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Scientific-Research Institute of Metallurgical Heat Engineering
OJSC VNIIMT

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OJSC Scientific-Research Institute of Metallurgical Heat Engineering (VNIIMT) established in 1930 as Ural Division of All-Union Heat Engineering Institute is widely known in Russia and the CIS. The Institute focuses on development of high-technology heat engineering units, energy efficient and ecologically friendly technologies in ferrous and non-ferrous metallurgy, machine-building and other fuel-consuming branches of industry.

Highly-qualified academic researchers, unique experimental and production facilities and own research and design centre enable efficient scientific-and-research, design-and-experimental, engineering and project works, delivery of equipment, designer's supervision and commissioning works including execution of turnkey contracts in the following areas:

Sintering:
- development of techniques and modes of metal raw material heat treatment;
- design of energy-efficient agglomeration hearths and agglomeration gas heat recovery circuits allowing to reduce energy consumption and dust and gas emissions.

Pellet production:
- optimal traveling grate pelletizing furnaces for heat treatment of iron-ore pellets from various concentrates (hematite, magnetite, etc.) with optimal automatic process control system.

Preparation of metallic and nonmetallic raw materials:
- technique of iron-ore raw material dephosphorization by roasting and leaching;
- installations for drying high-moisture dispersive materials of various designs;
- efficient techniques of magnetizing roasting and subsequent dressing;
- technique of rare-earth element extraction (for example, germanium from germanium iron ores).

Blast-furnace ironmaking:
- explosion-proof near-furnace systems of blast furnace slag granulation giving a high-quality product for cement production;
- optimal control system for hot blast stoves;
- an innovative bench for drying hot metal and steel-smelting ladles;
- copper coolers and tuyeres of blast furnaces.

DRI (direct reduction of iron)
- improvement of the reduction technique in shaft furnaces for radical improvement of technical and economic indicators of their operation (productivity is increased twice);
- technique of raw material reduction in rotary furnaces using coal as the reductant.

Lime production: development of the technique and increase of lime production process efficiency:
- in shaft furnaces;
- in double-shaft furnaces;
- in rotary furnaces;
- in “stacked-tower preheater - rotary furnace” installations;
- in “shaft calciner - rotary furnace” installations (VNIIMT innovative technology).

Granulation of metal melts:
- development of technologies and designs of explosion-proof plants for near-furnace granulation of metallurgical slag, molten metal, etc., including heat recovery;

Reheating furnaces:

- development of new and update of the existing designs of furnaces for stock heating;
- high-performance systems of reheating furnace firing with recovery and regeneration firing systems based on the innovative burner units designed by VNIIMT;
- switching the furnace firing systems to cheaper fuel types;
- development and implementation of optimal furnace operating parameters.

Heat-treatment furnaces development of techniques and equipment for heat treatment of roll stock and metal products including those with protective atmospheres:

- thermochemical treatment conditions ensuring retention or directional change in chemical composition of metal surface;
- gas dampers for heat-treatment furnaces;
- spray quenching units and other elements of convective cooling systems;

Furnaces with protective atmosphere and gas treatment units:

- development of the furnace structure, design, manufacture, delivery and commissioning works;
- development of a technology for treatment of articles and devices for protective gas generation;
- calculation, development and manufacture of endogas and exogas atmosphere generators for metal product thermochemical treatment units;
- gas analysis systems for monitoring and control of physico-chemical properties of protective process atmospheres.

Reheating, heat-treatment and drying furnaces with convection heat transfer:

- development, design and manufacture using industrial heat-resistant (up to 900 ^{o}C) furnace fans designed by VNIIMT.

Rolled products:

- techniques and units for controlled high-speed air-to-water cooling (quenching) of rolled ferrous and non-ferrous metal products including thick plate on mill 5000;
- replacement of oil quenching technology with VNIIMT's eco-friendly air-to-water technique;
- innovative technique of oily mill scale processing;
- line of wire rod accelerated air cooling with process improvement.

Manufacturing manufacture and delivery of:

- high-performance burner units;
- heat-resistant (furnace) fans (up to 900 ^{o}C);
- copper coolers for blast furnaces and nonferrous furnaces based on VNIIMT technology;
- Pitot tubes for measuring flow rates and pressures.

OJSC VNIIMT developments are widely used in metallurgical enterprises of Russia, Ukraine, Kazakhstan, China, India and others.

