S. GIL, W. BIALIK, J. OCHMAN

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ANALYSIS OF FUEL SAVINGS IN METALLURGICAL FURNACES WITH PROTECTIVE ATMOSPHERE

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In the paper, a case of improvement in energy efficiency of a rollway-continuous furnace used for heat treatment in production of cold-drawn tubes as well as gas savings resulting from application of modern burners for radiant tubes was considered. For the investigated furnace, energy balance calculations were performed for the currently operating status as well as following replacement of burners for modern devices with better parameters of combustion and recuperation, which showed a significant reduction in fuel consumption. The burners ensure uniform temperature distribution along the radiant tube, stable operation, high energy efficiency (also in high temperature furnaces) and low emissions.

Key words: metallurgy, furnaces, fuel savings, modern burners, protective atmosphere

INTRODUCTION

Concerning current global economy, costs of production and profits are among the most important criteria that determine business operations. A major item of production costs, particularly for metallurgical and metal treatment plants, is expenditure related to energy carrier purchase. Recently, a drop in electricity and oil-based energy source prices has been observed on global markets but many specialists find this a temporary trend. Therefore, attention should be paid to all kinds of activities aimed at reducing power consumption related to production processes. They can be multiple actions with key objectives being a change in work practices and modernisation of the technological process. Any interventions to reduce energy consumption with regard to the production line related to a technological process are usually associated with considerable financial outlays. In order to determine actual economical relationships between expected to the applied technologies should be determined by means of the energy balance outlays and intended savings that bring more profits, energy consumption related evaluation, followed by the analysis of reasonable modernisation scope as well as calculation of anticipated savings regarding energy carrier consumption and the resulting final economic effect.

ENERGY BALANCE OF THE ROLLWAY CONTINUOUS FURNACE

To identify energy balance of the rollway-continuous furnace, necessary measurements of mass, energy and enthalpy were performed. The following parameters and data were measured and collected: feed material temperatures and streams at the furnace inlet and outlet, furnace shell temperature distribution, temperatures and mass flow rates of cooling media, composition of flue gases in the suction manifolds and the surrounding temperature. The furnace is intended for the technological process regarding heat treatment of steel elements following their cold working. Within the furnace working space, controlled protective atmosphere is maintained to secure surfaces of processed elements from oxidation. The furnace features two zones (heating and compensation) where defined temperatures of approx. 850 °C and 920 °C are maintained. These temperatures are matched each time depending on the processed feed type. The furnace is powered by natural gas to be combusted in 38 burners of radiant tubes equipped with individual recuperators. The burners are arranged in two (upper and lower) rows. The mean heating capacity of the system during the technological process amounts to about 1,3 ÷ 2 MW. The composition and temperature of flue gases are markedly affected by the outdated burner and recuperator designs. Flue gases feature high contents of harmful agents and a high temperature at the outlet to the mixing device. Regardless of the systems where proportions of combustion substrates were poorly controlled, the contents of carbon oxide and nitric oxide were: CO (3 % O_2) = 1 000 ppm and NO_x (3 % O_2) = 180 ppm. These values exceed both the acceptable standards and the parameters of other burner designs. For a standard 30 kW burner within 800 – 900 °C, the following values should be ensured: CO = approx. 35 – 55 ppm, NO_x = approx. 100 –140 ppm [1]. In Figure 1, NO_x levels for standard 20 kW and 30 kW burners as well as for a modern GAFT burner [2,3] are presented.

S. Gil, W. Bialik, J. Ochman, Faculty of Materials Engineering and Metallurgy, Silesian University of Technology, Katowice, Poland

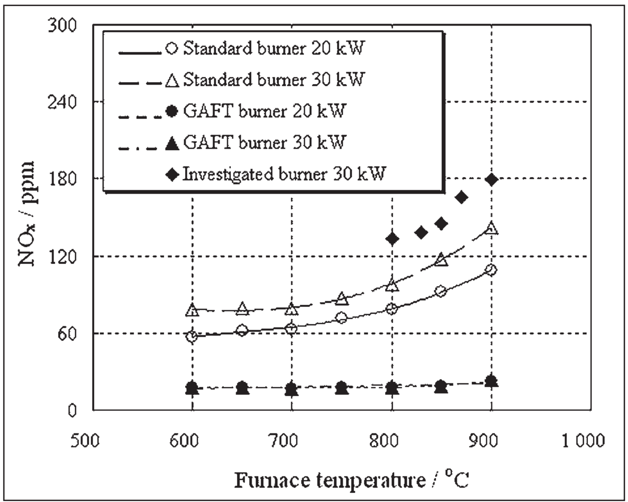

Figure 1 Effects of the furnace temperature on NO_x emission from the U radiant tube for *l* = 1,1

