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OPTIMIZATION OF TIMELY REPLACEMENT OF SECTIONAL FURNACE REFRACTORY LINING

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The goal of the study is to establish the influence of temporal wearing of refractory lining on energy losses of the furnaces by conducting heat through the furnaces walls. Object of the study were sectional furnaces, type SELAS, situated in the seam tubes production line in Željezara Sisak, Croatia. In order to reduce production costs, it was attempted to define the timely replacement of refractory lining by the criteria of comparing the costs resulted by heat loss through the furnace lining with the costs of refractory lining replacement. Data for the calculation of heat losses was obtained by use of the infrared camera.

Key words: *sectional furnace, heat loss, heat conduction, thermo camera*

Optimizacija vremena zamjene vatrostalne obloge na segmentnim pećima. Rad je izrađen s ciljem da se utvrdi utjecaj vremenskog trošenja vatrostalne obloge na energetske gubitke provođenjem topline kroz ziđe peći. Kao objekt istraživanja odabrane su segmentne peći tipa SELAS, koje se nalaze u valjaonici šavnih cijevi Željezare Sisak. U cilju smanjenja proizvodnih troškova pokušala se odrediti pravovremena zamjena vatrostalne obloge pojedinog segmenta prema kriteriju usporedbe povećanih proizvodnih troškova, nastalih povećanjem energetskih gubitaka provođenjem topline kroz ziđe peći, s troškovima zamjene vatrostalne obloge. Za proračun gubitaka topline koristili su se podaci dobiveni snimanjem infracrvenom kamerom.

Ključne riječi: *segmentna peć, gubitak topline, provođenje topline, termokamera*

INTRODUCTION

The production of metal and metal products requires great quantities of energy. On the other hand, the products requested by the market must be of the highest quality and affordable price. These requests could only be obtained by rationalization of work mode, use of manpower, machinery, materials and energy sources.

The aim of this research was to obtain the fuel savings by rationalization of the energy consumption through the improvement of economic production parameters of the sectional furnaces of SELAS type situated in the seam tubes production line in Željezara Sisak. Because of the age of these furnaces and obsolete technology of heating, the great thermal losses occur. The greatest losses occur with high temperature waste gases, which exit the furnace directly through the flue on section ceiling. Also, significant thermal losses occur by radiation through the openings for heated tube transport.

In this paper, the influence of temporal wearing of refractory lining, in terms of loss of refractory and insulation features, on the increase of energy losses by heat conduction through the furnace's walls was researched. By comparing the costs resulting from the heat loss through the furnace lining with the costs of refractory lining replacement the timely replacement of refractory was attempted to define.

For accurate calculation of thermal losses through the natural heat convection and radiation from the furnace shell to surrounding atmosphere, it was necessary to determine the temperature distribution on section outer surface as accurately as possible. For that reason, the furnace sections were photographed with the thermo camera and thermal images were processed by LIPS software. The results were incorporated in the thermal loss calculations.

DESCRIPTION AND CHARACTERISTICS OF SECTIONAL FURNACES

Sectional furnaces are through-type heating furnaces. They consist of small refractory-lined heating chambers i.e. sections, with water-cooled individually driven small-

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diameter rollers for transport of charge in the form of the continuous seam tube. The object of the study was a sectional furnace type SELAS built in 1963 as a part of the production unit of seam tubes in Željezara Sisak, Croatia, which is used for normalizing of the seam tubes after welding and heating before diameter reduction.

Overall length of the furnaces, including interspaces, is 90.28 m. The furnaces consist of 36 sections positioned in one line and divided into two groups by interspaces. The first group of 25 sections divided into 7 thermal zones is normalizing furnace. The second group makes a stretch-reducing furnace, which consists of 11 sections divided into 3 zones. General information about the individually zones are given in Table 1.

