Design of Optimal (Energy-Efficient) Roasting Systems

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Power consumption in the gas-transport system during pellet production in conveyor roasting machines accounts for 100% of the fuel (natural-gas) costs. Therefore, reducing power consumption in the roasting machines is of great importance. Moreover, modernizing the technology in this way provides a reserve of power for existing gas-transport systems and permits increase in productivity of the machine by the intensification of heat treatment, which is also important.

Power costs in pellet production are determined primarily by the state of the heating system and the correct choice of the gas-transport system for filtration of the heat carrier through the pellet bed and transportation of the gas fluxes through gas–air chambers. The power consumption in the drive of the gas-transport system varies widely for machines of different design: from 18–19 kWh/t for 480-m Lurgi machines (at OAO VNIIMT) [1]. Accordingly, comprehensive analysis of roasting-machine systems and components is required, with subsequent development of fundamental principles permitting the creation of an optimal thermal system with minimum power consumption.

In the present work, on the basis of a systematic approach, we develop basic design principles for optimal roasting systems with minimum power consumption, by breaking the equipment down into standard elements, which then undergo comprehensive analysis and synthesis. The basic components determining the overall efficiency are the gas-transport system, the gas–air chambers, and the organization of the gas fluxes.

The power consumed by the gas-transport system is

\[ N_{el} = \frac{\Delta PV}{\eta} = \frac{\Delta PV_0(t_{\text{gas}} + T_0)P_0}{\eta T_0} \]  

(1)

Given that the pressure loss (resistance) in the network is

\[ \Delta P = \xi \frac{rV^2}{2} = \xi \frac{r_0 V_0^2(t_{\text{gas}} + T_0)}{2T_0}P_0 \]  

(2)

we may write Eq. (1) in the form

\[ N_{el} = \frac{\xi r_0 (t_{\text{gas}} + T_0) V_0^2 P_0}{2 \eta T_0^2 (P_0)} \]  

(3)

where \( N_{el} \) is the power consumed by the gas-transport system; \( \Delta P, P, P_0 \) are the pressure difference created by the gas-transport system, the absolute pressure of the flux in that system, and the pressure in normal conditions, respectively (\( P_0 = 101 \text{ kPa} \)); \( V, V_0 \) are the gas flow rates for the actual parameters and the parameters reduced to normal conditions (\( P_0, T_0 \), respectively); \( t_{\text{gas}} \) is the temperature of the gas flux in the gas-transport system; \( T_0 = 273.15 \text{ K} \) is the absolute temperature in normal conditions; \( \eta, \eta_{\text{mot}}, \eta_{\text{fan}} \) are the efficiencies of the gas-transport system, the motor, and the fan, respectively; \( \xi \) is the aerodynamic drag; \( r, r_0 \) are the density of the gas flux for the actual parameters and the density reduced to normal conditions, respectively.

Analysis of the model in Eqs. (1)–(4) shows that reducing the power consumption in heat treatment of the pellets entails operating at maximum efficiency of the gas-transport system; reducing the quantity of gas transported by the system; reducing the total drag \( \xi \) of the pumping and suction channels in the aerodynamic network, which ensures transportation of a specified quality of gas at a smaller pressure difference \( \Delta P \); reducing the temperature of the gas fluxes \( t_{\text{gas}} \) in the transportation system; and optimizing the thermal system (Fig. 1).

Further analysis of these steps permits the development of practical design principles.

MAXIMIZING THE EFFICIENCY OF THE GAS-TRANSPORT SYSTEM

The system consists of an electric motor and a fan or exhaust fan, whose efficiency depends on their design—in particular, on the position of the working point within the aerodynamic characteristic. Therefore, in thermal-system design, the motor and fan must be chosen so that, in rated operation, the working points (the points of intersection of their characteristics and the network characteristics) are in the region of maximum efficiency, i.e., the aerodynamic characteristics of the fans and their networks must be matched.
According to Eq. (4), the electric motor must also be characterized by maximum efficiency and maximum load in rated conditions, in order to increase the efficiency, which is reduced when the motor load is above or below the rated level.

