Open Joint Stock Company
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 with a Hybrid Heating System

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Abstract—The reconstruction of a furnace with a rolling hearth for the heat treatment of welded metal structures is described. The primary heating system based on twelve high-speed recuperative burners is supplemented by a recirculation system for the exhaust gas, which is heated in a portable chamber. That ensures uniform temperature distribution in the furnace's working chamber, to within ±10°C. The introduction and debugging of the furnace is considered.

Keywords: furnace, heating system, recuperative burner, debugging, uniform heating
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In the assembly shop at OAO MZiK, furnaces with a 9.65 × 3.4 × 3.4 m working chamber and a rolling hearth are used for the heat treatment of welded metal structures (mass up to 15 t) in the range 20–650°C. In furnace heating by wall-mounted two-channel burners, with incomplete preliminary mixing, the temperature field within the working chamber is not uniform. In some conditions, the temperature difference within the working chamber is 60–100°C. As a result, some of the heat-treated welded structures do not meet the quality standards and are rejected. Consequently, the system has been reconstructed so as to ensure uniform temperature distribution in the furnace's working chamber, to within ±10°C.

According to the OAO VNIIMT design, one furnace with a rolling hearth is reconstructed, with modification of the metal framework, the lining, the furnace door with raising and lowering mechanisms and sealing mechanisms, the rolling hearth with its sealing mechanism, the gas and air supply systems, the smoke-extraction system, the automatic control system, and the electrical equipment.

To create a uniform temperature field, a recirculation system for the exhaust gas is introduced. By means of appropriate software, the gas dynamics and temperature fields in the working chamber are calculated with different configurations of the gas burners and the nozzles introducing the recirculated gas in the furnace and also with different flow rates of the recirculated gas from the nozzles and volumes of recirculated gas. That permits selection of the most effective recirculation system, in which the recirculated gas is returned to the furnace through two lines with slotted nozzles. The lines run along the side walls: one under the roof and the other (at the opposite wall) at the base of the furnace. Correspondingly, the recirculated gas travels downward along the side wall from one collector and travels upward from the other. The calculation results show that the distribution of the gas velocity close to the charge and the temperature at its surface are relatively uniform; the temperature difference is no more than 2–3°C.

The system is based on an OAO VNIIMT recirculation fan capable of operating up to 700°C, which is installed on metal structures above the furnace roof (Fig. 1). The high-temperature fan collects the exhaust gas from the working chamber through a hole in the roof and sends it to a portable heating chamber, equipped with an automated BIO 125H burner. The burner ensures smooth power regulation with minimum air excess, maintained using a regulator of the gas/air ratio. From the portable heating chamber, the exhaust gas is returned to the furnace's working chamber through two lines of variable cross section, with slotted nozzles. This ensures intense motion of the combustion products around the charge and equalization of the temperature over the whole working chamber. The flow rate of the recirculated gas is regulated by adjusting the speed of the fan motor using a frequency converter. On reaching the specified temperature in the furnace, the burners of the portable heating chamber are switched to the minimum level, and the furnace's primary heating system, based on twelve REKUMAT M250 high-speed automated recuperative burners (rated thermal power 160 kW), is switched on.

The burners are located at the furnace's side walls: six at the right above the charge; and six on the left, below the charge. Together with the recirculation system, this burner configuration, with a high flow rate of the combustion products (~150 m/s), ensures equalization of the temperature field over the working chamber and uniform heating of the charge. Recuperative heat exchangers built into the burners permit the return of approximately 50% of the heat from the exhaust gas. That significantly reduces the necessary fuel consumption.

