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# USAGE MODEL OF ELECTRICAL FURNACE GASES FOR HEATING IN ROTATION FURNACE

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## ABSTRACT

*During the obtained process of Ferronickel the contained gases in outlet of electrical furnace may use different heating and preheating within the complex of “Ferronickel”. The study of such possibility supported in a science methodology presents the main object of this work. In order to achieve this objective, in this work is developed a model for usage of energy contained in the gases in outlet of electrical furnace for the purpose of heating the rotation furnace.*

*The reached results during these calculations are real quantities and great interest for technological process of obtained nickel and it’s economizing.*

**Keywords:** *electrical furnace, gases, heating*

## 1. INTRODUCTION

Electric furnace gases (EF) within the complex of "Ferronickel" actually thrown through the respective chimney, directly into the atmosphere, without any prior treatment. In this way, their thermal energy remains untapped. In order to model of use of these gases for different thermal purposes within the complex of "Ferronickel" to be more precise, it is necessary to recognize the characteristics and different thermal parameters of these gases. For this reason were used measurements of parameters of gases in the chimney.

## 2. MEASUREMENTS OF THE PARAMETERS OF GASES IN CHIMNEY OVER EF

In chimney over electric furnace "Ferronickel" are made measurements of the concentration of components CO, $CO_2$, $O_2$, $SO_2$, NO and $NO_2$ as well the flow of gases, for electric furnaces regime 24 MW and 33 MW (table 1 and 2). Gas concentration measurements are made with the instrument "Maihack" with the detector with infrared ray and with instrument IMR. Gases flow measurements are made in the chimney at the level 16 m with the Pitott-Prandel tube, in the place of measuring with diameter 0.735 m.

*Table 1. Mean values of temperature, density, speed and flow of gases in the chimney of EF*

| Regime | Temperature *K* | Density $kg/m^3$ | Speed *m/s* | Mass flow *kg/s* | Mass flow *kg/h* |
|---|---|---|---|---|---|
| 24 *MW* | 1149,15 | 0,365 | 11,67 | 1,81 | 6516 |
| 33 *MW* | 1114,15 | 0,354 | 17,92 | 2,69 | 9684 |

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Table 2. *Participation by volume of gas ingredients of EF*, $r_i$

| Gas components | Regime samples 24 *MW* [%] | | | | Regime samples 33 *MW* [%] | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | | 1 | 2 | | 1 | 2 |
| CO, *%* | 60,66 | 62,82 | 63,19 | 62,19 | 71,60 | 70,23 | 72,96 | 71,60 |
| $CO_2$, % | 34,10 | 28,40 | 32,30 | 31,50 | 21,10 | 29,70 | 23,70 | 24,80 |
| $SO_2$, *ppm* | 264 | 220 | 1095 | 526 | 168 | 637 | 578 | 461,00 |
| $O_2$, *%* | - | - | 1,65 | 1,65 | 0,80 | - | - | 0,80 |
| NO, *ppm* | - | - | - | - | 28 | - | - | 28 |
| $NO_2$, *ppm* | - | - | 14 | 14 | 17 | - | - | 17 |
| Total, *%* | | | | 95,394 | | | | 97,250 |

## 3. CALCULATION OF MOLAR MASS, SPECIFIC HEAT AND DYNAMIC VISCOSITY COEFFICIENT FOR GASES OF EF

Molar mass of gases of *EF*, $M_{g.EF}$, $M_{g.EF}$ (for composition 100*%*), determined by relations:

$$M_{gFe} = \sum_i r_i M = r_{CO} M_{CO} + r_{Co_2} M_{Co_2} + r_{O_2} M_{O_2} + r_{SO_2} M_{SO_2} + r_{NO} M_{NO} + r_{NO_2} M_{NO_2} \, . \qquad \ldots (1)$$

$$M_{gFE} = M_{gFe} / \sum_i r_i \, . \qquad (2)$$

The values of the mass participation of ingredients of gases in electric furnace $g_i$ determined by volume participation of the components of gases $r_i$ (table 2) according to equation (3) in table 3.

$$g_i = r_i \left( M_i / M_{gFE} \right). \qquad (3)$$

*Table 3. The participation in the mass of the components of EF* gases, $g_i$

| | Regime 24 *MW* | Regime 33 *MW* |
|---|---|---|
| CO, % | 52.18 | 62.39 |
| $CO_2$, % | 41.53 | 33.96 |
| $SO_2$, % | 0.1008 | 0.0918 |
| $O_2$, % | 1.58 | 0.79 |
| NO, % | / | 0.0027 |
| $NO_2$, % | 0.0019 | 0.0024 |
| Total, % | 95.394 | 97.25 |