On the basis of the foregoing, we may select the following selection principles for the gas-transport system.

**Principle 1.** Maximum operational efficiency of the gas-transport system.

**Principle 1.1.** Selection of a fan or exhaust fan with maximum efficiency.

**Principle 1.2.** Fan operation in the region of maximum efficiency (matched characteristics of the fan and network).

**Principle 1.3.** Selection of the motor with the maximum efficiency and the optimal capacity.

**Principle 1.4.** More effective regulation of the productivity of the air-transport system, by (listed in order of decreasing effectiveness) changing the fan speed; employing an axial guide system; employing a simplified (gate) guide system; input choking; output choking.

**REDUCING THE QUANTITY OF GAS TRANSPORTED BY THE SYSTEM**

Minimization of the gas filtered through the pellet bed by optimizing the roasting-machine design and the heat treatment conditions was considered in detail in [2, 3]. Further significant reduction in the quantity of gas transported is made possible by the following principles.

**Principle 2.** Reduction of the quantity of gas transported by the system.

**Principle 2.1.** Using fans with a working temperature such that there is no need for dilution of the gas with cooling air.

**Principle 2.2.** Selection of the number of gas–air chambers connected to the collector so that, with any change in the process, there is no need to open the air-suction choke in order to reduce the temperature ahead of the gas-transport system.

**Principle 2.3.** The use of direct-flow collectors to transport the maximum quantity of high-temperature (up to 1000°C) gas from the cooling zone to the heating zone and increase the proportion of direct-flow gas.

**Principle 2.4.** Use of injection burners instead of two-line burners, so as to reduce the consumption of air transported by the system in combustion.

The last two principles significantly increase the fuel economy of the roasting machine.

**Principle 3.** Reduction of unorganized gas suction (inleakage).

**Principle 3.1.** Introduction of longitudinal lateral and transverse seals in the hearth and the gas–air chambers, their effective design, and productive operation.

**Principle 3.2.** Optimization of the ratio of the width of the roasting trolleys and the length of the machine, so as to minimize the total contribution of suction (inleakage) to the total gas balance, depending on the operational efficiency of the transverse and longitudinal seals. Currently, the contribution of suction declines with increase in trolley width in different machines from 2 to 5 m [4].

**Principle 3.3.** Automatic maintenance of the minimum necessary pressure (rarefaction) in the hearths of the machine.

In existing roasting machines, harmful suction (inleakage) accounts for 15–40% of the total gas. Therefore, principles 3.1–3.3 are very effective.

**REDUCING THE AERODYNAMIC DRAG $\xi$**

The drag in the network consists of the drag of the suction and supply channels, i.e., the drag of the trolley (pellet layer, bottom and lateral regions, grate), the gas lines, and the gas-cleaning units, local drag, etc. The aerodynamic drag of the trolley will be considered separately and in relation to all of its components, since it creates up to 40% of the total drag, and there is considerable interaction of the components. To reduce the trolley drag $\xi$ the following principles must be adopted.

**Principle 4.** Reduction in the aerodynamic drag of the pellet bed.

**Principle 4.1.** Optimizing the quality of the pellets sent to the roasting machine by excluding small (<5 mm) and large (>18 mm) classes and improving the initial pellet strength.

**Principle 4.2.** Packing the pellet bed with increased porosity [5].

**Principle 4.3.** Determining the optimal height of the pellet bed such that power costs are minimized.

**Principle 4.4.** Eliminating shrinkage of the pellet bed on heat treatment by organizing pellet drying with gas injection from below in the first section and suction from above in the second, with an optimal ratio of the areas of the sections and corresponding gas temperatures.
Principle 5. Reduction in aerodynamic drag of the bottom and lateral regions and grate.

Principle 5.1. Elimination of small pellets from the bottom region, to prevent clogging of the grate. (As a rule, commercial pellets are employed.)

Principle 5.2. The provision of side plates, intended to reduce the gas-filtration rate through the bed at the sides of the trolley, which increases on account of the wall effect, as well as dense gratings.

Principle 5.3. Selection of grate dimensions and configuration so as to ensure self-cleaning with passage of trolleys from the working to the idling branch of the roasting machine.