The furnace walls and roof consists of panels with a metal frame that are lined with compact MKRV-200 ceramic fiber. The base of the furnace is a metal frame lined with refractory brick. The door at the supply window is also lined with MKRV-200 ceramic fiber and is equipped with raising and lowering mechanisms (including an electromagnetic brake) and with clamps to ensure tight sealing. The door may be raised by 3300 mm, within an interval of 18.3 s. The rolling hearth takes the form of a trolley with a built-in motor. A mobile frame seals the hearth at the base of the furnace. The frame is driven by electrical mechanisms mounted at the furnace base on each side of the hearth
1 and takes the form of cells with claydite to minimize the mass. A layer of refractory brick is applied on top
1 of the claydite. Seven cast refractory plates on the brick base of the hearth support the welded metal structures that are to be heated.

The gas-supply system meets the relevant federal safety requirements. An SG16MT-250-40-S flow meter is mounted on the natural-gas pipelines, along with a control valve and sensors for automation purposes. The burners are supplied with air from VR 14-15-8PR fans (working and backup fans mounted in the immediate vicinity of the furnace). The air for combustion is supplied when the air valves are opened by signals from the burner-control modules. The pressure in the air line is maintained constant by changing the fan speed using frequency converters.

The exhaust gas is extracted from the furnace by means of a DN-12 pump mounted close to the smokestack. The dust-extraction system consists of two parts. Most of the exhaust gas (~80%) is taken by the ejectors of the REKUMAT M250 burners from the
2 built-in recuperators and sent to the furnace flue and hence to the smokestack. The remaining 20% of the exhaust gas is taken directly from the furnace in a pipe containing a circular valve with an MEO electric drive for regulating the pressure in the furnace's working chamber. Such a drive is also built into the flue. The exhaust lines are heat-insulated by means of TIO-128 ceramic fiber and coated with DPRKhT aluminum foil. Sensors for automation purposes are also mounted in the exhaust and air lines.

The automatic control system is based on a SIMATIC S7-300 universal controller with modular SCADA remote input/output stations (SIMATIC Win CC system). The operator interacts with the system through a dedicated workstation. The automatic control system permits control of the furnace in terms of a

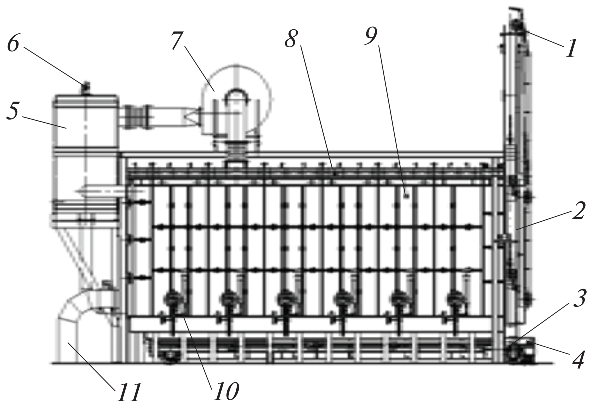

Fig. 1. Side view of furnace: *1*) mechanism for raising door; *2*) mobile guides for door-clamping mechanism; *3*) drive of hearth-sealing mechanism; *4*) rolling hearth; *5*) portable heating chamber for exhaust gas; *6*) burner for portable heating chamber; *7*) recirculation fan; *8*) roof panels; *9*) side panels; *10*) exhaust channel; *11*) primary burners.

fixed heat-treatment protocol (developed by technologists at the enterprise); the operator selects the program. All the information regarding furnace operation, the state of the equipment, and the settings and coefficients of the PID regulators are displayed on the monitor. On a system diagram, the state of all the furnace mechanisms and the technological parameters and their variation are shown. The system permits automatic or manual control of any mechanism. All the basic parameters are stored for at least three months in the archive, in the form of heating graphs and numerical values with time codes. The system turns off the gas supply to the burners and generates precautionary and emergency visual and audible signals when necessary—for example, when hazardous gas is present within the building or when the parameters deviate from their permissible ranges.