For detailed information on institute developments, please visit OJSC VNIIMT site at www.vniimt.ru

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Furnace Electric Heaters with Radiant–Convective Heat Transfer

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Abstract—Electric heaters with radiant–convective heat transfer between the heating elements and the walls of the sealed housing are developed. Industrial tests show that intensification of the heat liberation from the coils by ventilation using a circulatory fan increases their life by 30–50% in comparison with existing devices, by reducing the temperature of the elements. The sealed housing permits their use in convective furnaces with protective or aggressive atmospheres.

Keywords: electric heater, convective furnace, radiant–convective heat transfer

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To improve the efficiency and reliability of low-temperatures furnaces with protective or aggressive atmospheres, specialists from OAO VNIIMT and
1 OAO Uralenergochermet have developed closed heaters with radiant–convective heat transfer from the heating elements (for example, wire coils) through the walls of the sealed housing to the material that is to be heated.

In the existing closed electric heaters used in long furnaces for strip and rod heating in a protective atmosphere, thermal radiation at the heated surface is reduced significantly (by about half) in comparison with open heaters (radiant tubes) on account of the protective housing, which acts as a thermal screen [1–3]. Attempts to increase the thermal power of these heaters lead, as a rule, to overheating of the coils (above 1100°C), with corresponding abbreviation of their working life.

To reduce the working temperature of closed electric heaters and increase their efficiency and reliability, the system in Fig. 1 has been developed. The equations approximately describing the heat transfer within the heater in steady conditions take the form

$$Q_{el} = Q_r + Q_g,$$

$$Q_r = \varepsilon_{re} F_h \left[\left(\frac{T_h}{100} \right)^4 - \left(\frac{T_w}{100} \right)^4 \right],$$

$$Q_g = \alpha_1 F_h [t_h - 0.5(t_{g1} + t_{g2})], \qquad (1)$$

$$Q_g = \alpha_2 F_{he} [0.5(t_{g1} + t_{g2}) - t_w],$$

$$Q_g = V_g \rho_g C_g (t_{g2} - t_{g1}),$$

where Q_{el} is the electric power liberated at the coils, W; Q_r is the radiant heat flux from the coils to the heat exchanger and the housing walls, W; Q_g is the thermal power transmitted by the gas, W; ε_{re} is the reduced radiant heat-transfer coefficient, W/m^2 K^4; F_h and F_{he} are the surface areas of the heating coils and the heat exchanger, m^2; T_h is the coil temperature, K; T_w is the wall temperature of the heater housing, K; α_1 and α_2 are the convective heat-transfer coefficients from the coil to the gas and from the gas to the heat-exchanger

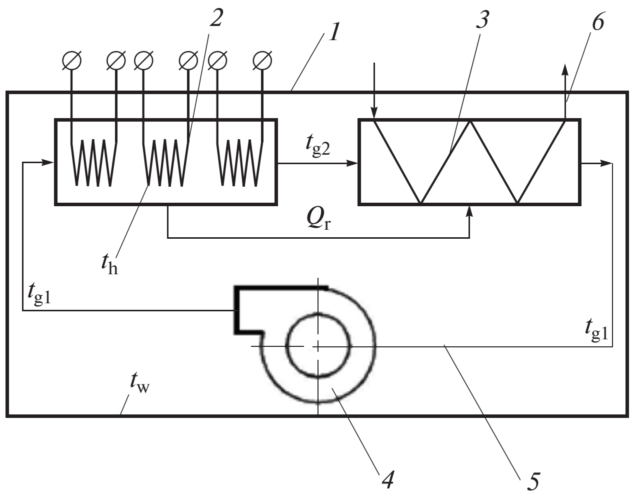

Fig. 1. Heat transfer in a closed electric heater with radiant–convective heat transfer from the coil to the housing: *1*) sealed protective housing; *2*) heating coil; *3*) tubular heat exchanger; *4*) high-temperature fan; *5*) input and output channels; *6*) hot dirty air. For further explanation, see the text.

