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Analyzing of the Air Preheater Operation of the Steam Generators in Power Plants

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Abstract— **The paper presents, in the firs part, the importance of the steam generator in the operation of power plants, especially, the importance of the air preheater, the last heat exchange surface on the route of the flue gas, with all physical phenomena produced, which lead to the shaping of the physical model. Then is presented the model in relative units imposed by the literature. The paper proposes the development of a mathematical model in absolute units and the simulation the operation of the air preheater of the steam generator. The theoretical model proposed is implemented in Matlab-Simulink obtained simulations in dynamic regime. In order to validate de model, the simulation results were compared with the parameters measured values of the installations during the real time function. The model wants eliminating the major recalculation sequence of parameters at each step - the patterns in relative units the entire set of coefficients are determined and entered into the model according to the parameters achieved in the previous reference system and meet operating values taken as the basis in developing the work. The approach of such a study is justifies by the development and use of computer technology and digital media communication in dynamic analysis of energy processes.**

I. INTRODUCTION

Among the priority issues that the modern society has to be solved, include also the energy and environmental issues. The notion of control (process control) has expanded in recent years, encompassing new areas such as automatic control of quality, the data processing with decisional purpose for one strategic leadership, ensuring uninterrupted of the system maintainability and thus, security and viability of the entire ensemble. In this context are part and the simplified simulation methods of the energetic installations from the power plants.

Simulation can be defined as a method used for studying the behavior of a real system or phenomenon. Thermal power plant simulations can be for operator training, operator guide or as a design aid. A training simulator need to be able to simulate very wide phenomena, all in real time, where as for design aid simulation range is much smaller and real time capability is not needed, in the case of operator guide real time and on-line capabilities is required.

The most important component of the conventional power generation plant for fuel optimization studies is the steam generator. The control of the steam generator to archive optimum performance is a difficult problem that has been studied during the last years.

The steam generator is a heat exchanger that converts water into steam pressure and temperature required, by the heat produced by the combustion of fossil fuels. The production of steam or hot water in the boiler is achieved by two successive energy conversion or chemical burn and transfer heat. Chemical energy of the fuel is converted into heat in the combustion process, resulting combustion gas with high temperature that transfers heat water or steam through pipes generator metal surfaces. The steam generator is continuously fed with water and debit continuous hot water or steam. The heating and water vapor takes place practically at constant pressure, neglecting frictional losses inside. The evolving gases from the steam boiler are steam boiler combustion air and gases resulting from combustion, their rates are directly proportional to the amount of fuel burned. Air-flue gas circuit of a steam heating of the combustion gases and the discharge of combustion gases into the atmosphere. Combustion air supply and exhaust fan is made by the action of air and flue gas driven with electrical motors.

Fig. 1 shows the route of air - fuel gases for a boiler having the basic fuel - lignite. The scheme can trace the following composition boiler traveled by air flow - gas: PE - air preheater using steam; this external preheating takes place in the winter, for the usage of sulfur-rich fuels, in order to prevent corrosion; VA - air fan; PA - air preheater face crossed by air; A - burner; F - furnace and the vaporization surfaces; SI - superheaters; EC - the economizer (water pre-heater); PA - air preheater face crossed by gas; FC - the filter for the ash retention from fuel gas; VG - gas fan.

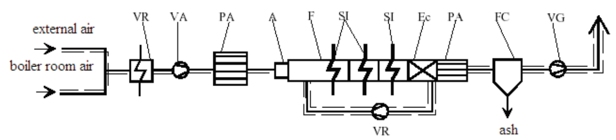

Fig. 1 Scheme of the route held air – gas, [6]

As a result of economic, air preheaters carried out; on the one hand on the use of the heat contained in the flue gas prior to discharge to the chimney, on the other hand, raising the combustion temperature causes an increase in the level of temperature along its whole length gases. Upper air preheating depends on the type of fuel used for burning, reaching up to 720 K when firing coal with high humidity. They may be constructed as a heat exchanger surface of two types. In the case of the first type recuperative beam tube is bathed in the combustion gases inside the longitudinal and the outside air that is preheated or transverse simple or mixed in a transverse-counter. The flue gases are always routed through the inside pipe to facilitate removal of deposits. In the latter case, the regenerative type preheater, the intermediate material of which heat exchange takes place is of steel plate with a thickness of 0.6 to 1.2 mm, mounted on the frame sections of the rotor charged. From the air common duct, downstream of the air preheater, is going more branches to the load and sustaining hydrocarbons burners, to the coal dust burners - secondary air, to the coal mills - primary air and additional primary air, Fig. 2.

