Prospects for the use of electro-technological heating systems in the arctic conditions

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Abstract

Introduction. The co-authors analyze the sources and consumers of thermal power in the Far North and the Arctic region. The co-authors describe industrial, fire, and environmental hazards coming from existing heating systems that consume burned hydrocarbons. The co-authors propose an alternative system that uses electro-thermal technologies.

Subject of research. Electro-thermal systems designated for the maintenance of the operation of industrial and social facilities in the Far North and the Arctic region.

Objective. Substantiation of the need to have flame heating systems, which are currently in operation, replaced by highly efficient, safe and eco-friendly electro-thermal heating systems in the Far North and the Arctic region.

Materials and methods. The co-authors analyze thermal power generation in the environment characterized by extremely low temperatures.

Findings. The co-authors describe several heating sources that comprise electro-thermal technologies, applicable in the Far North and the Arctic region.

Conclusions. Electro-thermal heating systems boost heat transmission and power efficiency of heating systems due to their high controllability. They can also reduce the environmental impact, caused by strong heat flows produced by flame furnaces onto the climate of the Far North and the Arctic region.

Keywords: electro-thermal heating system, induction heating system, flare heating systems, flare furnaces, direct heating, heating cable, self-regulating heat tape, current frequency


INTRODUCTION

The combustion of hydrocarbons, namely, coal, crude oil, fuel oil, and natural gas, is the main source of thermal power in Russia. Due to their relative inexpensiveness and simplicity of implementation, as well as their ability to produce heat and generate electric power at the same time, these heating systems are widely used by industrial enterprises and social facilities. Nonetheless, recently these systems get more and more discredited due to their high industrial and fire hazards as well as the low power efficiency, caused by the low turndown ratio of a heat flow generated by these sources.

When these systems are operated in the Far North and the Arctic region, their environmental impact gains in importance. It is triggered due to intensive thermal fields that cause the adjacent areas to thaw and to disturb the fragile environment. For example, the surface temperature of a heat exchange chamber inside modular tube furnace PTB-10 exceeds 60 °C [1], and it causes the adjacent areas to warm up, if the temperature is –35 °C.

The co-authors offer an alternative option that consists in the use of electro-thermal heating systems capable of supplying heat to social and industrial facilities in the Far North and the Arctic region.

MATERIALS AND METHODS

The majority of autonomous heaters have permanently installed hot water gas boilers, used to heat premises and to supply hot water designated for multiple purposes (Fig. 1) [2].
Their weakness is their low efficiency in case they are installed a distance from the facility to be heated. If several facilities are to be heated, several systems must be installed and the heating system turns more expensive. Moreover, in this event, the gas infrastructure must be in place. It must comprise a network of pipelines and a gas distribution plant. These systems also produce emissions, including combustion products and thermal pollutions.

Industrial facilities usually employ flame (flare) furnaces. Modular tube furnaces PTB-10 and PTB-5 are designated for the heating of crude oil and crude oil emulsion by the energy of burnt hydrocarbons (the process chart is provided in fig. 2). The core element of this furnace represents Heat Exchange Chamber 1, where crude oil emulsion is heated by the combustion gas emitted by burnt hydrocarbons. Intensive air supply by Fan 3 into Furnace Basement 2 boosts the velocity of heat transfer. Different parameters of the heating process are under control, and the process is stopped when the pressure inside the pipeline goes up or down, when the heating chamber has no fuel or flame, or when the temperature of combustion gases at the outlet exceeds acceptable values.

![Fig. 1. Permanently installed hot water gas boiler](image)

![Fig. 2. Process chart. Modular tube furnace PTB-10](image)
The non-destructive testing method may be used to test the insulation of the heat exchange chamber, to identify heat losses in the process of the furnace operation, to control the temperature at the outlet of combustion gas stacks, to check the condition of inlet and outlet pipes, to check the operation of combustion chambers and to identify their defects at an early stage.

Fig. 3. Furnace PTB-10. Regular operation mode: a — thermal image; b — photo

The information thus obtained may be used to analyze heat losses and economic losses caused by excessive fuel consumption needed to compensate heat losses. The insulation failure, caused by the long-term operation of the system, is manifested as the color change, corrosion and visible burnouts in defective areas.

Fig. 4 shows the emergency operation of furnace PTB-10. According to its thermal image (Fig. 4, a), the temperature of combustion gases at the outlet exceeds the acceptable values pre-set by the producer. According to the data provided by the instrumentation sensors, installed at the outlets of combustion gas pipes and in the radiant chamber, the temperature of combustion gases reaches 630 °C, while the flame temperature reaches 1008 °C. These temperatures may produce a negative impact on the main nodes of the furnace and cause an emergency situation. Hot spots on the surface of the heat exchange chamber have proven the insulation failure caused by the loose bolted-on connection and corrosion (Fig. 4, b).

Fig. 4. Furnace PTB. Emergency operation mode: a — thermal image; b — photo

The thermal method of non-destructive testing of tube furnaces is applicable to the system coil to identify defects there. The thermal control procedure is provided in fig. 5.

The application of the non-destructive testing method to perform the in-tube diagnostics of coils inside flame furnaces PTB-10 is only possible, if the furnace is partially dismantled. The diagnostics may be performed concurrently with the scheduled preventive maintenance to reduce the cost of a supplementary shutdown and
dismantling of a furnace, fast elimination of defects and replacement of defective nodes. After the shutdown, the furnace needs some time to cool down and reach a safe temperature; after that, its dismantling is initiated. This procedure helps to assess the condition of the main operating nodes and to identify defects at an early stage.

