline heated by the associated heating element compensates for the heat loss. We have developed an induction heating system that contains a power supply, a control system, a switching unit, and heating elements. Heating elements are made in the form of first and second conducting electrodes, separated by a dielectric, coiled. Heating elements are placed on the pipeline at intervals determined by the temperature regime and the pumping process. A conductive inductor cable is placed on the pipeline. A conductive inductor cable connected in series with the end of the first conductive electrode of each heating element. The conductive inductor cable forms a single heating component together with the heating element. The power supply is connected through the switching unit to the beginning of the second conductive electrode of the heating element and to the end of the conductive cable-inductor of each individual heating component [7-11].

4. Results of computer modeling

The authors have created a geometric model of a local induction heating system based on a multifunctional integrated electromagnetic component (Figure 3) in the ELCUT 6.4 program. MIEC acts as a local heating element. The function of a passing heating element is performed by a classic inductor. We have entered the main physical parameters of the simulated system into the software package. The main physical parameters of the modeled system include:

- pipeline wall thickness 2.8 mm,
- the number of turns of the local heater, 24,
- the number of turns of the associated heater, 24,
- the width of the copper plate of the local heater is 100 mm,
- the thickness of the copper plate of the local heater is 0.02 mm,
- the width of the dielectric polyimide film is 110 mm
- the thickness of the dielectric polyimide film is 0.012 mm
- the diameter of the conductor of the associated heater is 5 mm
- the pitch of the winding of the associated heating element is 7 mm.
Figure 3. Geometric model of the system in ELCUT 6.4.

We set the labels of the blocks of the geometric model and their properties for solving the problem of the magnetic field of alternating currents. After specifying the labels and properties of the blocks, a finite element mesh was built and the problem was solved, which resulted in a picture of the current density field (Figure 4).

Figure 4. Current density field model.

The information obtained as a result of solving the problem of the magnetic field of alternating currents made it possible to understand how the magnetic field lines propagate under the local and associated heating elements. Thus, the difference between the magnetic field strength under the local and associated heating elements is clearly visible, which indicates the high efficiency of the local heating element and allows us to understand how the process of maintaining the temperature in the section with the associated heating element will take place. It is necessary to solve the thermal problem for a full assessment of the efficiency of the simulated induction heating system, in addition to solving the problem of the magnetic field of alternating currents. We have created a new problem indicating the parameters of thermal conductivity and convection in the pipeline to solve it. The result of the solved problem is shown in Figure 5.
5. Conclusion
The main task of computer modeling of the developed technical solution was to obtain quantitative and qualitative results of the heating process of a locally associated heating system based on MIEC. As a result of solving the magnetic problem, the areas with the highest current density and magnetic field strength were identified, which made it possible to characterize the efficiency of the local heating element and judge the possibility of compensating for the heat losses of the associated heating element. The solved thermal problem showed the distribution of heat along the wall of the pipeline and confirmed the data obtained earlier - heating under the local heating element is more intensive and faster, in turn, the associated heating element maintains the temperature regime and acts as a compensation for heat losses.

References
[1] Gorbatkov S A, Kuvaldin A B, Mineev V E, Zhukovsky V E 1985 Chemistry 176
[2] Konesev S G, Khazieva R T, Khlupin P A, Kondratyev E Y 2013 Oil and gas business (electronic scientific journal) 5, 179-189
[3] Sadeghipour K, Dopkin J A 1996 Computers in Industry. 3, 195-205
[4] Rudolf R, Mitschang P, Neitzel M 2000 Composites Part A: Applied Science and Manufacturing. 11, 1191-1202
[5] Konesev S G, Khazieva R T and Kirillov R V 2017 X Int. IEEE Scientific and Technical Conf. (Omsk: IEEE) pp 1-5
[6] Sieniutycz S 2003 Progress In Energy And Combustion Science 29(3) 193-246
[7] Milyah A N and Volkov I V 1974 Constant current systems based on inductive-capacitive transducers (Kiev: Naukova Dumka) p 216
[8] Kaban V P 2012 Proc. of the Institute of Electrodynamics of the NAS of Ukraine (Kiev: Naukova Dumka) chapter 33 pp 87-91
[9] Konesev S G 2016 Multifunctional integrated electromagnetic component Patent 2585248
[10] Reznikov S, Bocharov V, Konyahin S and Gurenkov N 2010 Power Electronics 3 48-53
[11] Gubarevich V N, Podoľňýj S V, Spirin V M, Kaban V P and Matveev V Y 2010 Proc. of the Institute of Electrodynamics of the NAS of Ukraine (Kiev: Naukova Dumka) chapter 25 pp 114-118

Acknowledgments
This work was conducted with the support of Ufa State Petroleum Technological University.