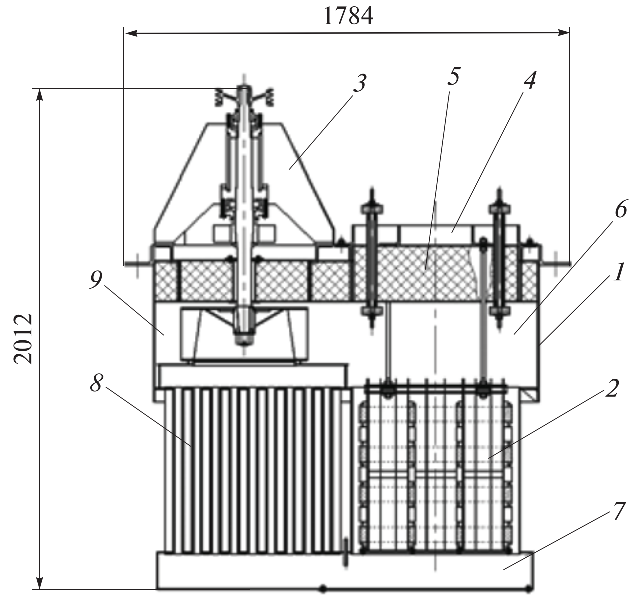

Fig. 2. Closed electric heater with radiant–convective heat transfer: *1*) housing; *2*) suspended attachment system for heating coils; *3*) custom-designed circulatory fan; *4*) supporting flange; *5*) heat-insulating layer; *6*, *7*) upper and lower passageways; *8*) tubular heat exchanger; *9*) built-in helical fan housing.

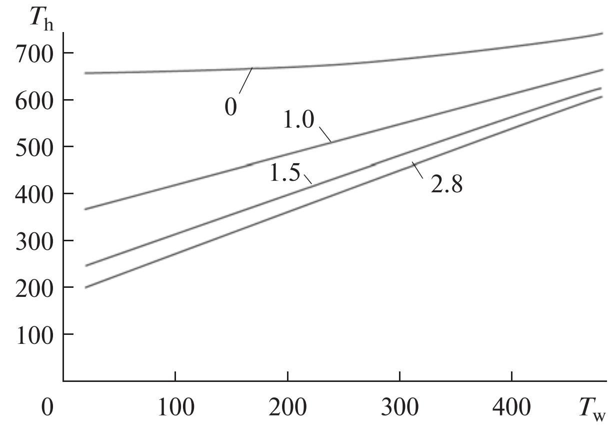

Fig. 3. Calculated dependence of the coil temperature on the mean temperature of the housing walls for a 55-kW heater; the values of the fan productivity (m^3/s) are given on the curves.

surface, W/m^2 °C; t_{g1} and t_{g2} are the gas temperatures at the heater input and the heat-exchanger input, °C; V_g is the productivity of the high-temperature fan, m^3/s; ρ_g is the mean gas density, kg/m^3; C_g is the mean specific heat of the gas, J/kg °C.

The characteristics of the electric heater are as follows:

Maximum electric power, kW	55
Electric power of a single phase, kW	18.3
Number of phases	3
Electric resistance of a single phase, Ohm	2.64
Diameter of X20H80 steel wire in heating coil, mm	5.5
Maximum gas temperature within heater, °C	650
Fan speed, rpm	1460
Power of AIR100L2U3 fan motor, kW	5.5
Motor speed, rpm	2860
Productivity of fan, m^3/sUp	to 3.0
Total pressure head in normal conditions, PaUp	to 2000
Total housing surface (including heat exchanger), m^3	26

A fan belt of A-1250 type is used. The walls of the heater housing are made of 12X18H10T steel.

The fan has a built-in shaft-cooling system. The new heaters were installed in a convective furnace for thermal grease removal from thin glass-fabric sheet supplied to OAO Sinarskii Trubnyi Zavod in 2014. The closed electric heater is selected because the heat treatment of glass-fabric sheet is accompanied by the pyrolysis of the paraffins present (saturated hydrocarbons), with the liberation of solid carbon (soot), which is subsequently deposited on the insulators and heating coils. Such deposits considerably increase the risk of short-circuits and system failure.

The electric heater (Fig. 2) consists of the following major components: housing *1*; suspended system for attachment of heating coil *2*; and special-purpose circulatory fan *3* with a vertical shaft. The heater housing consists of a supporting flange *4* with a heat-insulating layer *5*, upper *6* and lower *7* passageways, tubular heat exchanger *8*, and fan *9*, which is built into the coil housing.

Heat transfer within the heater occurs as follows. The electric power released as heat in the Nichrome coils is transmitted within the heater housing by two method: *1*) radiant transfer from the coils to the lateral walls of the vertical channels, whose exterior is in a flux of dirty air; *2*) convective transfer from the coils on account of the gas flux at the coil surface maintained by the fan.

Convective heat transfer occurs as follows. The convective flux from the fan built into the coil housing passes through the upper passageway in three parallel channels, where it is heated, thereby cooling the heating coils. Then gas is supplied within the lower passageway to the heat-exchanger tubes. Heat is transferred through the wall of the tube to the external dirty air flow. On account of the low pressure created by the circulatory fan, the cooled air is supplied to the input for a repeated heat-transfer cycle.

