The Scientific Bulletin of VALAHIA University – MATERIALS and MECHANICS – Nr. 7 (year 10) 2012

MATHEMATICAL MODEL AND COMPUTER PROGRAM FOR SIZING AIR CONVECTION HEATERS USED TO HEAT TREATMENT FURNACES

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ABSTRACT: *This paper presents a mathematical model and computer program for sizing air convection heaters, heat treatment furnaces used to reduce energy consumption of the furnaces used in steel construction materials. Mathematical model for sizing of the convection air heaters for heat treatment furnaces, was transcribed into a Microsoft Excel program. With its recovery to a dimensioned and calculated data were compared with experimental ones, resulting in minimal differences.*

Keywords: *energy consumption, furnace, heat treatment, mathematical model*

1.INTRODUCTION

Metallic materials industry is energy intensive branches, most of which are required in the form of heat. Efficient use of energy in metallurgy is not a simple problem, because high production capacities of industrial installations and the complexity processes taking place. Because natural energy resources are depleting and increasingly expensive, their use should be re-saving measures, waste reduction, modernization of facilities and energy technologies.

The problem of rational use of energy is very complex and involves many factors in various fields, six main areas where action should be:

- save primary energy resources, which are limited;
- obtain lower costs for primary energy;
- reduce investment and operating costs of thermal plants;
- reduce environmental pollution;
- recovery and efficient use of secondary energy resources.

Since heat treatment furnaces are energy-intensive facilities, with high fuel consumption and low efficiency, has become a more detailed analysis of possibilities to improve operating conditions, the efficient construction of air heaters are equipped with convection ovens and these enhancing energy recovery technology contained in the resources side, the preheat combustion air or fuel.

The technology of combustion air preheating is manifested in aggregate productivity growth, resulting in a quantity of fuel saving. By using such a solution would be achieved:

- ✓ saving the amount of heat that would be required to heat combustion air at ambient temperature to working temperature;
- ✓ saving the amount of heat that would be necessary to heat air to burn fuel quantity saved from ambient temperature to the temperature of exhaust gases.

The use of air pre-heaters for reducing fuel consumption will lead to lower exhaust gas enthalpy, increasing the fuel utilization factor and the importance of energy balance supplied fuel heat entering the facility.

Heaters are heat exchangers operating in steady state, using convection heat transfer to preheat combustion air, in order to reduce fuel consumption. By recovering heat from hot flue gases leaving the furnace and transferring it to the burner combustion air supply, you can send fuel consumption be reduced by an average of twenty five percent (25%). The two fluids (gas and air) runs on one side of a partition at the same time, heat transfer. Gas gives off heat that area of the wall, which spread by conduction to the other surface, hence it is assigned air (**fig. 1**). Stationary character of the preheater operation stems from the fact that after the normal operating temperature field remains constant over time, that is so the two fluid temperatures and the partition at any point in the preheater, do not change [1].

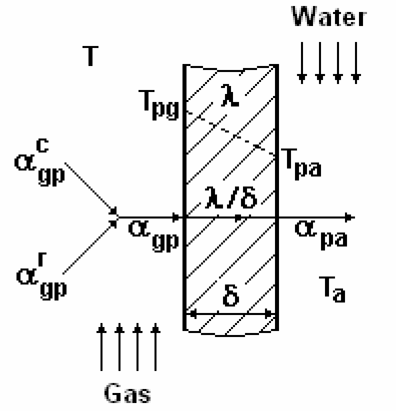
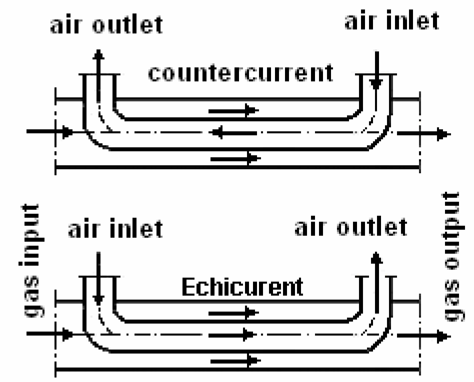
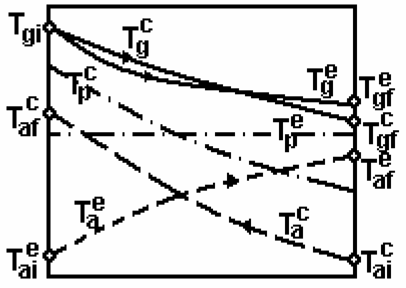