Table 1. **Natural gas and air consumption per zones of the sectional furnaces**
Tablica 1. **Potrošnja prirodnog plina i zraka po zonama segmentne peći**

Zone	1.	2.	3.	4.	5.
Sections number	4	4	4	4	3
Max. natural gas consumption [m^3/h]	283	283	283	283	212
Max. air consumption [m^3/h]	2832	2832	2832	2832	2120
Zone	6.	7.	8.	9.	10.
Sections number	3	3	4	4	3
Max. natural gas consumption [m^3/h]	212	212	254	254	184
Max. air consumption [m^3/h]	2120	2120	2540	2540	1840

Each section of the SELAS furnace is equipped by circumferentially positioned burners as well as the openings for tube transport and visual control of the section interior, an opening for discharge of scaling loss and channel for venting of waste gases (Figure 1.). The furnace is fired by natural gas that burns in non-preheated air.

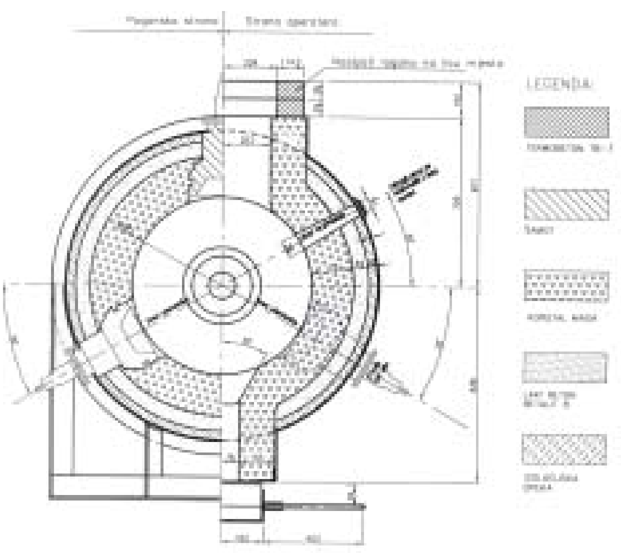

Figure 1. **Cross-section of sectional furnace**
Slika 1. **Poprečni presjek segmentne peći**

A refractory material used for inside layer in the sections is a KONSTAL 39 ramming mixture of Zagorka Silex type. The middle layer is thermo concrete BETALIT 8. The thermo concrete TB-7 is used for covering of the section sides. Outer layer is made of OL-18 chamotte isolation bricks. Characteristics of refractory used are given in Table 2. [1].

Table 2. **Properties of refractory materials**
Tablica 2. **Osobine korištenog vatrostalnog materijala**

Material	Refractoriness SK	Utilization temperature [°C]	Thermal conduct. [W/mK] on [°C]			
			600	800	1000	1200
OL - 08	-	850	0.24	0.26	-	-
Betalit 8	9/10	1100	0.58	0.706	-	-
Konstal 39	39	1600	0.96	1.06	1.15	1.25
TB - 7	28	1600	0.60	0.62	0.63	-

MEASURING EQUIPMENT AND DATA PROCESSING

To determine the condition of furnace lining, the portable thermal imager LAND Cyclops TI35+ was used. It provides high-resolution thermal images and an object temperature measuring in real time and temperature interval -20 °C to 1500 °C.

Portable camera Cyclops TI35+ has enough memory for storing up to 27 thermal images and ability for their transfer to VCR, color printer or computer with LIPS (LAND Image Processing System) [2] software for processing and analysis.

For analysis of results it is necessary to know the temperature distribution through furnace lining so it can be ascertained whether the real temperature exceeds allowed temperature for the material of each lining layer. The temperature distribution curve is defined on the basis of measured temperature of the section outer surface and the manufacturer information about thermal conductivity of each refractory material. Calculated temperature of inside surface lining was compared with values measured with thermo camera through the transport opening of the section.

