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Raising of energy efficiency of thermal performance of layered metallurgical units using layered type of natural gas combustion

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Abstract. While heating lump materials there are some difficulties such as poorly organized process of grate firing, conditions deterioration of gas-air mixture creation, limited discharge of combustion products out of a layer due to additional aerodynamic drag occurrence when gases flow. Grate firing of gaseous fuel can be completed in a dense layer of lump materials which have different chemical composition and particle-size distribution. To do this, it is necessary to provide formation of high-temperature area and complete thermal generation process directly between separate elements of treated materials. It allows providing specified temperature-time conditions of heat treatment of the different layer sections. Also, it is required to limit the direct contact of the high temperature zones with external boundaries of the unit smelting chamber and environment for increasing reliability and effectiveness. In this paper, we present existent heat-exchange schemes in grate process units during the heat treatment of lump materials. An ability of grate firing of gaseous fuel while organizing a delivery of prepared gas-air mixture into a dense layer or separate tuyser gas and air supply with separate flows is shown. Usage of indicated ways of feeding allows decreasing energy demands and improving quality of products delivered.

1. Introduction

Numerous theoretic and experimental researches of industrial thermo-technological processes and units show that usage of gaseous fuel while organizing their thermal performance in the capacity of central heat source and processing additive essentially increase technical-and-economic indices of high temperature process implementation [1–5]. However, first of all, it relates to the grate process units using different schemes of heat exchange between gases and materials [6].

The most common way of flame combustion of gaseous fuel while lump materials are heating, complicated with presence of blow down piece packing on the way of gas flow which facilitates the change-over jet fire gaseous fuel into badly-organized process of grate firing deteriorates the conditions of initial gas-air mixture creation, causes difficulties of its preheating up to inflammation temperature of combustible part, and limits discharge of combustion products out of a layer due to additional aerodynamic drag occurrence when gas flows.



2. Researches of features of grate type of gaseous fuel firing

Researches of thermo physical features of grate type of gaseous fuel firing [7] showed that it can be implemented in the dense layer of lump materials almost of any chemical composition and particle-size distribution. The differential characteristic of implementation of this process is direct involvement when forming high-temperature area in the dense layer of heated materials of solid surface of batch mixture lumps [8]. It allows for relatively simple provision of specified temperature-time conditions of heat treatment of different sections of the layer, completing thermal generation process between separate elements of treated materials. Bounding of the direct contact of the high temperature zones with external boundaries of unit smelting chamber and environment increases reliability and effectiveness of usage of this way of layered facility heating. Taking intermediate place between flare and plasma processes according to physical properties (temperature, heating rate, gas-phase composition), this way of thermal generation requires advance preparation of the base mixture of air and natural gas which includes homogenization of its composition and preheating.

Incineration process of the initial gas-air mixture in the dense layer of lump materials should be referred to micro jet fire, which is complicated by the presence of solid components with finite dimensions filling the volume of the smelting chamber.

When organizing initial gas flows supply directly into layer of lump materials of different dispersion degree being fired, implementation of two variants is possible:

- supply of treated gas and air mixture preliminarily prepared in special mixers which is peculiar to implementation of thermal generation process in a limited volume of heated layer (pellet firing, agglotstoe ignition process, etc.);
- gas and air supply through separate flows during tuyer supply thereof in the mine units.

Initial heat impulse for stable ignition of gaseous fuel in the layer can be implemented with the help of an open fire flare, electric spark, hot jet or heated surface. The most radical way to provide the conditions of gaseous fuel firing is rise temperature of the used layer surface in the mode of pre-heating from external energy source.

According to the combustion gas mixture theory, the conditions of its combustion depend on dynamics of boundary layer preheating on the front part of the pieces where heat passage is carried out mainly by thermal conduction [9].

First of all, oxygen molecules are adsorbed on the solid surface and distributed over it almost equally regardless of the nature of the surface itself. The presence of additional thermal resistance layer of adsorbed oxygen on the surface of layered particles requires increased temperature gradient between lump materials and molecules of the gas mixture. Because of it, the level of layer preheating for organizing grate gas combustion must be higher than ignition temperature of the initial gas mixture (500–550°C). According to the practical data its value should be 800–1050°C. Despite the significant value of the heat energy discharged in combustion of fuel, the presence of heat efflux for heating of layer elements and convection current with exit gases limit the general rise of the system temperature.

Increased adsorption activity of oxygen molecules in relation to the solid surface of the layer decreases their concentration in the interlump space in the initial section of gas-air mixture flow. Thus, to provide required concentrating proportions between combustible components and oxygen in the gas mixture when it is ignited, it is necessary to provide a significantly higher air flow compared to the flare combustion conditions. It makes sense to maintain air discharge coefficient at the value not lower than 2.5–3.0 for stable ignition of gas mixture in the dense layer.