Fig.1 The scheme of heat transfer in the wall of a preheater point

T- gas temperature at the point considered,
Ta-air temperature;
TPG-temperature wall surface in contact with gas;
Tpa-temperature wall surface in contact with air;
δ-thickness of the wall;
λ-thermal conductivity of the wall;
αgp-transfer coefficient from gas to wall surface with convective component $\alpha_{gp}{}^{c}$ and radiation $\alpha_{gp}{}^{r}$;
αpa - heat transfer coefficient from wall to air.



a) scheme of pre-heaters



b) temperature field

Fig.2. Preheater temperature field in the current parallel and counter echicurent
T_{gi} and T_{ai} – gas inlet temperature and air; $T_{gf}{}^{e}$ and $T_{gf}{}^{c}$ – final temperatures of the preheater gas in echicurrent respectively counter; $T_{af}{}^{e}$ and $T_{af}{}^{c}$ - final temperatures of air; $T_p{}^{e}$ şi $T_p{}^{c}$ – wall temperatures.

The scheme of movement of fluids affects the intensity of heat transfer from gas to air, that aspect of the preheater temperature field. For example they will be analyzed for heaters with current and counter echicurent parallel (**fig. 2**) [1].

In both cases we have considered the same values for initial temperatures of TGI gas, air and Tai same size heat transfer surface area. It is noted that in the case counter current the final temperature counter current air is higher than in the case of echicurrent($T_{af}{}^{c}$> > $T_{af}{}^{e}$), and final air temperature can exceed the final gas ($T_{af}{}^{c}$> > $T_{af}{}^{e}$). Also $T_{gf}{}^{e}$ > $T_{gf}{}^{c}$ All this shows that if counterflow heaters, gas heat recovery is entered into more fully used, so these pre-heaters are more efficient. However, the maximum temperature of the wall, in the case counter current is higher than for echicurent, which means that the construction of these pre-heaters, have used materials with higher thermomechanical properties.

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Practically, however, are not built heaters (except radiation) with parallel currents, they are building schemes by cross currents (**fig. 3**) with one or more branches of the cross [1,6].

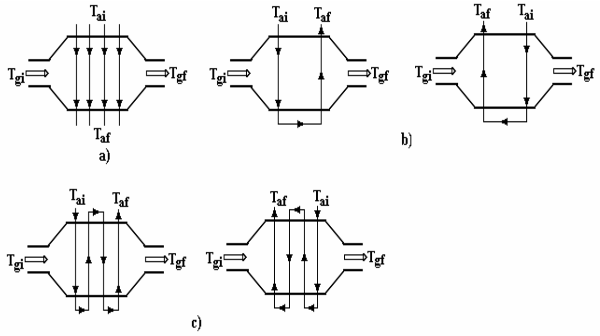


Fig.3. Cross traffic schemes fluids preheaters:
a) simple cross currents; **b)** currents crossed with two branches in echicurent and reflow; **c)** current cross with four branches in echicurent and reflow.

The main variants of metal convection pre-heaters are heaters in smooth pipes and heaters steel elements cast with needle and termobloc projections.

The metal heaters, heat transfer surface consists of a beam pipe walls, one among the two fluid circulating pipe and the other by pipes. The pipes are carbon steel or alloy steel commonly with refractory properties, laminates. Dimensional range covers diameters from

15 to 100 mm and wall thickness between 1.5 and 5 mm. Assembling pipe with plates welded tubular or mandrinare is providing a good seal. Tubular front frame assembly side plates are made with screws, sealing gaskets being made with asbestos contact one of the ends of the casing is made by means of expansion joints, flexible.

Preheaters to the steel pipe is used for various heating furnaces. Maximum temperature of inlet gas preheater is around 900 ° C, and maximum air preheat 600 ° C. Because of their semi-commonly used in building and running relatively simple technology, this type of pre-heaters is widespread.

