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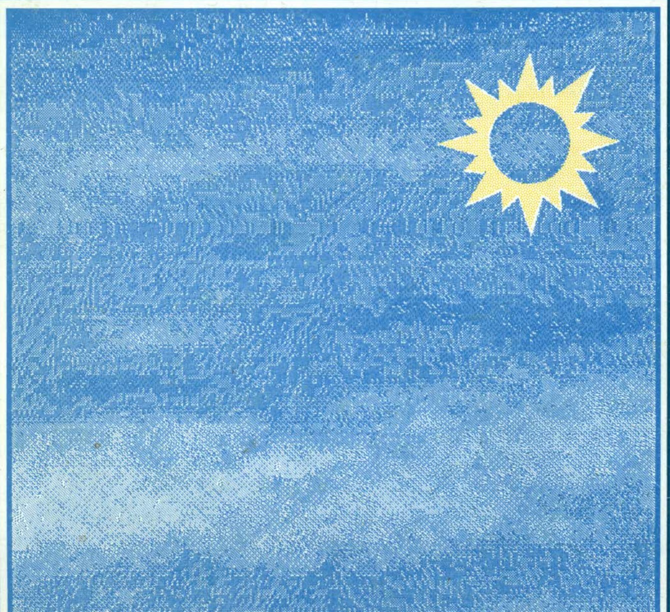

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DECREASED NATURAL GAS CONSUMPTION IN PUSHER FURNACE PRODUCES ADDITIONAL CO_2 EMISSION

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1. LIST OF SYMBOLS

a	oxygen percentage in air, %
B	mass-flow rate of fuel, Nm^3/s
c	specific heat capacity, J/kg-K
F	surface, m2
H_d	lower fuel-heat value, J/kmol
h	ratio of mass flows of high furnace to mixed gasses
M	relative molecular mass, kg/kmol
m	mass flow rate, kg/s
N	number of slabs in furnace
O_{2min}	air minimum, Nm3/Nm3 of b
p	furnace over pressure, Pa
Q	heat, W
r	Volumetric composition
s	envelope-layer width, m
T	weight of slab, kg
t	temperature, ^0C
V	gas flow rate Nm3/ Nm3 of b
W	moisture content, g/Nm3
Z	heat transmitance coefficient, W/K
•	heat transfer coefficient, W/m^2-K
f	furnace openings porosity.
l	coefficient of excess air
l	thermal conductivity, W/m-K
m	flow coefficient
r	density, kg/m^3
t	time, s
y	ratio of times of opened door to furnace operation.

indices

a	average
b	fuel
c	combustion air, cold
d	dry
e	environment
f	combustion products
g	gas
h	high furnace gas, hot
i	exit
m	mixed gasses
·	oxygen
·	normal conditions
·	furnace openings
p	natural gas, constant pressure
ph	preheater
pf	floor
j	indices
n	indices
k	correction
r	heat-recovery device
s	slab
sc	ceiling
sg	combustion
u	entrance
v	water
w	air,
z	wall
1	inside
2	outside

j=1-14 1(H_2), 2(CO), 3(CH_4), 4(C_2H_4),5 (C_2H_6)6 (C_3H_6), 7(C_3H_8), 8(C_4H_{10}), 9(CO_2), 10 (N_2), 11 (H_2O), 12(SO_2), 13 (H_2S), 14 (O_2)

2. INTRODUCTION

In metallurgy the industrial pusher furnace is very important object because of its large energy consumption and consequently the pollution influence to environment. Steel-heating process in pusher furnaces depends on different parameters so as kind and shape of material, kind and quality of fuel, percentage of oxygen in combustion air ect. One should take care of the refuse of energy of combustion products. This can be done by use of heat-recovery device (HRD) in which combustion products preheat furnace-combustion air [1].

Here, we try to see the effect of the mixing of natural gas with refuse high furnace gas and the mixing of oxygen with combustion air to natural gas saving and CO_2 emission to environment.

3. MATHEMATICAL MODEL

To represent this furnace (Fig.1) we have used bottom-up analysis as in Ref. 2. We have presented this furnace with the energy object network (Fig.2): modules of heat exchangers, combustion and stream mixing. The applied heat exchangers are purely convective with the constant coefficients of total heat transfer. On the basis of this mathematical model we have developed software POTIS that can be used for the simulation of this furnace operation.