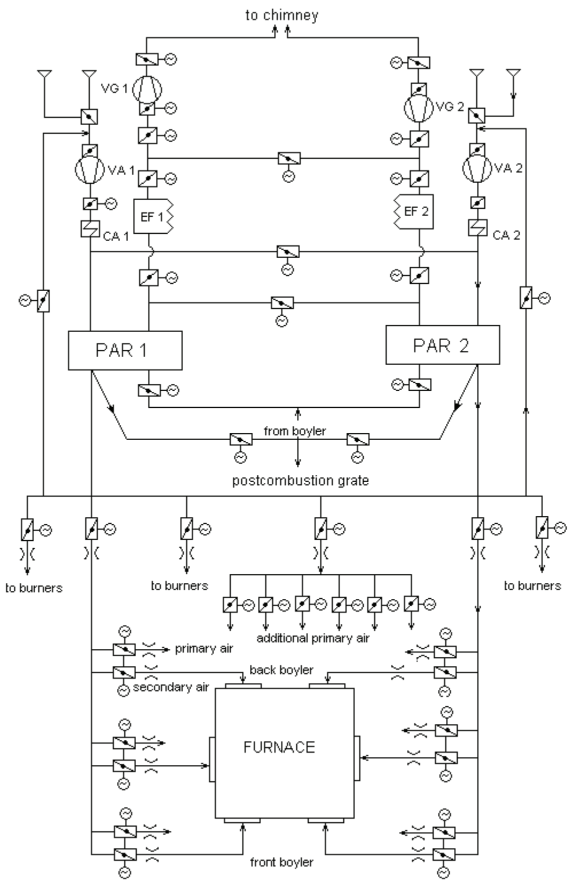

Fig. 2. Circuit diagram of air and flue gas

The steam generator is equipped with two rotating type heaters Ljungström. Ljungström type air preheater is a rotary regenerative preheater in which the accumulator is rotatable table, shown in Fig. 3, where the rotor 1 is made of corrugated or grooved to increase the exchange surface and the carcass 2, air channels 3 and 4 gas are the board. The air enters at the bottom and at the top of gas, the movement of the counter 5 is the vertical axis of rotation, and the drive motor is electric.

In the interior of a sealed carcass is rotating a spinning rotor than the corrugated sheets are mounted and constitute the heat exchange surfaces. Through the fixed carcass of the combustion gases circulating in counter-current and the combustion air tight separate with routes between them. Corrugated sheets due to rotor movement, alternately pass through gas path where heat is accumulate and gives air that wash them when and the airflow reaches to the tables It is designed in such a corrugated plate through the filling of heat transfer from the combustion gas to cool the combustion air.