Heaters of the tubes is achieved by cross currents, two or four branches cross, usually countercurrent **(fig. 4-5)**.[1,2]

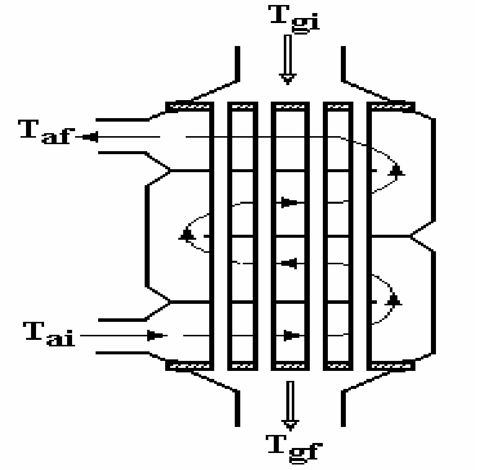


Fig.4. Preheater with vertical pipes with four passes

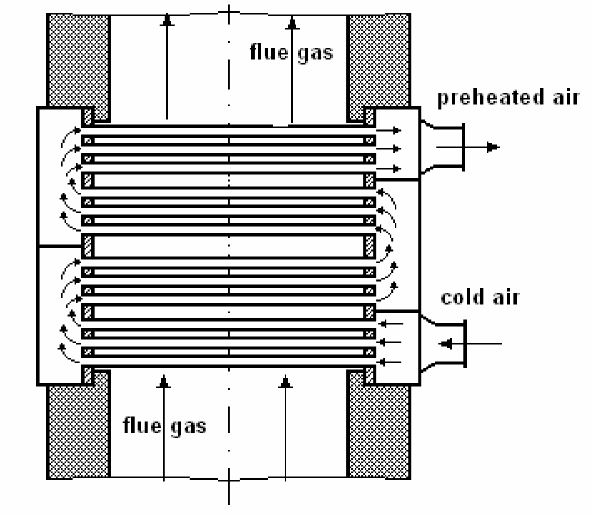


Fig.5. Preheater with horizontal pipe mounted vertically smoke channel

The first is its large heaters and heaters small second one (associated with small furnaces), which may be located above the oven. The large heaters, the first type, gas circulation is usually top-down, and the other, evidently up.

Pipe heaters can be arranged in staggered rows (the chessboard layout, **fig.6. a**) or in rows aligned (parallel arrangement, **fig.6.b).** [2]. The chessboard layout causes a greater movement of fluid turbulence among the pipes, causing an increase in convective heat transfer coefficient at the outer surface of pipe wall, so this kind of arrangement is preferred other.

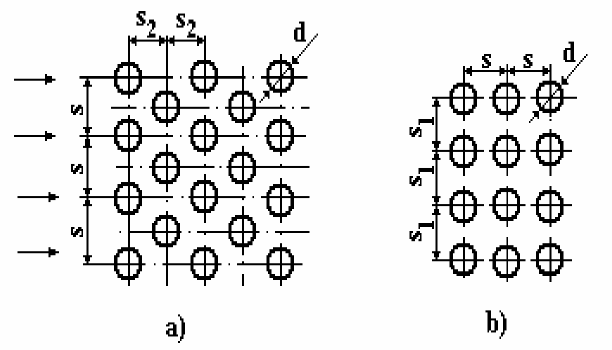


Fig.6. Pipe arrangement:
a) shifted rows (chessboard),
b) in rows aligned(parallel);

In **fig.7**. it presents the preheater (which is countercurrentcross), which tests were made.

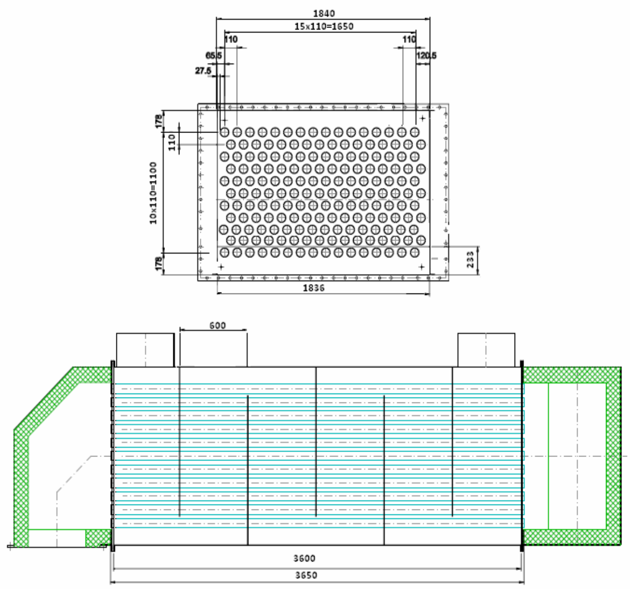


Fig.7. Air preheater tubes shifted the chessboard.