The temperature of flue gases that entered the device to be mixed with cold air amounted to 780 – 870 °C, depending on the furnace zone and temperature as well as on the radiant tube. These values also considerably deviate from the current standards. Results of the flue gas composition and temperature measurements in near-burner mixing devices are presented in Table 1.

Table 1 **Chemical composition and temperature of flue gases leaving the radiant tubes**

Parameter	Measurement point labels				
	R35	R29	R25	R17	R7
CO_2 / %	3,5	6,7	4,2	3,4	4,1
O_2 / %	14,6	8,9	13,2	14,5	12,9
CO / ppm	100	190	430	0	22700
SO_2 / ppm	0	0	0	0	70
NO_x / ppm	109	89	77	0	9
$T_{(housing)}$ / °C	74	119	117	112	87
$T_{(flue\ gases)}$ / °C	370	496	460	382	361

Daily temperature changes in the zones and natural gas consumption for a typical furnace operation during 24 hours are presented in Figure 2. The technological process was run during two diurnal shifts while at night, between 22 : 30 and 5 : 30, the furnace operated in the idle mode with reduced temperature and natural gas consumption below 40 m_n^3/h for each zone.

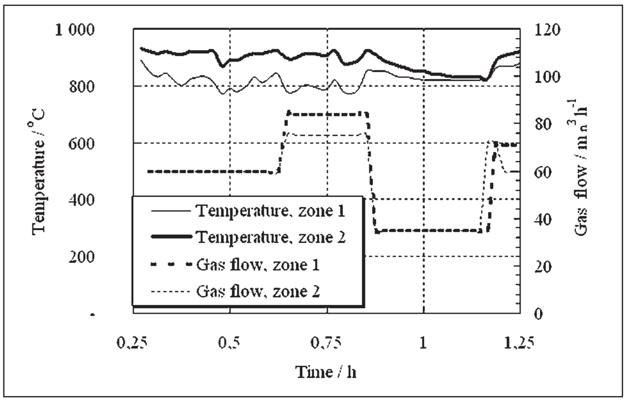

Figure 2 Temperature and natural gas consumption changes in the rollway-continuous furnace during the technological process

For a typical technological process, the energy balance was determined by means of a general equation (1) to identify potentials for the system thermal efficiency enhancement [4,5]:

$$\mathring{I}_g+\mathring{I}_a+\mathring{I}_{w1}+\mathring{I}_{ch1}=\mathring{I}_{w2}+\mathring{I}_s+\mathring{I}_{zg}+\mathring{I}_{ch2}+\mathring{Q}_{ot}, \quad (1)$$

where: $\mathring{I}_g$ - natural gas enthalpy flux, W; $\mathring{I}_a$ - preheated combustion air stream enthalpy flux, W; $\mathring{I}_{w1}$ - charge enthalpy flux at the furnace inlet, W; $\mathring{I}_{w2}$ - charge enthalpy flux at the furnace outlet, W; $\mathring{I}_{ch}$ - cooling media stream enthalpy, W; $\mathring{I}_s$ - flue gas stream enthalpy, W; $\mathring{I}_{zg}$ - scale stream enthalpy, W; $\mathring{Q}_{ot}$ - energy loss to the surroundings, W.