Principle 6. Reduction in aerodynamic drag of the channels (including the trolley) in accordance with the basic precepts outlined, for example, in [6].

Principle 6.1. Maintenance of the same flow velocity in each cross section of the pipeline, including the removal of gas from the collectors through the connecting pipe or, conversely, the introduction of gas in the collectors from the connecting pipe; smooth breakaway and coalescence of departing and incoming fluxes, respectively. (To this end, conical collectors are employed.)

Principle 6.2. Avoidance of sharp bends, broadening, and narrowing of the pipelines.

Principle 6.3. Installation of guide plates at sharp turns.


Principle 6.5. Selection of the pipeline diameter to match the quantity of gas, whose velocity must not exceed the standard value (15–20 m/s).


Principles 6.1–6.6 are very important, but are often ignored in the design process, especially principle 6.1.


Principle 7.1. The use of electrofilters, which are characterized by minimum aerodynamic drag and pressure losses and also by high efficiency and low power consumption.

Principle 7.2. Eliminating gas-cleaning equipment from the internal gas fluxes by using gas-transport systems that are resistant to abrasive wear (with protection of the rotor).

GAS TRANSPORTATION AT DIFFERENT TEMPERATURES.

Analysis of Eq. (1) shows that, in gas transportation by means of a system at temperatures \( t_1 \) and \( t_2 \), other conditions being equal, the power consumption will be directly proportional to the absolute temperature

\[
N_{el1}/N_{el2} = (t_1 + T_0)/(t_2 + T_0).
\]  

(5)

On that basis, we may formulate the following principle.

Principle 8. Transportation of gas fluxes at the lowest possible temperature. This principle is violated by designs in which the pellets are cooled by hot air in the first section (Fig. 2). Analysis of such systems indicates that this reduces the productivity of the cooling zone, increases coolant and power consumption, and impairs environmental conditions in the shop [2, 7–9]. There is also some reduction in fuel consumption, but this does not balance out the additional power consumption and the losses associated with the reduced productivity of the roasting machine. As the area of the section cooled by hot air increases, the performance of this system declines further relative to a system with cooling by atmospheric (unheated) air (Fig. 2b).

In fact, when using hot air (Fig. 2a), it is sent under pressure to the initial section of the cooling zone. In this case, the power consumption is

\[
N_{heat} = \frac{\Delta PV_{01}(t_1 + T_0) P_0}{\eta T_0} + \frac{\Delta PV_{02}(t_2 + T_0) P_0}{\eta T_0},
\]  

(6)

where

\[
\Delta P = P_{out} - P_{in}.
\]  

(7)

With the same pellet temperature at discharge, \( V_0 < V_{01} + V_{02} \), as shown in [7]. However, even on the assumption that \( V_0 = V_{01} + V_{02} \), the power consumption on cooling solely by cold (atmospheric) air at \( t_2 \) is

\[
N_{cool} = \frac{\Delta PV_{01}(t_2 + T_0) P_0}{\eta T_0} + \frac{\Delta PV_{02}(t_2 + T_0) P_0}{\eta T_0},
\]  

(8)

\[
= \frac{\Delta PV_{01}(t_2 + T_0) P_0}{\eta T_0} + \frac{\Delta PV_{02}(t_2 + T_0) P_0}{\eta T_0}.
\]
Hence, the extra power consumption on cooling by hot air is

\[
N_{\text{heat}} - N_{\text{cool}} = \frac{\Delta PV(\tau_1 + \tau_0)P_0}{\eta T_0} - \frac{\Delta PV(\tau_2 + \tau_0)P_0}{\eta T_0} = \frac{\Delta PV(\tau_1 + \tau_2)P_0}{\eta T_0}.
\]

With this technology, there will be excessive power consumption, even without considering the greater quantity of gas required for cooling. Taking this factor into account, the actual waste of power will be even greater [7].