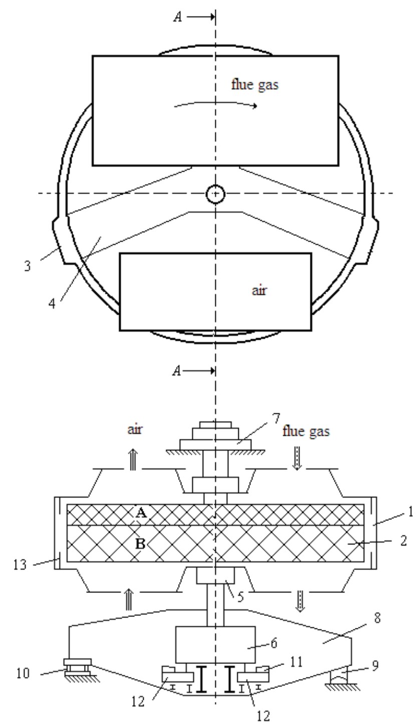

Fig. 3 Ljungström air preheater rotary type

were 1 is the carcass; 2 the rotor; 3, 4, 5, and 3 the sheath seal radially to the axis of the rotor, on the circumference of the rotor camps; 6 and 7 the carcass rotor; 8 the building support rotor; 9 and 10 the support; 11 the hydraulic motor drive; 12 the step speed reduction; A the warm zone and B the cold zone. The heat exchange surface is distributed to the longitudinal direction of the rotor into two areas: the hot (A), which temperature regime is higher and where the gas enters; the cold zone (B) from the flue gas outlet and air inlet. In the cold area is possible to appear the dew point with a high of 100 ÷ 200 mm. For this reason, the cold zone is separated from the hot plates being formed of a height of 300 mm. The corrugated sheet from the cold side has a thickness of 1 mm, 0.5 mm to the hot zone, in order to increase the resistance to corrosion.

II. PHYSICAL AND MATHEMATICAL MODEL OF AIR PREHEATER

Regenerative air preheaters are most widely used in steam generators in power plants due to the flows of air and flue gas high and very high. The combustion air is heated before entering in the steam generator second in two rotary air preheaters, regenerative type. The air for afterburning grate is taken over in a separate area from the air above the air preheater. The physical model of the air preheater, regardless of type, is shown in Fig. 4. Physical processes which describe the operation of the air preheater are: heat transfer from flue gas to the stuffing the rotor in motion; heat accumulation in the curled sheet material of the rotor; heat transfer from the curled sheet material of the rotor to the air who is heated; entry of gas into the air and the air into the gas - to a smaller extent.

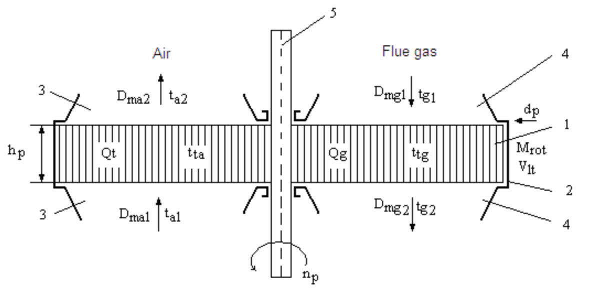

Fig. 4. Physical model of air preheater, [1]

where: 1 is the rotor; 2 - the carcass; 3 - the air channels; 4 – the channel gas; 5 - the axis of rotation; D_{ma1}, D_{ma2} – the mass flow of air input-output, kg/s; D_{mg1}, D_{mg2} are the mass flows of flue gas input-output, kg/s; Q_g – the heat transmitted from flue gas to sheet, kW; Q_t – the heat transmitted from sheet to air, kW; t_{a1}, t_{a2} – the temperature of the air input-output, ^oC; t_{g1}, t_{g2} – the temperature of the flue gas input-output, ^oC; $t_{ta,}$ t_{gt} – the mean temperature of the sheet in the air, respectively of the flue gas in the sheet, ^oC; M_{rot} – the metal mass in rotation, kg; n_p – the preheater engine speed, rot/min and V_{lt} is the total free volume, m^3.

The assumptions adopted in the implementation of the mathematical model are: model is with concentrated parameters; the capacity and thermal conductivity are constant and uniformly distributed; on the direction of fluid flow does not exist the heat transfer in the rotor material or thermal resistance of the material; the air and the flue gas are considered ideal gases; the heat transfer is predominantly by convection.

Mathematical model proposed is based on mathematical equations specific heat exchange area and some existing models that were suitable in view of the functional - the equation of energy conservation, heat transfer and accumulation - applied to the two fluids - flue gas and air, [1].

The conservation of mass equation:

- for the air:

$$D_{ma2} = D_{ma1} + 2 \cdot \pi \cdot n_p \cdot V_{lt} \cdot (\rho_g - \rho_a) - f_{sa} \cdot D_{ma1} + a_{rec} \cdot D_{ma1} \quad (1)$$

where: ρ_a is the medium density of the air, kg/m^3; ρ_g – the medium density of the flue gas, kg/m^3; f_{sa} – fraction of air leaks in the flue gas; a_{rec} – recirculated air fraction;

- for the flue gas:

$$D_{mg2} = D_{mg1} + 2 \cdot \pi \cdot n_p \cdot V_{lt} \cdot (\rho_a - \rho_g) + f_{sa} \cdot D_{ma1} \quad (2)$$

The energy conservation equation is:

- for the air:

$$V_{la}\rho_a \cdot \frac{d}{d\tau}(h_a) = Q_t + D_{ma1} \cdot h_{a1} - D_{ma2} \cdot h_{a2} + a_{rec} \cdot D_{ma1} h_{a2} + \\ + 2 \cdot \pi \cdot n_p \cdot V_{lt} \cdot (\rho_g h_g - \rho_a h_a) - f_{sa} \cdot D_{ma1} \cdot h_a \quad (3)$$

- for the flue gas:

$$V_{lg}\rho_g \cdot \frac{d}{d\tau}(h_g) = D_{mg1} \cdot h_{g1} - D_{mg2} \cdot h_{g2} + f_{sa} D_{ma1} \cdot h_a - Q_g + \\ + 2 \cdot \pi \cdot n_p \cdot V_{lt} \cdot (\rho_a h_a - \rho_g h_g) \quad (4)$$

where V_{la} is the volume free occupied by air, m^3; V_{lg} is the volume free occupied by the flue gas, m^3; kW; h_{a1}, h_{a2}, h_a – the enthalpy to the air input-output and medium, kJ/kg; h_{g1}, h_{g2}, h_g – the enthalpy to the flue gas input-output and medium, kJ/kg.

The heat transfer equation from the stuffing of rotor to air is:

$$Q_t = k_{ga} \cdot (D_{ma1})^{0.8} \cdot (t_{ta} - t_a) \quad (5)$$

The heat transfer equation from the flue gas to stuffing of rotor is:

$$Q_g = k_{gg} \cdot (D_{mg1})^{0.8} \cdot (t_g - t_{tg}) \quad (6)$$

where k_{ga}, k_{gg} are the global heat transfer coefficients from the stuffing of rotor to air and from the flue gas to stuffing of rotor, W/mK and S is the free surface of the heat exchange, m^2.

The heat accumulation equation in stuffing:

- for the air:

$$M_{rot} \cdot f_{rair} \cdot c_t \cdot \frac{d}{d\tau}(t_{ta}) = 2 \cdot \pi \cdot n_p \cdot M_{rot} \cdot c_t \cdot (t_{tg} - t_{ta}) - Q_t \quad (7)$$

- for the flue gas:

$$M_{rot} \cdot (1 - f_{rair}) \cdot c_t \cdot \frac{d}{d\tau}(t_{tg}) = Q_g - 2 \cdot \pi \cdot n_p \cdot M_{rot} \cdot c_t \cdot (t_{tg} - t_{ta}) \quad (8)$$

where c_t is specific heat of the metal, kJ/kgoC.

For air preheater is considered as known quantities external variable values, namely preheater air mass flow rate, flue gas mass flow entering the preheater, preheater rotary speed, flue gas temperature entering the preheater, inlet air temperature.

Calculated variables are the average temperature of the air, the average temperature of the flue gases, the average temperature of the sheet in the air zone, the average temperature of the sheet in the flue gas, mass flow rate of air entering the preheater, flue gas mass flow at the outlet the preheater, the heat transmitted from the rotor sheet metal to the air, the heat transmitted from the flue gas to the rotor sheet metal, the temperature of the preheated air and the flue gas temperature at the outlet of the preheater.

After mathematics processing and taking into account the equations of the thermodynamics, operational forms of the mathematical model equations, in relative units are, [1]:

The conservation of mass equation:

- for the air:

$$D_{ma1} = a_1 \cdot D_{ma2} + a_2 \cdot n_p + a_3 \cdot t_g + a_4 \cdot t_a \quad (9)$$

- for the flue gas:

$$D_{mg2} = a_5 D_{mg1} + a_6 n_p + a_7 t_a + a_8 t_g + a_9 D_{ma1} \quad (10)$$

The energy conservation equation is:

- for the air:

$$s \cdot t_a = a_{10} t_a + a_{11} n_p + a_{12} D_{m2a} + a_{13} t_{a1} + a_{14} D_{ma1} + a_{15} Q_t \quad (11)$$

- for the flue gas:

$$s \cdot t_g = a_{16} \cdot t_g + a_{17} \cdot t_a + a_{18} \cdot n_p + a_{19} \cdot D_{mg1} + \\ + a_{20} \cdot t_{g1} + a_{21} \cdot D_{ma1} + a_{22} D_{mg2} + a_{23} Q_g \tag{12}$$