For the feed stream enthalpy calculations by means of the general equation, enthalpy of devaluation (D_w, J/kg) and enthalpy of the phase transition related to structure change (Δi_p, J/kg) were considered according to equations (2) and (3) [5]:

$$\mathring{I}_{w1} = \mathring{m}_{w1}\left[c_{pw}(T_{w1} - T_{ot}) + D_w\right], \quad (2)$$

$$\mathring{I}_{w2} = \mathring{m}_{w2}\left[c_{pw}(T_{w2} - T_{ot}) + \Delta i_p + D_w\right], \quad (3)$$

where: c_{pw} - mean specific thermal capacity, J/(kgK); T_{w1} - feed temperature at the furnace chamber inlet, K; T_{w2} - feed temperature at the furnace chamber outlet, K. In the general equations (2) and (3), mass flow rates at the furnace inlet ($\mathring{m}_{w1}$) and outlet ($\mathring{m}_{w2}$) may be unequal due to the scale formation potential. Regarding the investigated technology, it was assumed (due to application of the protective atmosphere in the furnace – negligible degradation of the feed upper layer) that $\mathring{m}_{w1}$ = $\mathring{m}_{w2}$. The mean furnace performance amounts to 2,0 – 2,2 Mg/h of the preheated feed material for two-shift furnace operation. The individual heat consumption for a daily cycle is 2,67 MJ/kg to 2,95 MJ/kg of the feed. Considering only two-shift production, the individual heat consumption is slightly lower: 2,39 MJ/kg to 2,65 MJ/kg of the feed. The individual heat consumption depends on the type and design of the furnace as well as on the feed material type and the kind of furnace operating. Literature data show that for e.g. pusher furnaces, the individual heat consumption is 1,47 MJ/kg to 1,84 MJ/kg while for actual systems, values of even > 3 MJ/kg were reported.

During assessment of the system operation, thermal visualisation of selected representative furnace shell sections was applied. The results were used for determination of heat loss to the surroundings through the furnace shell via convection and radiation. In Figures 3 and 4, selected temperature distributions are presented. They were applied for the furnace energy balance analysis.

The energy balance for the investigated furnace is shown in Figure 5 as the Sankey diagram.

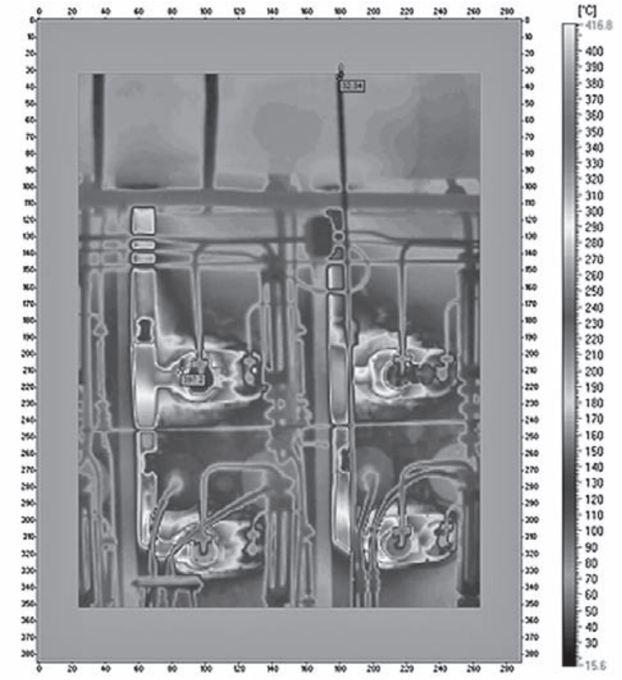

Figure 3 Temperature distribution of the no. 1 rollway-continuous furnace shell in a tube drawing mill during the technological process – right side

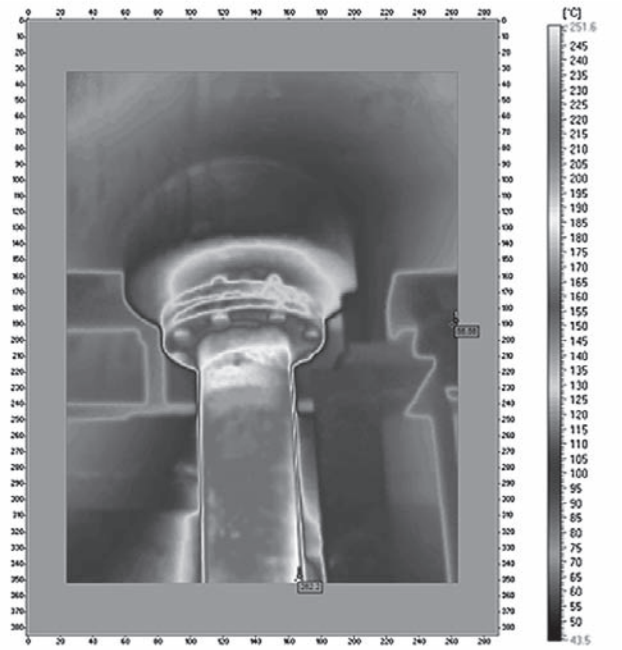

Figure 4 Temperature distribution on the burner flue gas collector surface – left side