Specific heat for electric furnace gases $Cp_{g.EF}$, $Cp_{g.EF}$ (for composition 100%) for temperature 850$^0$C as well for the regime 24 MW and 33 MW determined according to the following equations 2:

$$Cp_{gFe} = \sum_i g_i \, Cp_i = g_{CO} Cp_{CO} + g_{CO_2} Cp_{CO_2} + g_{O_2} Cp_{O_2} + g_{SO_2} Cp_{SO_2} \qquad (4)$$

$$Cp_{gFE} = Cp_{gFe} / \sum_i r_i \, . \qquad (5)$$

Coefficient of dynamic viscosity for electric furnace gases at temperature *850*$^o$C *for regime 24* MW and *33* MW *is:*

$$\mu_{gFE} = M_{gFE} / \left( \frac{r_{CO}}{\mu_{CO}} M_{CO} + \frac{r_{CO_2}}{\mu_{CO_2}} M_{CO_2} + \frac{r_{O_2}}{\mu_{O_2}} M_{O_2} + \frac{r_{SO_2}}{\mu_{SO_2}} M_{SO_2} \right). \qquad (6)$$

## 4. HEAT LOSSES OF GASES IN ENVIRONMENT

Carrier pipe diameters of gases from electric furnace to rotation furnace with insulator and wrapping are $d_1$, $d_2$, $d_3$ *and* $d_4$. Conductivity coefficient of steel pipe is λst. Insulator has a coefficient of conductivity $\lambda_{ins.}$ and thickness $\delta_{ins.}$. Mantle of pipe is from aluminum with the coefficient of conductivity $\lambda_{ma}$ and thickness $\delta_{ma}$. Also, for both regimes the average temperature of the environment is acquired to be $T_{envir.}$, while for that outer portion of mantle pipe is $T_{ma}$. According to Table 1 the flow speed of gases in chimney with diameter $d_{chimney}$=0,735*m* is $w_1$=11,67*m/s*, while density $\rho_1$=0,365 $kg/m^3$. In support of the continuity equation found the following mass flux of gases through the carrier tube:

$$w_2\rho_2 = \left(d_{tymtar} / d_{g.t.}\right)^2 w_1 \, A_{g.t.} \, \rho_1 \, . \tag{7}$$

Gases flow regime, is determined according to the criterion of Reynolds:

$$R_e = d_{g.t.} \, w_2 \, \rho_2 / \mu_{g.FE} \, . \tag{8}$$

Meanwhile the value of Prandtl's number determined by the following equation[3]:

$$P_r = \mu_{g.FE} \, C_{p_{g.FE}} / \lambda_{gFE} \; . \tag{9}$$

where $\lambda_{gEF}$ is coefficient of heat transfer of gases with conduction, at temperature 850$^0C$ and pressure $p_g$=101325*Pa*.

During the transportation of gases through the carrier tube, the heat transferred from gases toward the wall of the tube with required convection. Gases flow regime is turbulent. For that coefficient of heat transfer for gases can be determined with the simplified equation of Dittus-Boetlern [2]:

$$N_u = 0{,}023 R_e^{\;0.8} P_r^{0.4} \; . \tag{10}$$

Coefficient of the heat transfer from electric furnace gases towards the wall of the pipe carriers is [3]:

$$h_{g.FE} = \lambda_{g.FE} \, N_u / d_1 \, . \tag{11}$$

The average temperature near of the outer surface of the pipe is: $T_{mes} = \left(T_{mbj} + T_{ajri}\right)/2$. For air temperature $T_{avg.}$=293,15*K*, from the tabular data find values for the following parameters: $\upsilon_{ajri}$ ; $\lambda_{ajri}$ ; $P_{r_{ajri}}$ ; $\rho_{ajri}$ ; $\beta_{ajri}$ . While the value of Grashof's number is [1]:

$$G_r = d_{mb}^3 \, g \, \beta \, \Delta T / \upsilon_{ajri}^2 \, . \tag{12}$$

Since the heat from wall of the pipe towards environmental air is transported with natural convection, heat transfer coefficient determined by the relation of the Mc Adams [1], for horizontal pipes:

$$N_u = c\left(G_r \, P_r\right)^n = h_{ajri} \, d_{mb} / \lambda_{ajri} \, . \tag{13}$$

Since in the equation (13) the product $G_r \cdot P_r$ has value in the limit $2\cdot10^7 – 1\cdot10^{13}$, then the flow regime of air is turbulent ($c$ = 0,135 and $n$ = 1/3), while $h_{air}$ is the heat transfer coefficient for air.

