Oil heater with high temperature heat transfer agent

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Abstract. The work is devoted to the development of a block oil heater with a capacity of 40 t/h when it is heated from 10 to 60°C. The fuel used is natural or associated petroleum gas.

As a result of the analysis of heat-technical calculations according to the aggregate characteristics, a high temperature organic heat transfer agent, thermal oil, was adopted as a secondary heat transfer agent.

A block oil heater with a thermo-oil boiler unit is designed, consisting of two modules: a heat generation module and a heat transfer module. The description and operation of the heater with a thermo-oil boiler unit is presented.

The significance of the results obtained for the construction industry lies in the fact that this heater is able to operate in heating or hot water supply mode, when the automation system is switched to the appropriate installations. The developed block oil heater, in comparison with existing analogues, has the following advantages: it has compact dimensions and high specific power, the control unit is equipped with an automated microprocessor complex, and the modular design allows it to be transported by any type of transport.

Key words: heat generation, heating of oil products, boiler plant, heat transfer agent, thermal oil, mobile, automation.

1 Introduction

Global trend is in the decrease of light crude oil deposits, therefore exploitation of widely spread deposits of difficult to recover viscous and heavy crude oil becomes important. World reserves of heavy oil are several times higher than light oil reserves. Russia is on the third place in the world after Canada and Venezuela by deposits of heavy crude oil. Naturally the recovery from the heavy crude oil well does not exceed 6-15% [1].

Unconventional oils - mainly heavy and extra heavy oils - represent a significant share of the total oil world reserves. Oil companies have expressed interest in unconventional oil as alternative resources for the energy supply. These resources are composed usually of viscous oils and, for this reason, their use requires additional efforts to guarantee the viability of the oil recovery from the reservoir and its subsequent transportation to production wells and to ports and refineries [2].

The fuel and energy complex is one of the basic sectors of the Russian economy. Between the production and refining of oil and gas there is an important link in the fuel and energy complex - trunk pipelines. The operation of the pipeline system is linked and coordinated with various other transport systems.

With large volumes of transported petroleum products, their storage is due to uneven consumption and a number of other reasons, therefore only an extensive network of pipelines in strict agreement with other transport systems can reduce the storage volumes of the required amount of petroleum products [3-5].

Previously, we designed a mobile heat-generating unit with performance 1.600 kW. This unit is capable of working in the conditions construction and geological investigations in the northern regions
of the Russian Federation; in emergency situations, when heating system and domestic hot water do not working in the residential and public buildings; in the settlements where is no central heating [6].

In the modern market of equipment for heating oil, there are many installations, for example, PNPT-1.6, PP-1.6A, PBT-1.6 and others [7-9]. Most of them use fresh water as a heat transfer agent (THA). Such units are bulky and have a large mass, in addition, they require additional equipment for the chemical treatment of water THA. The paper discusses the use of thermal oil for heating oil, as well as heating and heat supply systems in residential and non-residential premises. According to studies, thermal oil has a number of positive characteristics compared to aqueous THA.

Objective: to develop a compact energy-efficient oil heater based on experimental and numerical studies of its operation on various types of heat pumps. To increase the energy efficiency of the installation for heating the produced oil, two tasks were solved in conjunction: 1 – choosing the optimal THA with the appropriate hardware and 2 - developing software (for process control systems) that supports the optimal operation of the unit by monitoring the main technological parameters of the system [6, 10, 11].

2 Materials and methods

The physical properties of high viscosity oils transported through pipelines are highly dependent on temperature. And this means that temperature is one of the main parameters, technological modes of oil transportation [4]. In order to improve the rheological properties and reduce the viscosity of oil during transportation to oil refineries, as well as to prevent the purchase of pipelines with paraffin, the oil is preheated [5, 12]. Block oil heaters (BOH) are installed at the wellhead, prevent waxing of pipes, reduce energy losses associated with its pumping through pipelines. In order to increase the energy efficiency of BOH, the following commonly used heat transfer agents were analyzed: fresh water, 45% propylene glycol aqueous solution, water vapor, and TLV-330 thermal oil [13]. It is estimated that 1.5 MW of energy is needed to heat oil from 10 to 60 °C at a flow rate of 40 t/h. The calculation results, a comparative analysis and selection of heat exchangers for the required heat transfer surface with the above of the HTA are presented in table 1 [14, 15].

Thermotechnical calculations showed that the thermal oil TLV-330 has the best aggregate indicators (table 1). In addition, high-temperature organic HTA more effectively prevent the process of waxing pipes due to the high temperature of the HTA, in the absence of the need to maintain high pressure, as occurs in steam boilers. For this type of heat pump, a horizontal gas-oil-fired boiler of the YaroMax company of the VOT 1500-30-1 PG standard size with a capacity of 300 to 1500 kW and a thermal oil flow rate of up to 90 m$^3$/h was selected [16]. Heat exchanger is selected according to the directory Technical conditions 3612-024-00220302-02 [18].

| Heat transfer agent | Fresh water | 45% propylene glycol aqueous solution | Water vapor | Thermal oil TLV-330 |
|---------------------|-------------|--------------------------------------|-------------|-------------------|
| Heat transfer coefficient, W/(m$^2$ K) | 336 | 291.4 | 474 | 392.4 |
| Required heat transfer area, m$^2$ | 98 | 113 | 19.95 | 12.38 |
| Actual heat transfer area, m$^2$ | 100.8 | 125.9 | 20.9 | 12.8 |
| Heat exchanger dimensions, mm | 600 × 6000 | 800 × 3000 | 400 × 2000 | 273 × 3000 |

Table 1. Comparative analysis of heat transfer agents.