In specialty literature [2], the fundamental equations for calculating thermal analysis of heaters: heat balance equation (**$Q_1 = Q_2 + Q_3$**) and heat transfer equation (**$Q = S*K*\Delta T_{med}$**, where : - **Q_1** = heat flux transferred from the flue gases;

- **Q_2** = thermal flux received by air;
- **Q_3** = losses in the ambient air;
- **Q** = flow of flue gas heat transmitted by air;
- **S** = heat transfer surface;
- **K**=global heat transfer coefficient,

it follows that there are seven independent variables:

- two debts: the flue gas and air;
- four temperatures: input and output of flue gases, respective air preheater;
- one heat exchange surface.

Therefore, the possibility of calculating thermal heaters are:

1.the calculation projection that determines the heat exchange surface, S, the other six sizes heat balance equation is connected;

2. the calculation of verification, known that the heat exchange surface, S, and aimed at inducing the thermal load that can transfer preheater, flue gas temperatures and exit air preheater, the flow and the temperature, or other combinations of two quantities.

2. DESCRIPTION OF MATHEMATICAL MODEL AND COMPUTER PROGRAM FOR SIZING AIR CONVECTION HEATERS USED TO HEAT TREATMENT FURNACES

In developing the mathematical model for sizing preheaters air convection were taken into account the following situations:

- combustion is at constant pressure and is considered to be complete;
- for dissociation are considered only the following equilibriums:

$$CO+\frac{1}{2}O_2 \rightleftarrows CO_2 \quad şi \quad H_2+\frac{1}{2}O_2 \rightleftarrows H_2O$$

because the flame temperature metallic materials industry, as others dissociation equilibriums are insignificant [3].

The mathematical model used for convection heaters sizing was conceived to achieve maximum efficiency in heat recovery from flue gases in the entire area of the heating furnace. For different operating modes, the mathematical model takes into account the values of: fuel flow, AC, nature and composition of fuel, flue gas temperature leaving the preheater, TGI, the coefficient of excess air out of the oven, αi, coefficient excess air to enter the burner, α, air temperature entering the preheater, TAI. Also are introduced and other input quantities, derived from the preheater design choice, such as:

- **TAM [^{0}C]**- ambient temperature;
- **Δα** - value that increases the coefficient of excess air preheater between entry and exit;
- **DI [m]** - inside diameter of pipe;
- **DE [m]** - outside diameter of pipe;
- **LT [m]** - length of pipe in a passage;
- **LV [m]** - vertical length of the tubular plate;
- **LO [m]** - horizontal length of the tubular plate;
- **PV [m]** - step of the vertical pipe;
- **PO [m]** - step of horizontal pipes;
- **DV [m]** - vertical distance from the wall;
- **DO [m]** - horizontal distance from the wall;
- **NTR** - number of passes;
- **PRES [bar]** - athmospheric pressure;
- **GF [m]** - thickness of the stratum of soot;
- **LAF [W/m/grd.]** - conductivity of the stratum of soot;

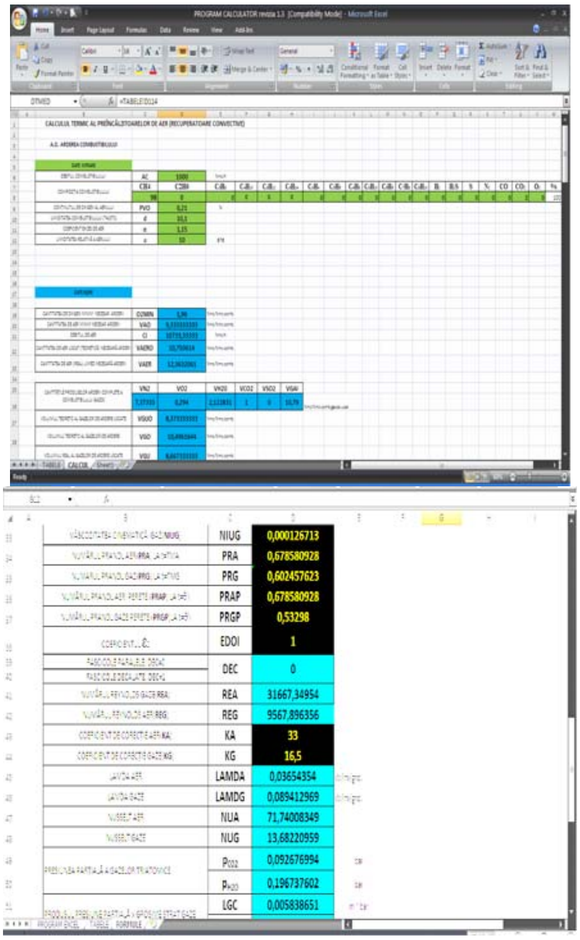
LAMDAO [W/m/grd.] - the conductivity of steel.