Gaseous fuel combustion process in the lump materials layer is presented as sequentially passing stages of heat exchange. Gas-air mixture heats when it is supplied to the preheated lump material layer and cools it down. After the gas mixture reaches ignition temperature, which is determined not only by its initial composition, but also by the conditions of its heating, and active combustion zone is generated. Its distinguishing features are high temperature and increased rate of oxidation of hydrocarbons with the possibility that combustion can shift over the entire layer. When moving through a relatively cool part of the layer, combustion products generated during gas combustion heat it up. These provide for conditions for gas fire propagation over the height of the piece packing.

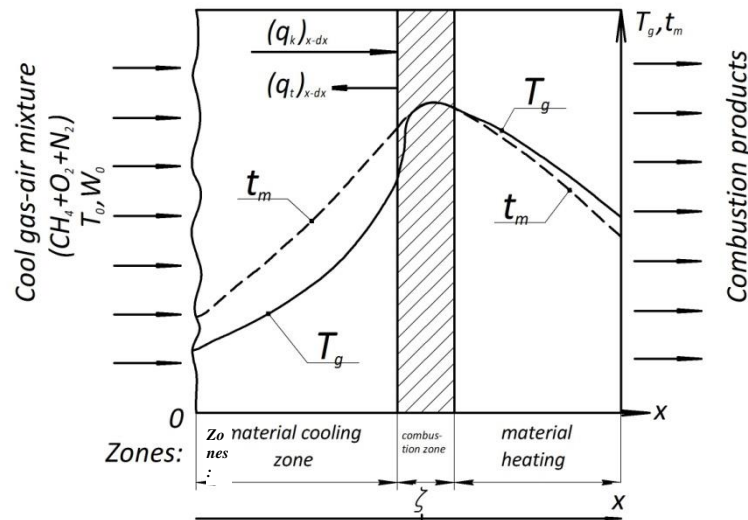


Figure 1. Heat-exchange circuit in gas combustion in the layer.

T_g, t_m – gas and material temperatures; X – current coordinate of combustion area.

Temperature level of combustion zone is determined by the conditions of heat-exchange in the layer cooling zone by the flow of initial gases, by activity of the intensive heat emission from oxidation of hydrocarbons directly in the active combustion zone and by the development of convective flow of exit gases.

Formation of the combustion zone of natural gas in the dense layer of lump materials is ensured by the equality of heating rates with thermal conductivity from layer elements $(\sum q_{T_i})_{\zeta-dx}$ to the combustion area with the coordinate of ξ , thermal emissions in it $(b \cdot Q_u^p)$ from oxidation of hydrocarbons and convection heat gas flow $(\sum q_{k_i})_{\zeta+dx}$ in the direction of the heated layer:

$$(\sum q_{T_i})_{\zeta-dx} = (b \cdot Q_u^p) + (\sum q_{k_i})_{\zeta+dx} \quad (1)$$

where q_T – specific heat flow rate with heat conduction in the direction of gas mixture, kJ/h; b – specific fuel consumption, m^3/m^3 ; Q_u^p – fuel combustion value, kJ/ m^3 ; q_k – specific heat flow rate with the convection in the direction of flow of exit gases, kJ/h.

Interruption of this balance determines the travel direction of fuel grate firing zone across the layer. If specific heat flow rate exceeds heat conduction magnitude of specific heat convective flux, the process of layered gaseous combustion will move towards the initial gas mixture. Otherwise, high-temperature combustion zone extends in the direction of gas flow.

Usage of treated gas mixture in the grate type of firing bounds the extension of gas combustion area zone in the layer to the distance not longer than 30–60 mm [10] directly near the entrance of the used gases into the heated layer (at the distance not longer than 5–25 mm) [11] with the movement speed of 8–16 mm/min when the temperature therein is not more than 1150–1350°C [12]. It provides the possibility to save on energy costs for development of layered processes up to 10–15% with improvement of qualitative parameters of the products obtained.

Under the conditions of tuyer air blowing into the smelting chamber of the grate unit and coaxial jetting supply of gaseous fuel into it under increased pressure, discharge of gas jets out of the nose-pieces (Figure 2a) is carried out in several flows of varying degrees of mixing between themselves, and it facilitates distribution of conditions for gas flow in the space filled with gaseous medium having the same physical properties as the jet substance in the form of separate jet flares. At the same time, each gas component is preliminarily held in stable molecular state. If there is a gas-penetrable

piece packing for lump materials on the way of jet penetration, jet process motion type changes significantly along with turbulization of gas flows, reduction of flare range capability and increase in their opening angle within 17–32 degrees.

According to the theory of development of turbulent isolated and coaxial jets, gaseous medium flowing out of the nozzle at a high speed [13] provides ejection into the flowing environment stream both along external and internal borders of the jet stream. Since there is no medium in the jet to satisfy its ejection requirements, pressure in this zone drops, and circulating vortexes directed along the jet to its starting point are generated inside the annular space. This provides stability of the gas component mixing conditions and ignition of generated mixture.

Initial heat impulse for stable ignition of gaseous fuel is affected by means of layer preheating by external heat source when layered type of natural gas firing in the dense layer is organized.