In Figs. 3 and 4, we show the heat transfer within the heater according to Eq. (1) and experimental data from an operational furnace. In Fig. 3, the calculated surface temperature of the heating coil is plotted as a function of the mean surface temperature of the housing walls, for different values of the fan productivity. We know that the temperature variation of the housing walls is determined by the heat-transfer conditions at its internal and external surfaces. The thermal operation of the furnace's external primary circulatory system was described in [1, 3].

Analysis of the results indicates that, at constant electric power (55 kW), the surface temperature of the heating coil declines significantly with increase in productivity of the fan that ensures convective heat transfer—in other words, the fan blowing gas at the heating coil. The coil temperature also depends significantly on the temperature of the housing walls. Thus, at the maximum wall temperature in the operational furnace (430°C), when the fan productivity is 2.8 m^3/s, the calculated temperature of the heating coils is 585°C. That creates favorable conditions for long-term coil operation, thereby ensuring reliable operation of the heater. With decrease in fan productivity from 2.8 to 1.0 m^3/s, say, due to decrease in fan speed, the coils are heated to 635°C, which is inexpedient in practice.

In Fig. 4, we show the calculated and experimental dependence of the gas temperatures in the heater on the mean surface temperature of the housing walls, at constant fan productivity of 2.8 m^3/s and constant electric power to the coil (55 kW). Curves *1* and *2* correspond to the gas temperature according to Fig. 1: t_{g1} and t_{g2} are the gas temperatures at the input to the heater and the heat exchanger, respectively. Curve *3* corresponds to the coil temperature t_h.

The calculated dependence of t_{g1} and t_{g2} on T_w is in satisfactory agreement with the experimental data. Thus, the increase in wall temperature typical of furnace temperature boosts the gas temperature within the heater. At the maximum wall temperature (430°C), the calculated values $t_{g1} = 456°C$ and $t_{g2} = 478°C$ are in complete agreement with the conditions for long-term operation of 12X18H10T steel walls. In addition, the use of a tubular heat exchanger with a developed surface and intense gas motion (circulation at 1.5 cycle/s) in furnace heating ensures a constant heat flux of 55 kW, with a slight difference in gas temperature within the heater ($t_{g1} - t_{g2} = 20–25°C$).

Analysis of the results indicates that the ratio of the convective and radiant heat-transfer components is 5 : 1 at the beginning of heating and 2 : 1 at the end of heating.

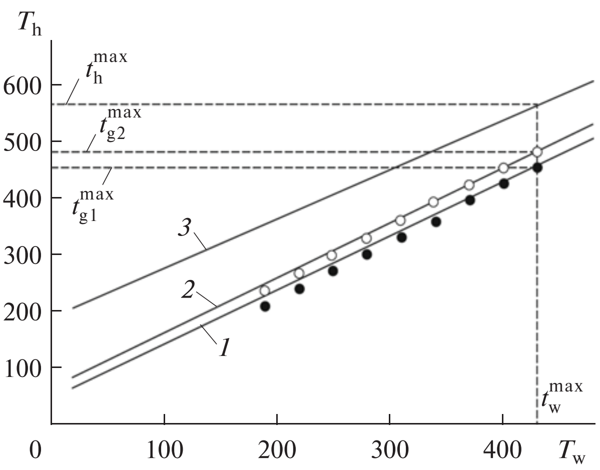

Fig. 4. Dependence of the coil temperature and gas temperature on the mean temperature of the housing walls for a 55-kW heater, when the fan productivity is 2.8 m^3/s): *1–3*) calculated gas temperature at the input to the heater t_{g1}, at the entrance to the heat exchanger t_{g2} (*2*), and at the heating coils t_h (*3*); ○, ●) experimental t_{g1} and t_{g2} values, respectively; t_h^{max}, t_{g1}^{max}, and t_{g2}^{max} are the maximum temperatures of the heating coils and gas in furnace operation.

CONCLUSIONS

We have developed a closed electric heater with radiant–convective heat transfer between the heating coils and the housing walls. Analysis shows that heat transfer from the heating coils in a circulatory gas flux extends the working life by 30–50% in comparison with existing systems on account of decrease in the coil temperature. The new design is recommended for use in low-temperature furnaces with convective heat transfer in protective or aggressive atmospheres.

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Translated by Bernard Gilbert

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