Also the inputs are introduced:

- **CC** and **SC** - the flow scheme of the two fluids (echicurent,**SC=0**; pure countercurrent **SC≠0** and **CC=1**; current cross **SC≠0** and **CC=0**);
- arrangement of pipes;
- **FCI** - mode of movement of the two fluids.

Model has been used mathematical relations and formulas (for example gas radiation coefficient calculation ALFARG or specific heat) of specialty literature. [1, 2, 3, 4, 5, 6, 7, 8; 9]

Based on knowledge flow and composition of fuel gas (methane in this case) and factors such as oxygen PVO, d fuel moisture, excess air coefficient α, humidity x, flue gas temperature at entering and leaving the preheater TGI, TGE, air temperature entering and leaving the preheater TAI, TAE, preheater efficiency η, have been calculated using the mathematical model implemented in EXCEL, several parameters of flue gas and an optimum sizing (depending on requirements) of the preheater. (**Fig. 8**)



NIUG	0,000126713
PRA	0,678580928
PRG	0,602457623
PRAP	0,678580928
PRGP	0,53298
EDOI	1
DEC	0
REA	31667,34954
REG	9567,896356
KA	33
KG	16,5
LAMDA	0,03654354
LAMDG	0,089412969
NUA	71,74008349
NUG	13,68220959
P_{CO2}	0,092676994
P_{H2O}	0,196737602
LGC	0,005838651

Fig.8. Capture of the software made in Excel

First mathematical model calculates air flow and flue gas from entering the preheater, DAI, respectively, DGAIA [m^{3}N aer /h], respectively [m^{3}N flue /h], after determining the amount of heat continues to air entry into preheater, QAI and amount of substances contained in waste gas heat from entering the preheater, QGI [W].

Flue gas temperature leaving the preheater, TGE, is determined by successive approximations describing energy balance relationship of the two fluids, taking account of heat losses ceded environment and temperature of combustion air preheat, TAE.

The flow scheme of the two fluids is calculated logarithmic mean temperature difference, ΔTMED and average temperatures of air and flue gas TMA, TMG.

Calculate the equivalent hydraulic diameter and The flow velocities sections of fluids, taking as input the inner and outer diameter of the pipe and the geometry of the steps of preheater tubes.

Convection coefficient for air and gas that is calculated criterial relations data by Reynolds invariable value, type, etc. flow.

Gas radiation coefficient is calculated from the relationship Stephan - Boltzmann with emissivity coefficients, which are based on the average temperature of gases, the product of the pipe wall and gas partial pressure and the thickness of the gas triatomice.

Required heat exchange surface is determined based on global heat transfer coefficient and compared with surface heat exchanger geometry chosen, until the exchanger geometry changes, reaching a maximum difference of 0.3%.

Sizing algorithm mathematical model of convection heaters shown in **Fig. 9.**

3. VALIDATION OF MATHEMATICAL MODEL.

The application was made for sizing an air convection preheater for heat treatment furnaces.

Computer program was executed for different operating modes of the oven, gas flow data, temperature and composition of flue gas leaving the furnace. Maximum preheat temperature was imposed by the burner, the TAE = 500 ° C.

Listing data obtained for sizing is presented in **Table 1**.

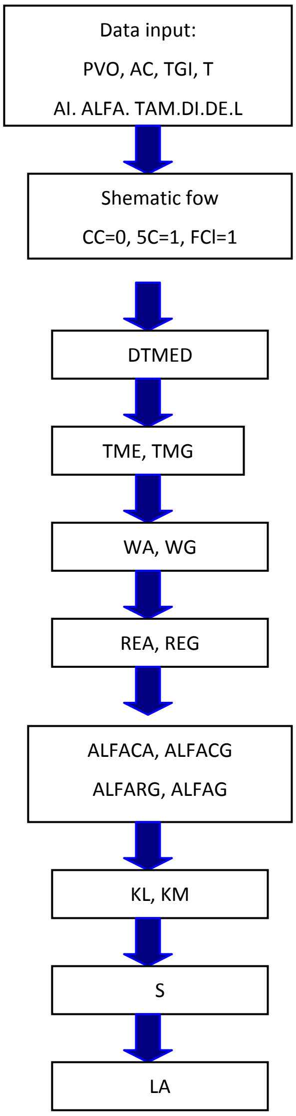


Fig.9. The scheme calculation algorithm

Table 1.