Equations of the combustion module, the mixing module of oxygen and air, and equations for mass flow rates of combustion products, air entering HRD and steel slabs are [3]

$$H_d, O_{2min}, V_f, r_{fj}\ (j=1,2,..,14) = f\ [r_{mj}\ (j=1,2,..,14),\ a_i, W_w, l];\ V_o, V_{wi}, V_{wu}=f(a_u, a_i, O_{2min}, l);$$
$$m_f = V_f\ B\ M_f/22.4;\quad m_w=V_{wi}\ B\ M_{wi}/\ 22.4;\ m_s=T\ N/\tau$$
$$m_{CO2} = M_{CO2}\ V_{CO2}\ B/22.4\ ;\ m_p = M_p\ B\ (1\text{-}h)\ /22.4 \qquad (1)$$

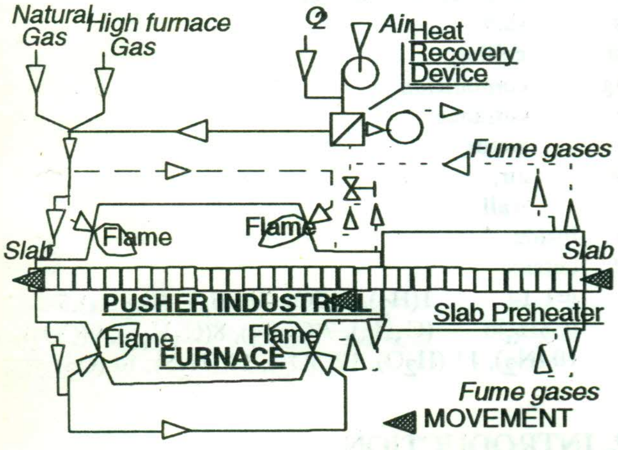

FIG.1 PUSHER INDUSTRIAL FURNACE

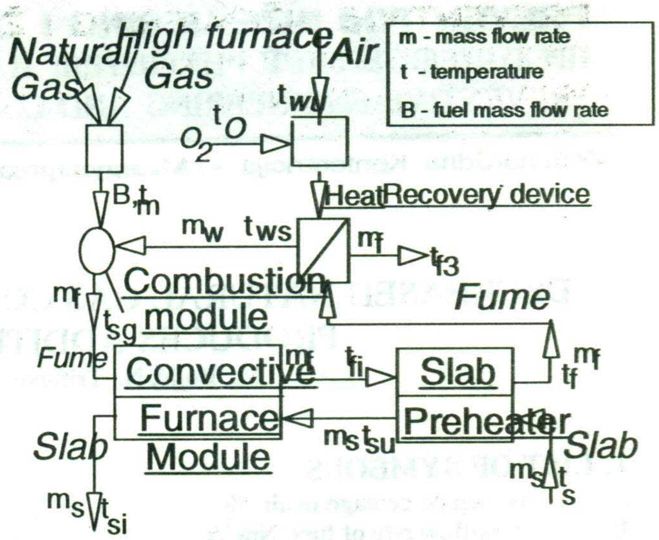

Fig. 2 Schematics of the energy modules network for the pusher furnace

where the volumetric data for wet fuels are: r_{hj}, r_{nj}, r_{Oj}, r_{wj} (j=1,2,...,14).Temperature of air with mass flow rate V_{wi} and a_i percentage of oxygen at the exit of the mixing box (mixing of air and oxygen) and combustion temperature is given as

$$t_{wi}=(V_{wu}c_{pwu}t_{wu}+V_O c_{pO}t_O)/(c_{pwi}V_{wi}),$$
$$t_{sg}=(c_{pm}\ t_m+V_{wi}\ c_{pwi}\ t_{ws}+H_d)/(V_f\ c_{pf}). \qquad (2)$$

Heat consumption by water for the cooling of furnace, heat lost by radiation, by flame through the furnace opening, through the furnace wall, heat obtained by the slab oxidation from exothermic reactions, temperatures out of convective furnace module, and temperature correction for this module are given by [3]

$$Q_v=1.1\ m_v\ c_{pv}\ (t_{vi}\text{-}t_{vu}),\ Q_r=f(t_{fi}, t_{sg}, F_{of,u}, F_{of,i}, f_{iu}, f_{ii}, y_{su}, y_{si});\ Q_{is}=f(t_{sg}, t_{fi}, r_{fj}(j=1,2,..,14), p, m, F_{of,u}, F_{of,i}, t_s, y_{su}, y_{si});\ Q_z= f(_g, t_s, F_z, s_{zj}, l_{zj}, F_{sc}, s_{sc,j}, l_{sc,j}, F_{pf}, s_{pf,j}, l_{pf,j})\ \text{for}\ j=1,..,3.,\ Q_k=f(m_s),$$
$$t_{fik}, t_{si}=f(t_{sg}, t_{su}, m_f, c_{pfa}, m_s, c_{psa}, Z_f);$$
$$t_{fi}=t_{fik}\text{-}(Q_v+Q_r+Q_{is}+Q_{ot}+Q_z\text{-}Qk)/(m_f\ c_{pf}). \qquad (3)$$