A lot of various production processes associated with water heat pumps (fresh water, steam) require preliminary treatment (deaeration, demineralization, etc.), which is associated with significant operating and other costs. The use of organic HTA is an alternative to water heat pumps and is a very convenient solution for achieving elevated temperatures (at moderately low working pressures) in production processes. In addition, thermo-oil heating systems have many other advantages [14, 18]. It
should be noted that due to the high heat-carrying ability of thermal oil, the required volume of heat pumps is reduced and, accordingly, the dimensions and weight of the BOH are reduced. Subject to operating rules, the warranty period for the use of TLV-330 is not limited [13], which reduces the operating costs of the entire thermo-oil system [19, 20].

Significance for the construction industry. In Russia, in connection with the widespread construction of residential buildings in areas where there is no central heating, mobile heat-generating plants are a relatively inexpensive way out of the situation without the need to lay expensive heating pipelines, where thermal energy is additionally lost.

![Diagram of a block oil heater system](image)

**Figure 1.** The hardware-technological scheme of the block oil heater:
1 – thermally oiled boiler; 2 – network pump; 3 – a pump for replenishing the HTA; 4 – expansion tank; 5 – tank stock of HTA; 6 – safety valve; 7 – ball valves; 8 – check valve; 9 – magnetic screen filter; 10 – automatic air vent; 11 – shell-and-tube heat exchanger; 12 – ball valves without a handle, 13 – actuator.

BOH can be used for heating and hot water supply of residential buildings, public buildings, industrial and warehouse premises and agricultural complexes, located at a considerable distance from sources of traditional heat supply methods. BOH can be connected to both a new and an existing heating system or hot water supply. In the absence of gas supply, BOH can use LNG as fuel.

BOH can be used as an emergency heat supply system in case of emergencies at thermal power plants or boiler houses. Due to its mobility and compactness, BOH can be delivered to a settlement in
a short time. The crystallization temperature of thermal oil TLV-330 is not higher than -40 °C [13], i.e. there is no danger of HTA freezing even during prolonged shutdowns in winter or during transportation to remote areas with low ambient temperature.

The circuit scheme of BOH is shown in figure 1. Oil with a temperature of 10 °C enters the shell-and-tube heat exchanger 11, where it is heated to a design temperature of 60 °C. In figure 1 you can see the BOH thermal circuit with a thermo-oil boiler 1 (BOT 1500-30-1 PG), which is equipped with a safety valve 6 and a HTA drain system. To preheat the HTA in the system, a node 1 is provided, which, using ball valves 12 and actuators 13, allows it to circulate along a small hydraulic circuit (detail 1).

![Figure 2](image)

**Figure 2.** Drawing of a block oil heater (top view): 1 – heat generation module; 2 – heat transfer module; 3 – thermo oil boiler; 4 – fuel preparation unit; 5 – shell-and-tube heat exchanger; 6 – burner device; 7 – block system automation and security; 8 – network pump; 9 – chimney; 10 – expansion tank; 11 – capacity for replenishing the HTA; 12 – feed pump.

When the set temperature HTA is reached, the automatics brings the heater to operating mode by changing the position of the shutoff valves 12 by the actuators 13. The circulation of organic heat transfer agent is provided by the high-temperature network pump 2 (TOE-MI) with a working temperature of thermal oil up to 350 °C [21]. Make-up is carried out from the HTA reserve tank 5 by means of a make-up pump 3. The HTA reserve tank 5 is equipped with an inert gas-nitrogen pad, which prevents its oxidation. Auxiliary fittings (pos. 6-10) are selected for operation at sufficiently high temperatures (up to 300 °C).

After installation of the equipment and connection of all pipelines, the heater is a single unit (figure 2), consisting of two main modules: a heat generation module and a heat exchange module.

In the heat generation module 1 with dimensions 7370 by 2360 mm, there is a fuel preparation unit 4, which delivers purified gas fuel to the burner 6 of the thermo-oil boiler 3, the exhaust gases are removed using a chimney 9, which is placed in the heat exchange module 2 during transportation. In the heat exchange module 2, with dimensions of 7370 by 2080 mm, a shell-and-tube heat exchanger 5 and an automation control unit 7 are installed.

The implementation of the power equipment heat saving monitoring system provides not only the option for estimation of fuel reserve estimation, but also to identify the areas of power resources...
excess consumption and to find the method for its elimination. The employment of the newly identified resources will provide the highest level of heat saving [22].