After furnace reconstruction, it requires debugging. The flow rate of the recirculated gas through supply nozzles over the length of the gas lines is also verified. To this end, the dynamic pressure difference of the recirculated gas flow from all twelve slots over the length of the gas lines is determined by means of a pneumometric tube, at different motor speeds of the recirculation fan. Uniform dynamic pressure difference (approximately the same exit velocity) is observed over the length of the gas lines at motor speeds no higher than 2000 rpm. Therefore, the frequency drive of the recirculation fan is adjusted accordingly. We may then expect more uniform and stable circulation of the gas in the furnace and a more uniform temperature field within the working chamber.

Uniform heating of welded metal structures differing in mass and shape is possible with a uniform temperature distribution of the heating gases over the

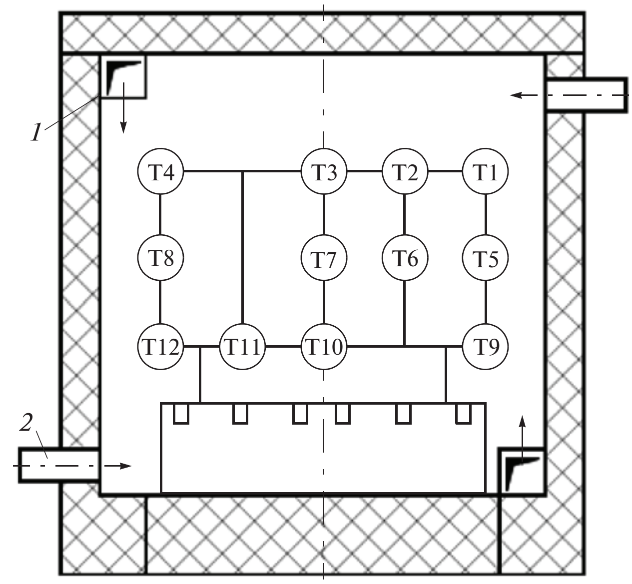

Fig. 2. Configuration of thermal converters on the moving frame: *1*) line supplying recirculated gas; *2*) burner.

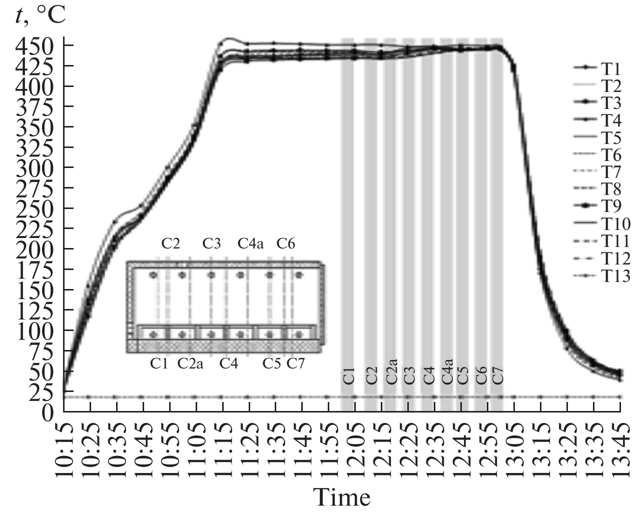

Fig. 3. Experiment with the moving frame (furnace temperature 450°C).

whole working chamber and with prolonged holding of the metal at constant final surface temperature. (With uniform heating of structures of any shape, the uniformity of the final temperature distribution over the whole mass of metal is determined by the holding time.)

To determine the uniformity of the gas temperature over the whole working chamber, a special measuring system is made, with a metallic frame that moves along the furnace on a temporary track, by remote control. The temperature at twelve points of any furnace cross section may be measured by means of twelve flexible Chromel–Copel temperature sensors (thermoelectric converters) attached to the moving frame (Fig. 2). The temperature sensors are connected to four CENTER-309 digital temperature recorders in a double-insulated thermos flask with a water jacket. The flask is attached to the base of the frame and remains within the furnace throughout the experiment. That ensures automatic temperature recording at all twelve points, at 30-s intervals. In addition, an additional sensor monitors the internal flask temperature in the course of the experiments.