MEASURING RESULTS

In order to establish the influence of refractory lining condition on energy losses, thermal images of two sections in 8^{th} zone were made:

a) with worn-out refractory lining (Figure 2.);

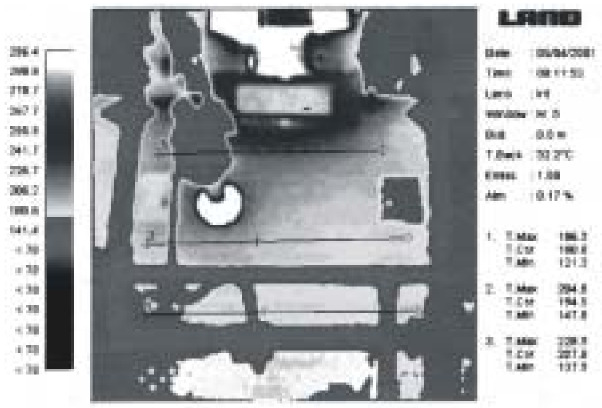

Figure 2. **Thermal image of the 8th zone section with worn-out refractory lining**
Slika 2. **Termička slika segmenta 8. zone sa istrošenom vatrostalnom oblogom**

b) with renewed refractory lining (Figure 3.).

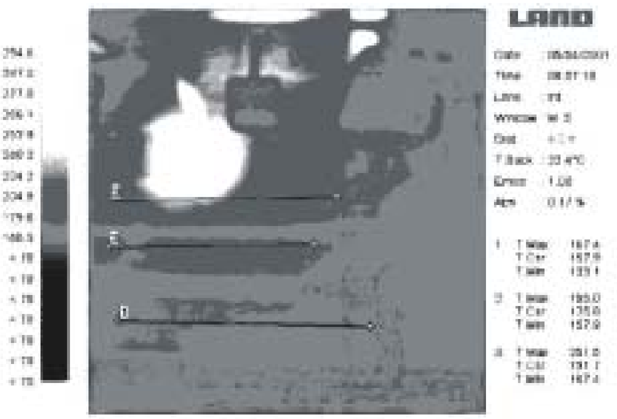

Figure 3. **Thermal image of the 8th zone section with renewed refractory lining**
Slika 3. **Termička slika segmenta 8. zone s novom vatrostalnom oblogom**

The results show more uniform temperature distribution of temperatures over the outer surface of the section with newly installed refractory lining (130 - 210 °C). Temperatures were approximately 30 °C higher on furnace section with partially wear-out refractory lining but considerably higher temperatures were observed around flue opening (to 280 °C). Temperature of the inside surface of lining, which was calculated earlier on the basis of measured temperatures of the section outer surface was also controlled (Figure 4.). Measured temperature (around 1200 °C) shows very good agreement with the values obtained by calculation.

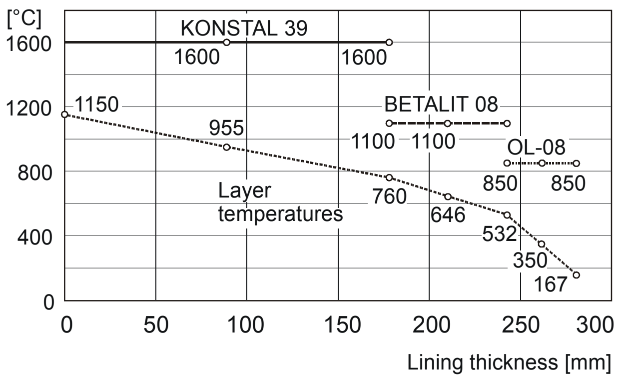

Figure 4. **Diagram of temperature distribution in furnace lining**
Slika 4. **Dijagram temperaturnog rasporeda u ziđu peći**

HEAT LOSS CALCULATIONS

Heat transfer from the section surface to the to surrounding air was calculated by the expression:

$$Q = \alpha\left(T_s - T_0\right)\cdot A \;\; [\mathrm{W}] \tag{1}$$

where

α = overall heat transfer coefficient ($\alpha = \alpha_c + \alpha_r$), [W/m²K];
α_c = convection heat transfer coefficient, [W/m²K];
α_r = radiation heat transfer coefficient, [W/m²K].