The heat transfer equation is:

- from the stuffing of rotor to air

$$Q_t = a_{24} \cdot t_{ta} + a_{25} \cdot t_a + a_{26} \cdot D_{ma1} \tag{13}$$

- from the flue gas of rotor to stuffing of rotor

$$Q_g = a_{27} \cdot t_{tg} + a_{28} \cdot t_g + a_{29} \cdot D_{mg1} \tag{14}$$

The heat accumulation equation in stuffing is:

- for the air:

$$s \cdot t_{ta} = a_{34} \cdot t_{ta} + a_{35} \cdot t_{tg} + a_{36} \cdot n_p + a_{37} \cdot Q_t \tag{15}$$

- for the flue gas:

$$s \cdot t_{tg} = a_{30} \cdot t_{tg} + a_{31} \cdot t_{ta} + a_{32} \cdot n_p + a_{33} \cdot Q_g \tag{16}$$

The equation to determine the outlet temperature:

- for the air:

$$t_{a2} = a_{36} \cdot t_a + a_{39} \cdot t_{a1} \tag{17}$$

- for the flue gas:

$$t_{g2} = a_{40} \cdot t_g + a_{41} \cdot t_{g1} \tag{18}$$

Obtaining the system of equations that determines the operational quantities unknown relative units, [1]:

$$\begin{cases} s \cdot t_a = b_1 \cdot t_a + b_2 \cdot t_g + b_3 \cdot t_{ta} + b_4 \cdot n_p + b_5 \cdot D_{ma2} + b_6 \cdot t_{a1} \\ s \cdot t_g = b_7 \cdot t_g + b_8 \cdot t_a + b_9 \cdot t_{tg} + b_{10} \cdot n_p + b_{11} \cdot D_{mg1} + b_{12} \cdot D_{ma2} + b_{13} \cdot t_{g1} \\ s \cdot t_{ta} = b_{14} \cdot t_{ta} + b_{15} \cdot t_{tg} + b_{16} \cdot t_g + b_{17} \cdot t_a + b_{18} \cdot n_p + b_{19} \cdot D_{ma2} \\ s \cdot t_{tg} = b_{20} \cdot t_{tg} + b_{21} \cdot t_{ta} + b_{22} \cdot t_g + b_{23} \cdot n_p + b_{24} \cdot D_{mg1} \\ D_{ma1} = a_1 \cdot D_{ma2} + a_2 \cdot n_p + a_3 \cdot t_g + a_4 \cdot t_a \\ D_{mg2} = a_5 \cdot D_{mg1} + a_6 \cdot n_p + a_7 \cdot t_a + a_8 \cdot t_g + a_9 \cdot D_{ma1} \\ Q_t = a_{24} \cdot t_{ta} + a_{25} \cdot t_a + a_{26} \cdot D_{ma1} \\ Q_g = a_{27} \cdot t_{tg} + a_{28} \cdot t_g + a_{29} \cdot D_{mg1} \\ t_{a2} = a_{38} \cdot t_a + a_{39} \cdot t_{a1} \\ t_{g2} = a_{40} \cdot t_g + a_{41} \cdot t_{g1} \end{cases} \tag{19}$$

Coefficients a_1 - a_{41}, b_1 - b_{24} are determined according to their sizes air preheater calculated under reference, the expressions given in the literature.

Equations underlying mathematical model in order to determine the absolute units following unknown variables, [2]:

The inlet air mass flow:

$$D_{ma1} = \frac{1}{1 + f_{sa} + a_{rec}} \left[D_{ma2} - 2\pi \cdot n_p \cdot V_{lt} \left(\rho_g - \rho_a \right) \right] \tag{20}$$

The outlet flue gas mass flow:

$$D_{mg2} = D_{mgg} - 2\pi \cdot n_p \cdot V_{lt} \left(\rho_g - \rho_a \right) + f_{sa} \cdot D_{ma1} \tag{21}$$