Tests are conducted with the furnace at 200°C, 450°C (Fig. 3), and 650°C. In Fig. 3, we show the intervals when the mobile frame is at specific cross sections C1–C7 within the working chamber. The mean (over the cross section) temperatures at sensor 4 are somewhat elevated, because this point is close to the gas jet emerging from the recirculation line (Fig. 2). In furnace operation, the charge will not be in this zone. Because of the time constraints on the experiment (depending on the life of the batteries in the temperature sensors), the furnace is held at the specified temperature for a minimum time before the frame begins to move. This may account for the more uniform temperature at the end of the measurements.

The experimental results indicate that the temperature difference from the mean value in the working chamber is no more than ±7°C. At the highest test temperature (650°C), the readings of twelve stationary temperature sensors mounted at the furnace walls are recorded. When the frame position is such that the temperature sensors are in cross sections C1, C4, and C7, the deviation of the sensor readings from the mean temperature in the working chamber is no more than ±6°C. Therefore, the temperature distribution may be regarded as uniform.

The metal heating in the furnace is adjusted so as to ensure optimal temperature, with allowance for all the components of the thermal balance. In the course of adjustment, the pressure of the natural gas in its supply line and the air pressure at the burner are continuously monitored, along with the furnace pressure, the pressure in the exhaust channel, the temperature in all twelve heating zones of the furnace, the temperature of the recirculated gas, and the natural-gas flow rate. Exhaust-gas samples are taken and analyzed.

The heat-treatment conditions for the welded metal components are as follows:

Component	1 (in a dock)	2
Heating rate, °C/h	300 (up to 300°C), 120 (300–640°C)	225 (up to 450°C)
Holding time, h	2 (at 600°C)	3 (at 450°C)
Cooling	With furnace to 300°C	In air

Tests are conducted in conditions of manual control (for structure 1 in a dock) and completely automated control with preliminary specification of the heating graph (for structure 2). The corresponding heating processes are shown in Fig. 4, on the basis of the readings of stationary temperature sensors in twelve heating zones. In both cases, the temperature deviation in the working chamber is no more than ±5°C.

In addition, twelve temperature sensors (Chromel–Alumel thermocouples) are mounted on welded metal structures subjected to heat transfer, so as to monitor the temperature uniformity. The results are shown in Fig. 5. The lag of the readings from thermocouples T2 and T4 in the heating of component 1 (Fig. 5a) is due to their proximity to the massive dock (heat sink). Analogously, for component 2 (Fig. 5b), slow temperature rise is seen close to the massive base plate (T6, T8). At the end of holding, the temperature difference over the surface of the part is 16°C (Fig. 5a): 638.5°C at T3 and 622.9°C at T7. The difference tends to decline over time. Most likely, the holding time at the enterprise may be regarded as sufficient for equalization over the heated items.

Tests with specified heat treatment provide the data regarding furnace operation required to calculate the heat balance [1]. In furnace operation, the gas composition is typically as follows: 10.85 vol % CO_2; 1.60 vol % O_2; and 0.007 vol % CO. The maximum quantity of NO_x recorded in the exhaust gas is 184 mg/m^3, corresponding to the requirements on burner operation.

Pyrometer measurements of the external furnace temperature permit calculation of the heat losses in external cooling. With furnace holding at 640°C, the external temperature is 25–38°C at the door and 39–55°C at the roof.

The basic heat losses during heat treatment are as follows:

Component	1	2
Total heat consumption in cycle, MJ	20222	10680
Components of heat consumption, %		
heating of welded metal	10.9	8.5
heating of baseplate	23.8	22.6
heating of lining in furnace hearth	35.1	40.7
heat lost with exhaust gas	21.5	20.1
heat losses through walls	8.7	8.1
Fuel consumption, kg/t	28.65	146.2

The results of such tests are summarized in charts that are kept at the plant.

The burners employed ensure complete fuel combustion in the working chamber. The CO and NO_x concentrations are within the limits specified in State Standards GOST 21204–97 and GOST R 50593–97, respectively.