Automation of the block oil heater. To maintain optimal operating conditions and control the main parameters, BOH uses the automated microprocessor complex AMK-1, which fully provides automatic control of the process and equipment (by command from the upper level - by the command of the dispatcher). The AMK-1 supposes function emergency protection and alarm; automatic control of control parameters; presentation on the display of the complex of values of technological parameters, regulation by actuators (A) from the keyboard of the complex (manual mode); communication with external devices - computer, modem, radio modem; protection against incorrect operator actions; unauthorized access to process control and A; archiving of events (start, stop, etc.), measured operating parameters; emergency situations; background to the accident; automatic self-diagnosis and diagnostics of technological equipment.

Based on the specifics of the object, the automatic control system (ACS) of the BOH is built as a multi-level hierarchical decentralized system.

The first – the lower level includes measuring sensors, actuators, normalizing converters, etc.

The second – the control level includes programmable logic controllers with input / output modules that solve the tasks of monitoring and controlling the equipment of technological areas.

Third – the upper level includes an automatic workstation (AWS) of the operator. The AMK-1 complex has the ability to remotely transmit data on the operation of the heater to the AWS operator. If necessary, control over several BOH can be combined into one system [23, 24].

The main characteristics of the created automation system are as follows. One of the main goals of process automation is to increase the reliability, efficiency and safety of all equipment. The automation system is designed to automatically control the processes of preparation for work, ignition, shutdown, with the remote transmission of information about the process flow.

The target criterion for the development of the system is a minimum of material and energy costs for a given technological process productivity and the achievement of complete emergency safety under various modes of the technological process. The computer system of the automation system receives data on the current state of the controlled thermo-oil boiler thanks to various sensors. The processing procedure involves storing and comparing with generalized indicators characterizing the operation mode of the BOH. The operator receives on the screen a message about the measures taken, which were processed according to the principle of necessity in a certain mode. This accelerates the analysis of the condition of the on-load tap-changer and, in fact, increases the reliability of operational control, which is extremely important in emergency situations [25].

The following composition of the complex of technical means was selected taking into account the following requirements: stable maintenance of the outlet temperature of oil (or water for the heating system and hot water supply); increased heater performance; selection of rational modes in conditions of multi-connected regulation, taking into account the readings of industrial sensors and analyzers installed on the equipment and operational adjustment of control; real-time information on the progress of technological processes; diagnostics and prevention of emergency situations [26].

The main parameters of control and indication include: supply and return temperatures of thermal oil, temperature of flue gases; pressure of thermal oil, air, fuel in front of the burner; liquid level in the stock tank of thermal oil; reaching critical temperatures of the supply thermal oil pipe and the gas pressure behind the main stop valves; the flame control; position of stop valves. AMK-1 also maintains the optimal ratio of air and fuel [27, 28] supplied to the burner of a boiler, depending on the selected mode and other system parameters.

3 Results
The results of calculations and studies have shown that when using TLV-330 as a HTA, the heat transfer process is substantially intensified. The heat transfer coefficient when using this HTA reaches 392.4 W/(m²K), which leads to a decrease in the heat transfer surface to 12.4 m². In accordance with this surface, a heat exchanger with dimensions of 273×3000 mm and an actual heat exchange area of
12.8 m² was designed and selected, which is significantly less than when using other HTA. In this case, while maintaining the required capacity of 40 t/h, the dimensions of the heat generation module were 7370×2360 mm, and the heat exchange module was 7370×2080 mm.

Designed a block oil heater with a thermo-oil boiler unit was designed, consisting of two modules: a heat generation module (with a boiler unit and a fuel preparation unit) and a heat exchange module (with shell-and-tube heat exchanger and automation unit). The description and operation of a heater with a thermo-oil boiler unit is presented. The significance of the results obtained for the construction industry is that this heater is capable of operating in the heating or DHW mode, when switching the automation system to the corresponding installations. The developed block heater of oil in comparison with existing analogues has the following advantages: it has compact dimensions and high specific power, the control unit is equipped with an automated microprocessor complex (AMK-1), and the modularity of the structure allows it to be transported by any kind of freight transport or by air.

4 Conclusion
1. A compact block oil heater was designed, the transportation of which is possible by any type of freight transport.
2. The use of thermal oil TLV-330 as a high-temperature HTA is an alternative and a very convenient solution to achieve elevated temperatures at a fairly low operating pressure in comparison with water heat pumps.
3. Organic HTA circulates in a closed circuit and saves properties for a long time, which leads to lower operating costs of the entire system and the cost of maintenance.
4. Thermal oil (TLV-330) has a fairly wide range of operating temperatures (from −45 to 350 °C), and is suitable for use in northern latitudes with a low ambient temperature.
5. BOH, if necessary, can be used for heating rooms or for hot water supply in case of emergency on centralized heat supply systems.
6. BOH ACS based on AMK-1 significantly increases the reliability of service, provides a reduction in downtime, improves working conditions of personnel.

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