The heat source has to be located close to the gas jet entrance in the heated layer. The closer the gas-air mixture ignition zone is to the entrance, the more evenly temperature distribution in the layered combustion zone will be. The length of the preheating zone shall provide the constant heating of the gas-air mixture up to the ignition temperature at which thermal emission will exceed thermal absorption in the layer.

Despite the significant value of the thermal energy flow discharged in the combustion fuel, the presence of heat efflux for heating of layer components and convective current with exit gases limit the growth of the layer temperature not more than to 1150–1350°C [14].

Changes of supply conditions and mixing of co-current streams enables adjustment of conditions of gas mixture distribution over the depth of the layer in wide range [15–17]. Extension of jet processes in the piece packing will depend on the mixing conditions of the central high-speed gas jet with annular air stream delivered with lower speed, and also on gas flowing out of the environment. The formation of the required initial composition of gas-air mixture, its mixing, ignition and expansion in the volume of the layer part being fired will occur in the border zone of the general flare development. The range of expansion of hot combustion zone in the direction of gas efflux is, for the most part, determined by kinetic energy of gas jet.

Absence of oxygen along the central part axis of the burner unit turns the layer combustion process into the zonary type. There is a cold jet of natural gas in the central part of the gas flow (Figure 2a, 4). In the peripheral part thereof, a gas-air mixture is formed by means of suction of concurrent air flow (Figure 2a, 3). The presence of the preheated layer with the temperature of 800–1050°C on its path at the entrance of gas mixture into the layer of batch mixture leads to the heating of natural gas and air flows with shift of the high-temperature area to the peripheral flare part. As a result, there is combustion zone (Figure 2a, 5) where the energy generation processes occur. However, there is a high-speed natural gas flow in the central part of the gas flare the chemical composition of which is close to the gas composition at the nozzle edge (Figure 2a, 2).

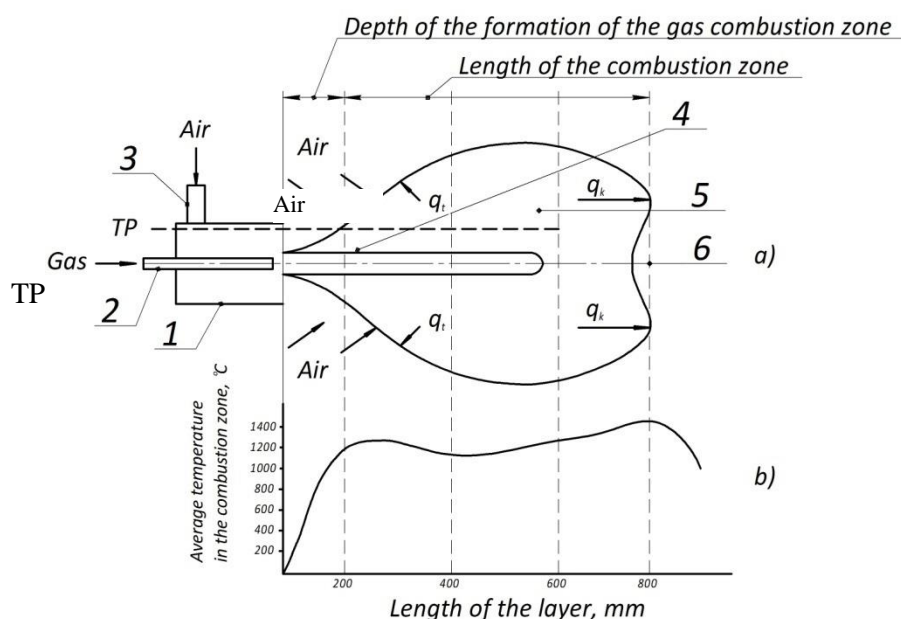


Figure 2. Scheme of the development of the gas combustion process in the layer under the conditions of tuyer gas components supply (a): 1 – burner body; 2 – gas nozzle, 3 – air pipe; 4 – gas jet; 5 – gas-air mixture combustion zone in the layer; 6 – combustion products; TP – thermometer probe; (b) – layer temperature variations with the air flow rate factor of 1.52 and speed of gas exit out of the burner of 2.97 m/s.

Around the periphery of the combustion zone there is a zone formed in the result of natural gas mixing with air and combustion products. Length of this zone in the horizontal direction is evaluated by the conditions of natural gas mixing with air and by the conditions of gas-air mixture ignition. Combustion products generated during gas firing go through the relatively cool part of the batch mixture layer and generate conditions for after flaming of gas in the dense lump material layer outside the zone by means of ejection of air flow from the environment.

3. Conclusion

Consequently, usage of the layered natural gas combustion process upon heating of piece packing can take the volumetric form and cover a considerable part of its smelting chamber while providing total fuel consumption for hard firing at the level not more than 140 kg per nominal thousand tons. The presence of high heating temperatures of initial gas mixture in the layer under the lack of oxygen opens up space for the development of the gaseous oxygen methane conversion with the formation of the stream of CO and H₂ reducing gases.

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