The air average temperature:

$$t_a = \int \frac{1}{V_{va} c_a \rho_a} \left[Q_t + h_{1a} D_{ma1} - h_{2a} D_{ma2} + a_{rec} D_{ma1} h_{a2} + 2\pi \cdot n_p V_{lt} \left(\rho_g h_g - \rho_a h_a \right) - h_a t_a \right] d\tau \tag{22}$$

The flue gas average temperature:

$$t_g = \int \frac{1}{V_{1g} c_{pg} \rho_g} \left[D_{mg1} h_{1g} - D_{mg2} h_{g2} + h_a t_a - Q_g - 2 \cdot \pi \cdot n_p V_{lt} \left(\rho_g h_g - \rho_a h_a \right) \right] d\tau \tag{23}$$

The average temperature of the sheet in the flue gas:

$$t_{tg} = \int \frac{1}{M_{rot} \left(1 - f_{rair} \right) c_t} \left[Q_t - 2\pi \cdot n_p M_{rot} c_t \left(t_{tg} - t_{ta} \right) \right] d\tau \tag{24}$$

The average temperature of the sheet in the air zone:

$$t_{ta} = \int \frac{1}{M_{rot} \cdot f_{rair} \cdot c_t} \left[-Q_t + 2\pi \cdot n_p \cdot M_{rot} \cdot c_t \left(t_{tg} - t_{ta} \right) \right] d\tau \tag{25}$$

The preheated air temperature:

$$t_{a2} = 2 t_a - t_{a1} \tag{26}$$

The flue gas temperature at the outlet of the preheater:

$$t_{g2} = 2 t_g - t_{g1} \tag{27}$$

The heat transmitted from the rotor sheet metal to the air:

$$Q_t = \alpha_{ta} \cdot S \cdot \left(t_{ta} - t_a \right) \tag{28}$$

where α_{ta} is the convective heat transfer coefficient rotor sheet metal – air.

The heat transmitted from the flue gas to the rotor sheet metal:

$$Q_g = \alpha_{gt} \cdot S \cdot \left(t_g - t_{tg}\right) \qquad (29)$$

where α_{gt} is the convective heat transfer coefficient flue gas – rotor sheet metal.

III. THE SIMULATION OF THE AIR PREHEATER

The coal (lignite) coal, lignite, is provided from the mines of mining basin Oltenia. In table 1 are given the energy characteristics of fuels.

TABLE 1. THE CHARACTERISTICS OF THE FUELS

Fuel	Characteristics	U.M.	Value
Primary fuel	Total humidity	%	46
	Volatiles	%	24
	Total carbon (organic)	%	25
	Ash	%	24
	Hydrogen	%	2.3
	Sulfur	%	1.75
	Sulf fuel	%	1.5
	Oxygen + nitrogen	%	12.5
	Nitrogen	%	1.06
	Chlorides	%	0.009
	Lower calorific value	kJ/kg	8360
Support fuel	CO_2	%	3.5
	O_2	%	3.5
	CH_4	%	99.2
	S	g/m_N^3	0.05
	Lower calorific value	kJ/m_N^3	35455

The steam generator works with a steam flow by the 421t/h (82.55 %), flue gas temperature after the economizer, 237°C, flue gas temperature after the air preheater, 148°C, input air temperature in the air preheater, 26°C, output air temperature in the air preheater, 243°C, load flue gas fan 37,1%, the air pressure after the air preheater 4mbar, construction features of the air preheater: rotor diameter 8400 mm, rotor height 2340 mm, heating surface: height cold zone 306 mm, height hot zone 1818 mm.

The proposed analytical methodology covers the following general requirements: modeling technology specific heat exchange surface of the steam generator – in this case the air preheater; simulation schemes operating between 50 and 100%; data entry in each model are given their own model and related data calculated by the model (flow, pressure, temperature); the output of each model are flow rates, pressure, temperature, enthalpy.

MATLAB functions were created for Prandtl number, kinematics viscosity, Fig. 5, thermal conductivity, Fig. 6, and specific heat of air, but, also, of the flue gas; they are determined by the temperature of the fluid.