Power economy in the transportation of gases at different temperatures is also important. Calculations show that transportation of the gases by separate systems is more economical than mixing the gases and transportation of the mixture in a single system. However, the saving is no more than 0.5% on mixing fluxes with a temperature difference of up to 500°C; if the difference is 1300°C, it may be ~5%. This is explained by the higher mean specific heat of the high-temperature gas flux and, correspondingly, the nonlinear increase in mean mixture temperature; as the proportion of high-temperature gas increases, the effect will be more pronounced.

**Principle 9.** In terms of power consumption, it is best to transport gas fluxes at different temperature by means of different transportation systems, i.e., without mixing (especially with a large difference in temperature and specific heat of the fluxes). However, for the gas fluxes mixed at roasting machines in practice (with a temperature difference no greater than 500°C), the difference in power consumption is no more than 0.5%.

**OPTIMIZING THE COMPONENTS OF THE THERMAL SYSTEM**

On the basis of a systematic approach, the thermal system may be broken down into a series of standard elements, whose analysis permits optimization (minimization) of the power consumption.

In the hearths of different technological zones within the roasting machine, pressure/rarefaction in the range between 0.2 and ~0.5 kPa is maintained. An analogous rarefaction is established in the aspiration systems. In the gas–air chambers, pressure/rarefaction of 3–6 kPa is maintained, i.e., an order of magnitude greater than in the hearths. For convenience of the subsequent analysis, the hearth zones may be characterized as low-pressure zones, and the gas–air chambers as high-pressure zones.

In general, the gas fluxes may include the following interacting standard components: gas transfer from hearth to hearth; gas transportation simultaneously from or to the hearth and the gas–air chambers of one gas-transportation system; gas transfer from the gas–air chambers to the hearth or from the hearth to the gas–air chambers; gas transfer from the gas–air chambers to the gas–air chambers.

**GAS TRANSFER FROM HEARTH TO HEARTH (FROM A LOW-PRESSURE TO A LOW-PRESSURE ZONE)**

In this case, a pressure difference of 0.2–0.3 kPa is sufficient; this may be produced by means of a flow system with low aerodynamic drag on account of the short rectilinear gas lines and the conical collector configuration. There is no need for additional gas-transportation systems or dilution of the flux (Fig. 3). Therefore, we may formulate the following principle.

**Principle 10.** Maximization of the quantity of gas transported from one low-pressure zone to another (for example, between hearths) by direct flow (without the need for additional gas-transportation systems).

Only old machines (OK-108 machines) transfer gas between hearth sections using a gas-transportation system. In that case, the gas from the cooling-zone hearth is diluted with atmospheric air to 300–350°C, permitting the use of the transportation system. On more recent equipment—OK-306 machines, OK-320 machines, 480-m² Lurgi machines (at OEMK), and OK-228 machines—most of the air from the cooling zone is transported by direct flow through the corresponding collector or hearth, and the remainder is transported by means of the gas-transportation system either to the first drying section (with injection) or to the hearths of the machine and to the burners. Therefore, in modernizing thermal systems, maximizing the direct flow from the cooling zone represents an important resource for power economy.

**GAS TRANSPORTATION SIMULTANEOUSLY FROM OR TO THE HEARTH AND GAS–AIR CHAMBER BY A SINGLE GAS-TRANSPORTATION SYSTEM (FROM OR TO LOW- AND HIGH-PRESSURE ZONES)**

In some thermal-system designs, the aspirational and discarded gas fluxes from the hearth of drying sec-
tion 1 and cooling section 2 are moved by a gas-transportation system that is simultaneously forming a rarefaction in the gas–air chambers (Fig. 4). These designs are employed in the OK-228 (Kachkanarsk enrichment facility) and OK-108/116 (AO SSGPO) roasting machines, among others. This calls for parallel evacuation of high-pressure gas fluxes from the gas–air chambers and fluxes from low-pressure sections (down to ~0.5 kPa). An additional choke Ch1 is used here to ensure the necessary aerodynamic drag of channel 2 for the evacuation of gas flux V_2; according to Eq. (1), this leads to increased power consumption.