Convection heat transfer coefficient was calculated by *Nusselt number (Nu)*:

$$Nu_m = \frac{\alpha_c D}{\lambda} \tag{2}$$

where

D = section outer diameter, [m];
λ = thermal conductivity of air, [W/mK].

Nusselt number was calculated according to the empiric formula for a case of a free convection on horizontal cylinder [3]:

$$Nu_m^{1/2} = 0.60 + \frac{0.387 Ra_D^{1/6}}{\left[1+\left(0.559/Pr\right)^{9/16}\right]^{8/27}}$$

$$\text{for } 10^{-4} < Ra_D < 10^{12} \tag{3}$$

where

Pr = *Prandtl number* for air,
Ra_D = *Rayleigh number* (*Ra*) defined as product of *Grashof* (*Gr*) and *Prandtl* (*Pr*) *number*.

G*rashof number* (*Gr*) was determined by the equation (4):

$$Gr = \frac{g\beta L^3\left(T_s - T_0\right)}{\nu} \tag{4}$$

where

L = the characteristic dimension, in this case section outer diameter, [m];
β = volume coefficient of thermal expansion, [K^{-1}];
ν = kinematics viscosity, [m^2/s];
g = gravitational constant, [m/s^2].

β is defined as

$$\beta = \frac{1}{T_0} + 0.25(T_s - T_0) \quad [K^{-1}] \tag{5}$$

where the T_0 is temperature of the surrounding air and T_s is temperature of sections outer surface.

For calculation of the radiation heat transfer coefficient α_r the following equation was used:

$$\alpha_r = \sigma_c \cdot \varepsilon_s \cdot \left(T_s^2 - T_0^2\right)\left(T_s - T_0\right) \ [W/m^2K] \tag{6}$$

where

σ_c = Stefan-Boltzmann constant [$\sigma_c = 5.669 \times 10^{-8}$ W/m^2K^4];
ε_s = emissive coefficient of furnace shell.

Input data for the heat losses calculation:

- gas consumption in the 8th zone at max. production is 254 m^3/h;
- gas consumption per section of the 8th zone is 63.5 m^3/h;
- lower heating value of natural gas is 36 MJ/m^3;
- mean temperature value of outer surface of the section with worn-out lining is 424.25 K;
- mean temperature value of outer surface of the section with renewed lining is 409.75 K;
- estimated mean temperature value of outer surface of the section with worn-out lining is 466.25 K.

The calculated share of the heat losses by heat conduction through the furnace's lining in the total energy balance sheet of the section is:

- in the case of renewed section lining 3.13 %;
- in the case of the estimated mean temperature of worn-out section lining 3.80 %.

Considering the price of a natural gas of 0.11 EUR/m^3, the annual expenses induced by increased consumption of natural gas total 385 EUR/year. The total costs of section replacement with renewed refractory lining are 3967 EUR.

CONCLUSIONS

The aim of this study was to establish the influence of refractory lining condition on heat losses through the furnace's walls i.e. on fuel consumption and economic validation of timely section replacement in regard to energy losses.

It is important to mention that the furnace was not working constantly lately, so it wasn't possible to compare the condition of a really worn-out section lining with the new one. For that reason, the average temperature difference between the sections was assumed as 70 °C. In that case, the increase in costs due to the heat conduction losses per section was 385 EUR/year. On the other hand, the costs of section replacement are 3967 EUR.

It can be concluded that the importance of the section replacement does not lie as much in cutting the heat losses as in the safety reasons. The greatest thermal load on refractory lining is at the waste gas exiting area i.e. on transition between the cylindrical part of the section and vertical flue where faster decrease of lining thickness occur as well as loss of its refractory and isolation properties, which is manifested in significant increase of section shell temperature. Thermo camera proved to be an excellent measuring device for detecting of furnace condition and the indicator of timely section replacement.

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