General equations governing preheater (counterflow heat exchanger model) and heat recovery device [3] are

$$t_f, t_{su}=f(t_{fi}, t_s, m_f, c_{pfa}, m_s, c_{psa}, Z_{ph}),$$
$$t_{f3}, t_{ws}=f(t_f, t_{wi}, m_f, c_f, m_w, c_w, Z_{r1}, Z_{r2}). \qquad (4)$$

Total general equation for the whole furnace with the preheater is

$$B = f\ [m_f, m_r, h, a_i, T, Z_{r1}, Z_{r2}, r_{dhj}, r_{dpj}, r_{dOj}, r_{dwi}\ (j=1,2,..,14), W_h, W_p, W_O, W_w, a_u, l, t_{wu}, t_O, t_m, t_s, t_{vi}, t_{vu}, N, t, m_v, F_{of,u}, F_{of,i}, F_z, F_{sc}, F_{pf}, f_u, f_i, y_u, y_i,$$

$p, m, s_{zn}, s_{sc,n}, s_{pf,n}, l_{zn}, l_{sc,n}, l_{pf,n}$ (n = 1, .,3),a_1,a_2 Z_f, Z_{ph}], (5)

4. RESULTS AND ANALYSES

The initial values of different parameters of the example-pusher furnace are given in Appendix 1 and simulation results in Figs. 3,4. When the oxygen percentage is enlarged form 21 to 27 % the consumption of the natural gas is around 30% lower so as CO_2 production. For 21% of O_2 in combustion products, high furnace gas percentage (h) increase in mixed gas gives higher natural gas consumption but for 27% of O_2 there is lower natural gas consumption with the increase of h. Generally, the increase of h form 0.2 to 0.5 means in average 75% higher CO_2 production.

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[1] Tomić, M., Bojić,M., "POTIS software for simulation of energy behavior of pusher furnace," Scientific meeting, Institute of Thermal Technology, Technical University of Silesia, Gliwice, Poland, 1994.

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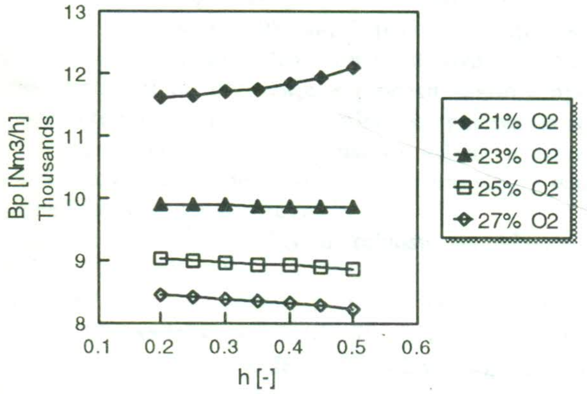

Fig.3 Mass flow rate of natural gas as a function of ratio of high furnace to mixed gas for different oxygen percentage in combustion air.

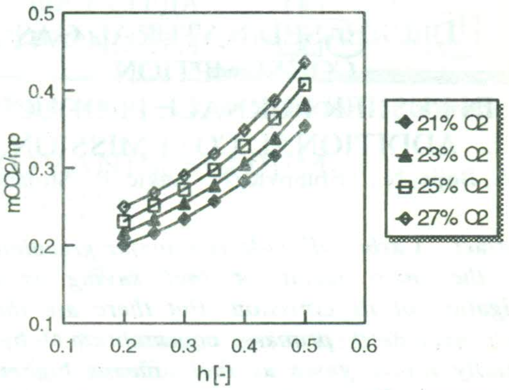

Fig.4 Produced CO_2 per kg of natural gas as a function of ratio of high furnace to mixed gas for different oxygen percentage in combustion air.