Coefficient of the heat transfer from inside the pipe on the environment is [3]:

$$k = \pi / \left( \frac{1}{h_{g.FE} d_1} + \frac{1}{2\lambda_c} \ln\frac{d_2}{d_1} + \frac{1}{2\lambda_{cz}} \ln\frac{d_3}{d_2} + \frac{1}{2\lambda_c} \ln\frac{d_{mb}}{d_3} + \frac{1}{h_{ajri} d_{mb}} \right) . \tag{14}$$

During the transfer of thermal energy of the gases from electric furnace to rotary furnace, the flow of heat loss (per unit of the length) with conduction and convection on the environment will be [3]:

$$q_{L,k+k} = k\left(T_1 - T_{air}\right). \tag{15}$$

Losses of heat flow with radiation are [2]:

$$q_{rr} = A_1 C_{1/2}\left[\left(\frac{T_{mb}}{100}\right)^4 - \left(\frac{T_{ajri}}{100}\right)^4\right] = \pi d_{mb} L \varepsilon_1 C\left[\left(\frac{T_{mb}}{100}\right)^4 - \left(\frac{T_{ajri}}{100}\right)^4\right]. \tag{16}$$

where in the above equation $C$ is constants of the radiation for absolutely black body (5,67 $W/m^2K$), While $\varepsilon_1$ is the emission coefficient for aluminum (0,055).
Total losses of heat flow, in units of the length, in the environment are:

$$q_{L,k+k+rr} = q_{L,k+k} + q_{L,rr}. \tag{17}$$

## 5. RESULTS CALCULATIONS BY MODEL

Input values in the model are: $\lambda_{st}$=59.313 W/mK. $\lambda_{ins.}$=0.037 W/mK $\delta_{ins.}$=0.05 m; $\lambda_{mb}$ =229.111 W/mK; $\delta_{ma}$=0.0008 m; $d_1$=0.16 m; $d_2$=0.17 m; $d_3$=0.270 m; $d_4$=0.2716 m; $T_{envr.}$ =283.15 K; $T_{mb}$ = 303.15 K; $d_{chimney}$ =0.735 m; $w_1$ =11.67 m/s; $\rho_1$ =0.365 kg/m$^3$; $\lambda_{gEF}$=0.09575 W/mK; $p_g$=101325 Pa; $T_{ma}$=283.15 K; $T_g$=850°C; $T_1$=1149.15 °C; $\Delta T$=20°C; $\beta$=0.00341; $\varepsilon_1$=0.055; $C$=0.135; $n$=0.3333; $M_{CO}$=28; $M_{CO2}$=44; $M_{SO2}$=64; $M_{O2}$=32; $M_{NO}$=30; $M_{NO2}$=46; $\upsilon_{air}$=15.06 $10^{-6}$ m$^2$/s; $\lambda_{air}$=0.025 W/mK; $Pr_{air}$=0.703; $\rho_{air}$=1.205 kg/m$^3$; $Cp_{CO}$=1114.425 J/kgK; $Cp_{CO2}$=1094.85 J/kgK; $Cp_{O2}$=1020.75 J/kgK; $Cp_{SO2}$=767.25 J/kgK; $\mu_{CO}$=$4.5 \cdot 10^{-5}$Pa; $\mu_{CO2}$=$4.6 \cdot 10^{-5}$Pa; $\mu_{O2}$=$5.1 \cdot 10^{-5}$P; $\mu_{SO2}$=$3.8 \cdot 10^{-5}$Pa. While the results calculated by the model are given in Table 4.

*Table 4. Model results*

| Output parameters | 24*MW* | 33*MW* | Units |
|---|---|---|---|
| Re | 317505 | 473002 | |
| Pr | 0.522255 | 0.523264 | |
| Nu | 446.973 | 615.327 | |
| hgFE | 267.485 | 368.235 | W/(m2K) |
| Gr | 59100715 | 59100715 | |
| Nu | 46.757 | 46.757 | |
| hair | 4.464 | 4.464 | W/(m2K) |
| k | 0.44246 | 0.44285 | W/(mK) |
| qL,k+k | 383.167 | 368.012 | W/m |
| qL,yy | 5.369 | 5.369 | W/m |
| qL,k+k+yy | 388.535 | 373.381 | W/m |

## 6. CONCLUSIONS

Overall losses within the transmission pipe of the gases energy flow in the case of the work regime 33 *MW* are less than for the work regime 24 *MW*;
Losses of heat flow with radiation in the environment for 33 *MW* regime are the same as the for 24 *MW* regime, so $q_{L,r}$=5.366 *W/m*.
The flow of gases energy of electrical furnace decreased, depending on the length of the pipe.
Temperature drop for the work regime 24 *MW* is higher than for the work regime 33 *MW*
Thermal energy flow given during the work regime 33 *MW* is higher than the work regime 24 *MW*;

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