MODERNISATION PROPOSALS

Based on the current experience, modernisation of the system with the use of modern burners, placed in radiant tubes, was suggested. The priorities of the proposed changes are: reduction in natural gas consumption and decrease in harmful agent levels in flue gases. Recommended GAFT burners [2,3], intended for radiant tubes, feature a far more effective design of internal recuperators. This results in lower temperature of flue gases that leave the radiant tube and, hence, a higher

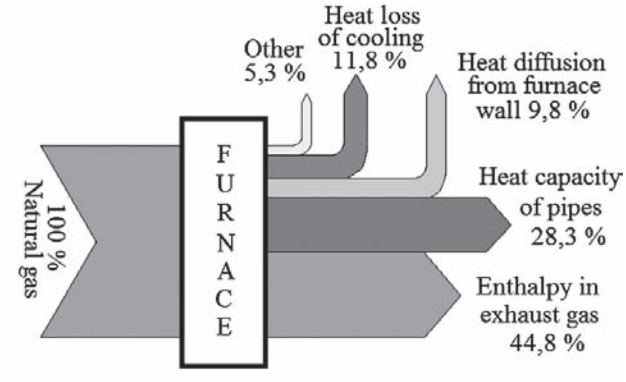

Figure 5 Sankey diagram for the rollway-continuous furnace energy balance

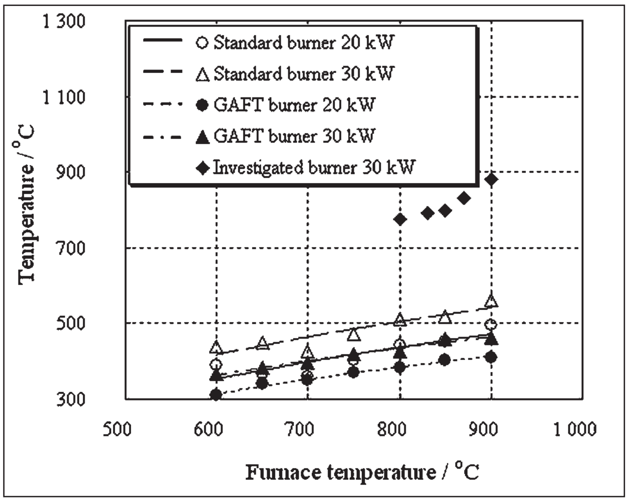

Figure 6 Flue gas temperatures at the U radiant tube outlet for l = 1,1 [1]

level of the preheated combustion air stream enthalpy [6]. As a consequence, gas fuel consumption is reduced.

In Figure 6, compared temperatures of flue gases that leave the radiant tube for currently used burners, standard burners and GAFT burners are presented [1].

SUMMARY

The measurements and data analysis of GAFT burner application show that the temperature of flue gases that leave the radiant tubes can be reduced from 780 – 870 °C to 450 – 470 °C, depending on their location in the furnace. These changes will result in 20 – 25 % gas fuel consumption reduction compared with the initial values. Reduced amounts of combusted fuel generate less flue gases that feature lower temperature, which will lead to significant reduction in electricity required for the flue gas suction ventilator operation. Moreover, due to their unique design, the proposed new burners ensure far lower CO and NO_x levels in flue gases compared with standard burners. For the GAFT 30 kW burner within 800 – 900 °C, the values are as follows: CO approx. 20 ppm, NO_x approx. 18 – 24 ppm [1], while for the so far used burners, the CO (3 % O_2) level in flue gases amounted to even 1 000 ppm. Application of new solutions will result in enhanced furnace thermal capacity (from 28,3 % to 39 %) and markedly reduced annual emissions of harmful agents, including carbon dioxide, to the atmosphere.

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Note: The person responsible for the translation of the paper into the English language is Marzena Małgorzata Ochman, Certified Translator, Katowice, Poland