In this case, it is expedient to evacuate the aspirational or discarded gas flux from drying section 1 or cooling section 2 by a separate low-pressure gas-transportation system, which eliminates the need for Ch1. Taking into account that

\[ V = V_1 + V_2, \]  

the power consumption in these two cases will be as follows:

for the nonoptimal design (Fig. 4a)

\[
N_{nonopt} = (P_{out} - P_{in})V/\eta \\
= (P_{out} - P_{in})(V_1 + V_2)/\eta \\
= (-P_{in}V_1 + P_{out}V_1 - P_{in}V_2 + P_{out}V_2)/\eta, \tag{11}
\]

for the optimal design (Fig. 4b)

\[
N_{opt} = ((P_{out} - P_{in})V_1 + (P_{out} - P_{in}2)V_2)/\eta. \tag{12}
\]

The power saving is

\[
\Delta N = N_{nonopt} - N_{opt} = -(P_{in}V_1 - P_{in}2)V_2/\eta. \tag{13}
\]

Given that P_{in} is considerably greater than P_{in}2, we may write

\[
\Delta N = N_{nonopt} - N_{opt} = -P_{in}V_2/\eta. \tag{14}
\]

The wasted power is determined analogously in the case of simultaneous gas supply by a single gas-transportation system to gas–air chambers and hearths. For example, a nonoptimal design is encountered when the gas from the hearth in cooling section 2 is supplied simultaneously to the gas–air chambers of drying section D1 (a high-pressure zone) and to the hearths of drying section D2 (a low-pressure zone; Fig. 5). In that case, the specified gas flow rate V_2 must be ensured by using choke Ch1 to reduce the pressure from P_{out} to P_{hearth} = 0. This nonoptimal situation arises in modernizing the drying zone, when the area of the section operating with gas injection is reduced and a drying section with gas suction is organized in the free area. The changes required to optimize the system are shown by dashed lines in Fig. 5.

The only difference from the designs in Fig. 4 is the configuration of the pumping and suction channels.

The possible power saving is

\[
\Delta N = N_{nonopt} - N_{opt} = (P_{out} - P_{out2})V_2/\eta, \tag{15}
\]

or analogously, in the first approximation

\[
\Delta N = N_{nonopt} - N_{opt} = P_{out}V_2/\eta. \tag{16}
\]

In addition, in accordance with principle 10, it is expedient to eliminate gas-transportation system T2 from the optimal design and permit direct flow of the gas to the drying sections.

Thus, in both nonoptimal cases, the gas is choked by Ch1 to reduce the pressure from the level in the gas–air chambers to the level in the hearth, which wastes power.

On the basis of the foregoing, we may formulate the following principles.

**Principle 11.** Ensuring that the pressure head created by the gas-transportation system is distributed to the point where it is required, i.e., elimination of gas supply to/from both low- and high-pressure zones by a single gas-transportation system. Supplying gas simultaneously to sections of different pressure by means of
a single gas-transportation system is nonoptimal, on account of the need for a choke. Therefore, to reduce power consumption, the following principles must be observed.

**Principle 11.1.** Ensuring that gas fluxes from the hearth and aspirational exhaust fluxes are not connected to the high-pressure gas-transportation system extracting gas from the gas–air chambers.

**Principle 11.2.** Eliminating simultaneous supply of gas fluxes to/from hearths and to/from gas–air chambers by a single gas-transportation system.

**Principle 11.3.** For organization and regulation of the required gas flow from some sections of the equipment to others, maintenance of minimal controllable aerodynamic drag and also minimal pressure difference sufficient to ensure the required flow.

**GAS TRANSFER FROM GAS–AIR CHAMBERS TO HEARTHS AND FROM HEARTHS TO GAS–AIR CHAMBERS (FROM HIGH-TO LOW-PRESSURE ZONES AND VICE VERSA)**

Gas supply from the hearth (low-pressure zone) to the gas–air chambers (high-pressure zone)—for example, from the hearth of cooling section 2 to the gas–air chamber of drying section 1—is widely used in roasting-machine design (Fig. 6a). Gas supply from the gas–air chamber (high-pressure zone) to the hearth (low-pressure zone) is used in moving gas from the gas–air chambers of the roasting and recuperation zones to the hearths of the heating zone (Fig. 6b).