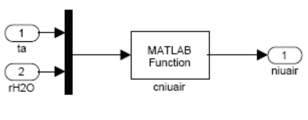

Fig. 5. Function for the calculation of the air viscosity

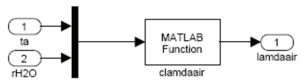

Fig. 6. Function for the calculation of the air thermal conductivity

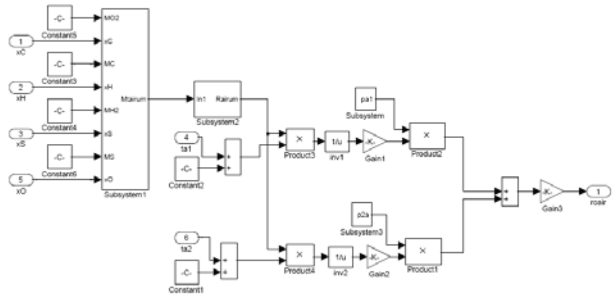

Fig. 7. Diagram calculation of average air density

As stated in the presentation of mathematical model equations of heat transfer models used in relative units, data from the literature were replaced by equations of heat transmission by convection. For both the convective heat transfer coefficient of flue gas to the rotor sheet metal and the rotor sheet metal to the air were prepared from the calculation block diagrams, Fig. 8.

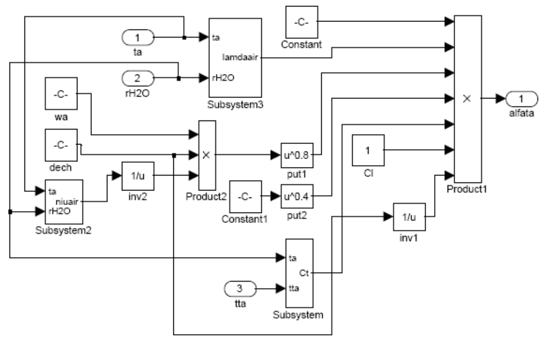

Fig. 8. Diagram calculation of the convective heat exchange coefficient

Free volume occupied by air is determined by the fraction of air leaks in the combustion gases and the total free volume. Diagram calculations are presented in Fig. 9 and Fig 10.

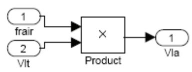

Fig. 9. Diagram calculation of air volume from total volume

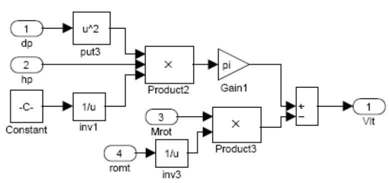

Fig. 10. Diagram calculation of total free volume

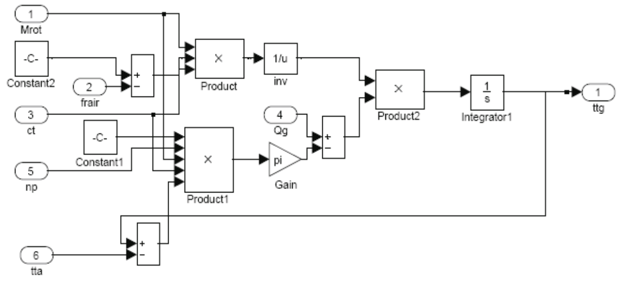

Fig. 11. Diagram calculation of average temperature of the sheet in the air zone

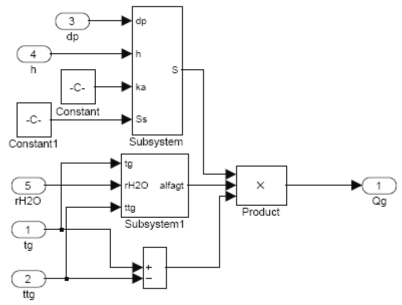

Fig. 12. Diagram calculation of the heat transmitted from the flue gas to the rotor sheet metal