Fig. 5. Thermal control of the coil of a heat exchange chamber inside a PTB furnace: \(a\)–\(c\) — furnace coil nodes exposed to non-destructive testing; \(d\) — position of an operator in the process of non-destructive testing performed using the thermal method.

Heated crude oil must flow through the coil, exposed to non-destructive testing, for thirty minutes, in order to stabilize the temperature mode. This thermal control procedure helps to obtain a viewable idea of the condition of the main nodes, to identify defective sections, and, if possible, to have them replaced. Coil defects may include burnouts inside pipes and twins, sediments on pipe sections. Fig. 5 \(a\)–\(c\) demonstrates controllable nodes of a heat exchange chamber and coils; fig. 5, \(d\) shows positions of a testing unit used for thermal control.

**Crude Oil Heating Points**

Intensive settling will require crude oil heating to 50...60 °C. The heating process also involves flare heating systems, including line heaters and modular tube furnaces. Line heaters are designated for the heating of crude oil, crude oil emulsion, gas and local water by the thermal energy emitted by the heated water. Water is heated by a flare inside a line heater; then heat is transmitted to the heated product (Fig. 6).

Intensive heat flows, generated inside the furnace, and a high fluid velocity may help to heat an enormous amount of the temperature-dependent liquid. However, this process has several weaknesses, including its negative impact produced on the environment by emissions of combustion products and thermal fields, as well as high industrial and fire hazards; therefore, the application of these processes in the unstable climate of the Far North and the Arctic region is inadmissible. Besides, the flame (flare) furnace is considered a local source of thermal impact, therefore, it can only be used to heat a product, and it cannot maintain the temperature inside pipelines and tanks [1].
Electro-technological Heating Systems

Electro-technological systems are user friendly; they do not generate combustion products to be emitted into the atmosphere, and they are easy to operate. The application of electric energy to generate thermal fields is exemplified by electric stoves, electric heaters, resistance wires, electric heating elements, and induction heating systems [3, 4]. The direct heating method is applied to electric heating elements, resistance heating wires having a permanent or a variable capacity, induction systems having industrial and elevated frequencies [5].

The problem of thermal impacts to be produced onto industrial and social facilities in the Far North and the Arctic region is solved by the co-authors with the help of induction heating systems (IHS) [6–13]. In particular, the co-authors have developed a novel engineering solution for an HIS. Its principal objective is to improve the heat transfer efficiency of the heating system, the controllability of heat transfer processes, the capacity, and dimensions of the area covered by the thermal field [14].

Fig. 7, a, b shows the proposed pipeline induction heating system, composed of conversion and control unit 1, induction wire 2, heat exchanger 3, made of a pipeline that has radial magnetic plates 4 attached to its inside surface along the pipeline length. It is noteworthy that direct and return wires are positioned as far from one another as possible, and this wire-to-wire distance is equal to the pipe diameter so that the impact produced on the heat exchanger were most intensive. However they could be positioned closer to one another.

Fig. 8 shows different designs of a heat exchanger. A section of pipeline 3 has magnetic plates 4 inside.

The heat exchanger operates in the following manner. The conversion and control system, equipped with autonomous current inverter 1, applies variable sinusoidal voltage to the loop of induction wire 2 that forms a heating contour featuring a complex geometry. Being exposed to the impact of whirling currents, arising inside metal heat exchanger 3, the pipeline and magnetic plates inside it get heated, and the heat is transmitted from the pipeline walls and plates to the fluid that is being heated. Thanks to the plates inside the pipeline, one flow...
breaks down into several ones which get mixed so that the heated liquid running along the pipeline walls and over the plates gets mixed and penetrates into the flow, thus, gradually boosting the heat transfer intensity. The area exposed to the thermal impact depends on the area of the loop of an induction wire, the number of loops, the diameter of a pipeline and areas of the plates.

**Fig. 8.** Alternative designs of magnetic plates inside a pipe: 1 — the pipe of a heat exchanger; 2 — magnetic plates inside the pipe

In case the pre-set maximal temperature value of the heated liquid is exceeded, the power intensity is automatically reduced or cut off by control system 1 of induction wire 2.

**Fig 9.** a shows a pipeline induction heating system that has several independent heat exchangers 3, connected as a sequence. They boost the heating capacity and increase the heated area, improve the controllability of the heat transfer process. Each heat exchanger has independent converter and controller 1 and induction wires 2. Heat exchangers can be connected in parallel (Fig. 9, b).

**Fig. 9.** Designs of a local heat exchanger for an induction heating system: a — coil type; b — tube heat exchanger type; I — a conversion and control system equipped with an autonomous current inverter; 2 — induction wire; 3 — heat exchanger pipe; 4 — magnetic plates inside the pipe
CONCLUSIONS

There is a need to reconsider the widespread application of flame heating systems and to develop a set of actions aimed at the replacement of the systems that are in operation or being placed in operation for power efficient electro-thermal systems capable of improving heat transfer efficiency, reduce industrial and fire hazards and a negative thermal impact produced on the environment of the Far North and the Arctic region.

The use of induction heating systems is the most effective choice of an electro-thermal heating unit, capable of maintaining the operation of industrial and social facilities in the Far North and Arctic region.

REFERENCES


Received March 20, 2019.
Approved for publication May 21, 2019.

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