Using formulas analogous to Eqs. (10)–(14), we may show that, in terms of minimum power consumption, where the use of other control systems is impossible, choke Ch2 must be used to control the quantity of air supplied to (Fig. 6b) and from (Fig. 6a) the gas–air chambers. The use of choke Ch1 for regulation increases the power consumption on account of the violation of principle 11, since in this case the gas is supplied simultaneously to a high-pressure zone (the gas–air chamber of drying section 1) and a low-pressure zone (atmospheric discharge through Ch1) by means of a single gas-distribution system.

**Principle 12.** In gas transfer from a hearth to a gas–air chamber (or vice versa), when the use of other systems to regulate the gas flow is impossible, a regulating choke must be established on the side of lower absolute pressure.

**GAS TRANSFER FROM ONE GAS–AIR CHAMBER TO ANOTHER (BETWEEN HIGH-PRESSURE ZONES)**

Gas transfer from one gas–air chamber to another (Fig. 7) is used in machines for moving gas from the gas–air chamber in the roasting and recuperation zones to the chambers in drying section 1 or in cooling section 1. One important problem here is to optimize the load ratio of the exhaust fans in the suction and pumping channels of the aerodynamic network.

In this case, the number of gas–air chambers connected to collectors C1 and C2 must be chosen so that the coolant supply rate to C1 is equal to the flow rate to the suction channel of gas-transportation system T1, while the ratio of pressure P1 and P2 in collectors C1 and C2 of the corresponding zones must be optimal in terms of power consumption, with equal productivity of these zones [2].

Analysis of the system in Fig. 7 with different combinations of chokes Ch1 and Ch2 is of interest.

The system without Ch1 and Ch2 must be regarded as ideal, but they are required in order to control the process. In the absence of Ch1 and Ch2, the pressure in C1 rises and the pressure in C2 falls as the gas permeability of the bed in drying section 1 declines; the quantity of gas declines in both C1 and C2, which leads to incomplete pellet roasting. When the section of the pellet bed with low gas permeability advances toward C2, the rarefaction there is enlarged and bed filtration in the region of C1 deteriorates further. Such feedback complicates the control of pellet heat treatment. There is no waste of power in this system, but productivity and pellet quality fall, since drying zone 1 and the recuperation
SYNTHESIS OF OPTIMAL THERMAL SYSTEMS OF ROASTING MACHINES

Note that the design of optimal systems is a problem that remains to be fully formulated, on account of its complexity. Therefore, successful designs largely depend on the skill of developers, a comprehensive approach to design and parameter estimation, and the availability of appropriate software.

Gross design errors may be eliminated on the basis of the principles here outlined, together with the recommendations in [2]; the process may also be formalized to the greatest extent possible. This permits the development of optimal systems, taking account of the initial pellet characteristics, the quality requirements on the final pellets (for blast-furnace production or for reduction) specified by the major customers, and correspondingly the degree of reconstruction required and the available space for installing additional equipment in the event of modernization.

Principle 15. On the basis of the approach proposed in [2], minimization of the machine’s overall power consumption entails first determining the optimal ratio of the corresponding areas and the pressures required in the gas–air chambers. They depend on the characteristics of the initial pellets, which determine the temperature curve of heat treatment, the quality requirements on the roasted pellets, the specified productivity of the machine, and other requirements. At fixed productivity of the roasting machine, the power consumption declines with increasing in the useful area.

In the next stage, optimal thermal systems corresponding to minimum power consumption are synthesized on the basis of principles 1–15, taking account of the initial and boundary conditions and the technological constraints.

These design principles may be used in preparing engineering and commercial proposals and in simulation of the roasting machines at different enterprises (AO SSGPO, Oskol’sk Electrometallurgical Works, and the Lebedinsk, Kachkanarsk, Northern, and Central Mining and Enrichment Facilities).

CONCLUSIONS

On the basis of systematic analysis using mathematical models, basic design principles for the thermal systems of pellet-roasting machines with minimum power consumption have been developed.

REFERENCES


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 °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 °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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