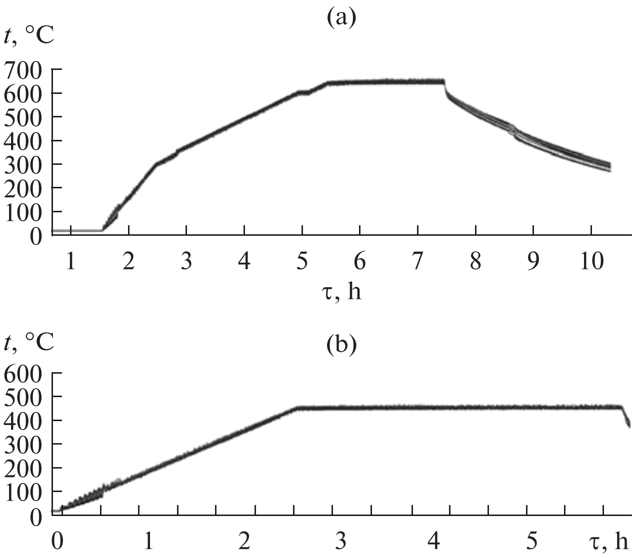

Fig. 4. Heat treatment of components 1 (a) and 2 (b).

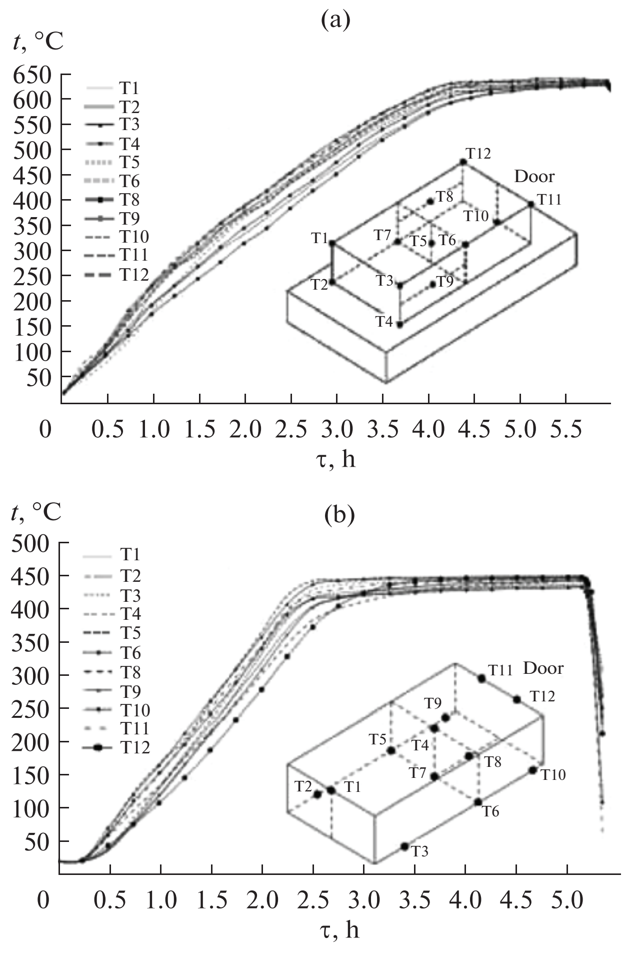

Fig. 5. Heat treatment of components 1 (a) and 2 (b).

CONCLUSIONS

The reconstruction of rolling-hearth furnace 2 in assembly shop 25 at OAO MZiK for the heat treatment of welded metal structures is described, from the preliminary calculations to debugging. The basic goal is to ensure uniform temperature distribution in the furnace's working chamber, to within ±10°C. The new system includes recuperative gas burners and an automatic control system ensuring completely automatic heat treatment of welded metal structures.

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Translated by Bernard Gilbert

SPELL: 1. claydite, 2. recuperators