APPENDIX 1 - INITIAL DATA OF THE MODEL.

r_{dhi} ($r_{dh,CO}$=28%, $r_{dh,H2}$=2%, $r_{dh,CH4}$=0%, $r_{dh,C2H4}$=0%, $r_{dh,C2H6}$ =0%, $r_{dh,C3H6}$=0%, $r_{dh,C3H8}$=0%, $r_{dh,C4H10}$=0%, $r_{dh,H2S}$=0.5%, $r_{dh,CO2}$ = 10%, $r_{dh,O2}$=0.5%, $r_{dh,N2}$=58.5%, $r_{dh,SO2}$=0%, $r_{dh,H2O}$=0%). r_{dpi} ($r_{dp,CO}$ =0.5%, $r_{dp,H2}$=1.5%, $r_{dp,CH4}$=90.9%, $r_{dp,C2H4}$=06.%, $r_{dp,C2H6}$=2%, $r_{dp,C3H6}$ = 0.6%, $r_{dp,C3H8}$=0.8%, $r_{dp,C4H10}$=0.2%, $r_{dp,H2S}$=0.2%, $r_{dp,CO2}$ =1%, $r_{dp,O2}$=0.2%, $r_{dp,N2}$=1.5%, $r_{dp,SO2}$=0%, $r_{dp,H2O}$=0%). r_{doi} ($r_{do,CO}$ = $r_{do,H2}$ = $r_{do,CH4}$= $r_{do,C2H4}$= $r_{do,C2H6}$= $r_{do,C3H6}$= $r_{do,C3H8}$= $r_{do,C4H10}$ = $r_{do,H2S}$= $r_{do,CO2}$= $r_{do,N2}$= $r_{do,SO2}$= $r_{do,H2O}$=0%, $r_{do,O2}$=100%), r_{dwi} ($r_{dw,CO}$= $r_{dw,H2}$= $r_{dw,CH4}$= $r_{dw,C2H4}$= $r_{dw,C2H6}$= $r_{dw,C3H6}$= $r_{dw,C3H8}$= $r_{dw,C4H10}$= $r_{dw,H2S}$= $r_{dw,CO2}$= $r_{dw,SO2}$= $r_{dw,H2O}$=0%, $r_{dw,O2}$=21%, $r_{dw,N2}$=79%,), W_h = 20 g/Nm^3 of dg, W_{p_3} = 5 g/Nm^3 of dg, W_w = 2 g/Nm^3 of dg, W_o = 0 g/Nm^3 of dg, h = 0.6, a_i =21 %, a_u = 21 %, l = 1, t_{wu} = t_O = t_m = 20^{0}C, t_s = 1250^{0}C, T = 16848 kg, N =36, t = 9648 s, f_u = 0.78, f_i =0.6, y_u =0.1, y_i =0.1, p= 3 Pa, m=0.85, m_v=1000 kg/s, t_{vu}=90^{0}C, t_{vi}=98^{0}C, $F_{of,u}$ = 7.8 m^2, F_{of,i_2}=9.1 m^2, F_z=524 m^2, F_{sc}=526 m^2,F_{pf}=446 m^2,s_{z1}=0.4 m, s_{z2}=0.13 m, s_{z3}=0.12 m, $s_{sc,1}$=0.23 m, $s_{sc,2}$=0.03 m, $s_{sc,3}$=0.06 m, $s_{pf,1}$=0.2 m, $s_{pf,2}$=0.25 m, $s_{pf,3}$=0.20 m, $s_{pf,4}$=0.15 m; a_1=58.14 W/m^2-K, a_2=11.28 W/m^2-K; $_{z1}$=1.459 W/m-K, l_{z2}=0.605 W/m-K, l_{z3}=0.179 W/m-K, $l_{sc,1}$=1.221 W/m-K, lsc,2 = 0.605 W/m-K, $l_{sc,3}$=0.142 W/m-K, $l_{pf,1}$=1.459 W/m-K, $l_{pf,2}$=1.429W/m-K, $l_{pf,3}$=1.395 W/m-K, $l_{pf,4}$=0.142 W/m-K, Z_f=42694 W/K, Z_{ph}=0 W/K, Z_{r1}=4267 W/K, Z_{r2}= 6706 W/K.

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Abstract - Carbon dioxide is a major greenhouse gas and the main result of fuel saving is usually mitigation of its emission. But there are the cases when decreased primary consumption by using partially refuse gases as fuel means higher CO_2 *generation. This is the case with industrial pusher furnace in metallurgy when natural gas is mixed with refuse high furnace gas in order natural gas consumption to be decreased. When the oxygen percentage is enlarged form 21 to 27 % the consumption of the natural gas is around 30% lower so as* CO_2 *production. For 21% of* O_2 *in combustion products, high furnace gas percentage (h) increase in mixed gas gives higher natural gas consumption but for 27% of* O_2 *there is lower natural gas consumption with the increase of h. Generally, the increase of h form 0.2 to 0.5 means in average 75% higher* CO_2 *production.*

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