Nr.	**Notation**	**Symbol**	**U.M.**	Experimental value / Value mathematical model
	Data input			
1	Carbon dioxide	CO_2	m^3N/ m^3N	0.02
2	Carbon monoxide	CO	m^3N/ m^3N	0.0
3	Hydrogen	H_2	m^3N/ m^3N	0.0
4	Hydrogen sulfide	H_2S	m^3N/ m^3N	0.0
5	Methane	CH_4	m^3N/ m^3N	0.98
6	Acetylene	C_2H_2	m^3N/ m^3N	0.0
7	Ethane	C_2H_6	m^3N/ m^3N	0.0
8	Propene	C_3H_6	m^3N/ m^3N	0.0
9	Propane	C_3H_8	m^3N/ m^3N	0.0
10	Butene	C_4H_8	m^3N/ m^3N	0.0
11	Butane	C_4H_{10}	m^3N/ m^3N	0.0
12	Pentane	C_5H_{12}	m^3N/ m^3N	0.0
13	Azoth	N_2	m^3N/ m^3N	0.0
14	Oxygen	O_2	m^3N/ m^3N	0
15	Fuel flow	AC	m^3N/h	1000/1000
16	Air flow	DA	kg/h	10909.36
17	Input air temperature	TAI	º C	10/10
18	Exit air temperature	TAE	º C	500/500
19	Preheater efficiency	ETA	-	0.98
20	Coefficient of excess air burner	ALF	-	1.15
21	Ambient temperature	TAM	ºC	10/10
22	Flue gas temperature at the entrance	TGI	ºC	950/950
23	Interior diameter of pipe	DI	m	0.07/0.07
24	Outside diameter of pipe	DE	m	0.076/0.076
25	Pipe length in a crossing	LT	m	0.51/0.51
26	Vertical length of the tubular plate	LV	m	1.2/1.2
27	Horizontal length of the tubular plate	LO	m	1.8/1.8
28	Step of vertical pipes	PV	m	0.11/0.11
29	Step of horizontal pipes	PO	m	0.11/0.11
30	Distance from the vertical wall	DV	m	0.05
31	Horizontal distance from wall	DO	m	0.05
32	Number of passes	NTR	-	6/6
33	Atmospheric pressure	p	bar	1
34	Thickness of the soot	GF	m	0
35	Conductive stratum of soot	LAF	W/(m ºC)	0
36	Thermal conductivity of steel	LAMDAO	W/(m ºC)	50
	Output data			
37	Flue gas flow at the entrance	DGAI	m^3N/h	11909.36
38	Flue gas flow out	DGAE	m^3N/h	11909.36
39	Medium specific heat of gas at the entrance	CPI	kJ/ (m^3N ºC)	1.5346775
40	Medium specific heat output gas	CPE	kJ/ (m^3N ºC)	1.4762106
41	Heat contained in the input gas	QGI	W	4823104.2
42	Heat output gas contained	QGE	W	2833824
43	Flue gas temperature at the exit	TGE	ºC	580.28138/ 609.9
44	Mean temperature difference	DTMED	ºC	518.52552
45	Mean temperature gases	TMG	ºC	765.14069

46	Mean air temperature	TMA	ºC	246.61517
47	Quantity of useful heat water taken	QA	W	1949494.7
48	Number of pipes in a row in a vertical shift	NV	-	11/11
49	Number of pipes in a row in a horizontal crossing	NO	-	16/16
50	Gas of flow section	SG	m^2	0.67732896
51	Air of flow section	SA	m^2	0.46176
52	Gas velocity	WG	m/s	19.66
53	Airspeed	WA	m/s	14.77
54	Gas convection coefficient	ALFACG	W/(m^2 ºC)	37.55259
55	Convection coefficient of air	ALFACA	W/(m^2 ºC)	75.38322
56	The thickness of the gas	LG	m	0.063
57	Gas radiation coefficient	ALFARG	W/(m^2 ºC)	5.01608
58	Transfer coefficient from gas to wall	ALFAG	W/(m^2 ºC)	40.24867
59	Global heat transfer coefficient	KL	W/(m^2 ºC)	5.68356
60	Coefficient transfer	KM	W/(m^2 ºC)	24.79523
61	Machine length	LA	m	0.63275
62	Heat transfer surface	S	m^2	150.701
63	Required heat transfer surface	SN	m^2	143.045

Because the functioning furnace change some of its parameters (fuel flow, temperature of flue gas), leading to changes in functional parameters of the air preheater, runs were made which took into account the different values of input. So you could choose air preheater efficiency.

Since recovery plant was commissioned recently were able to take data mining to operate without air preheater deposits, but at different temperatures of combustion air preheat, TAE keeping excess air ratio,α_i=**1,15.**

These experimentally obtained values are listed in the diagram **fig.14**, are presented as straight air preheat temperature variation of combustie TAE, depending on air speed, WA.

In the graph in **fig.15** we can see changes in air temperature TAE, leaving the preheater, depending on air flow section, SA.

There is a good agreement between experimental values and those obtained using the mathematical model.

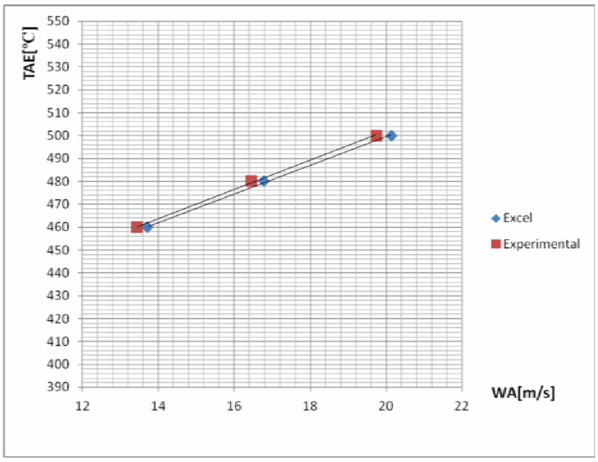


Fig.14. Variation of temperature of combustion air preheat, TAE, depending on air speed, WA

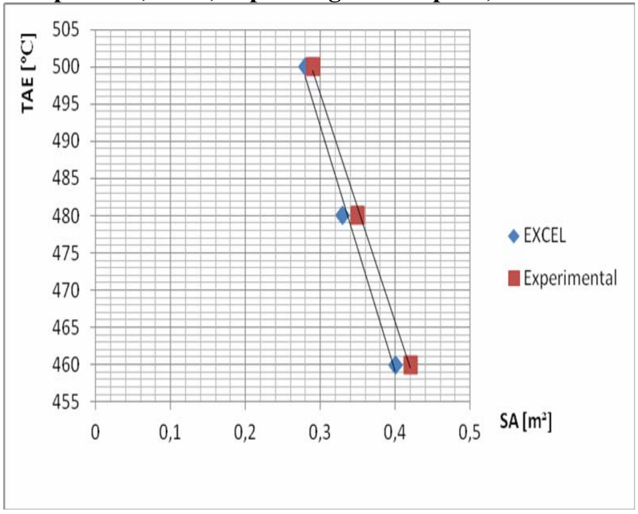


Fig.15. Variation of temperature of combustion air preheat, TAE, depending on air flow section, SA

Analyzing the data in the table with the values obtained with the mathematical model and experimentally, one can see easily that reducing the flow section, SA, increased air velocity, WA and global coefficients KM and KL, finally leading to values higher air temperature leaving the preheater, TAE, keeping the same surface heat exchange, SMR.

4. CONCLUSIONS

- Heat recovery from exhaust flue gas physical heat treatment furnaces of steel construction materials can be made in technological direction by preheating combustion air through the preheating low calorific fuel gas and preheat preforms and energy direction, usually in form of steam. Given the low thermal efficiency of heat treatment furnaces, recovery should be made primarily in the technological direction, conducting performance recuperatoare, the combustion air to warm to temperatures as high.

- For sizing air heaters that recover heat from exhaust flue gas furnaces heat treatment was performed a mathematical model that was transcribed in Excel, in order to perform automatic calculations and with the various types of heat treatment furnaces for validation.

- This computer program was used for sizing an air preheater the flue gas exhaust heat recovery from a heat treatment furnace.

- The experimental results obtained on the air preheater, are consistent with those obtained by computer simulation.

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