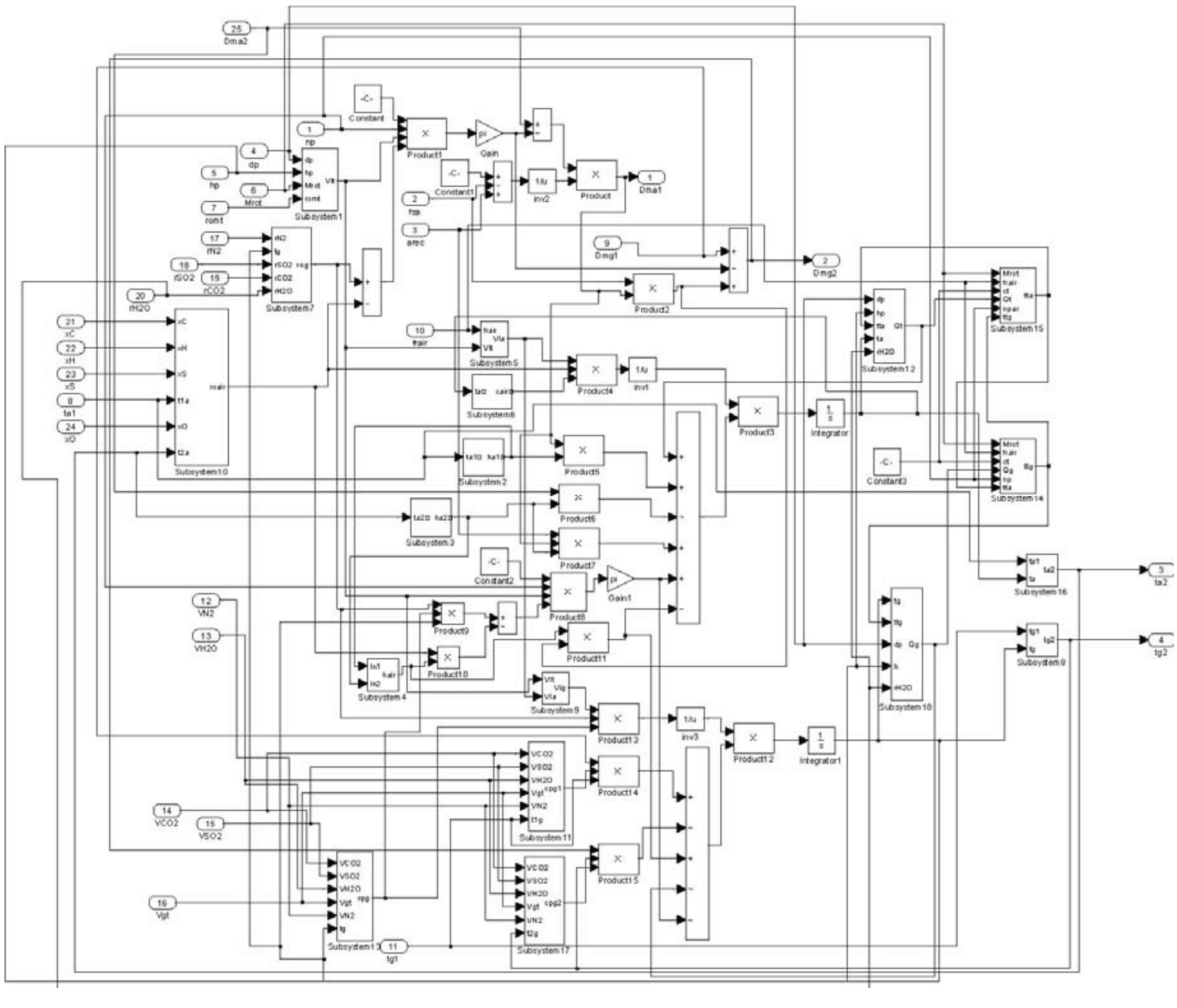

Fig. 13. Diagram calculation of the air preheater

The mathematical model of the air preheater is part of the steam generator model. Thus, the input variables of the block diagram of calculation are part of them, the output variables of the block diagrams for the heat exchange surfaces placed before the preheater on flue gas. Fig. 14 presents the connection between the block diagram of the air preheater and the block diagram of the combustion in the furnace steam generator.

The scheme of furnace allows the calculation of the combustion and calculation of the exit temperature of gases in the furnace. The calculation of the combustion impose, in a first stage, the determination to the equivalent fuel (the mixture: solid fuel - support fuel) and in the second stage aims at determining the combustion products: the theoretical volume of water vapor, the theoretical volume of diatomic and triatomic gases and the real volume of the combustion gases, [9]. Some of these variables are used in the block diagram of the preheater in the calcul subsystems for the density and specific heat of the flue gas and, also, in the determining the actual flow of the flue gases who, at the end air-flue gas route, cross the air preheater.

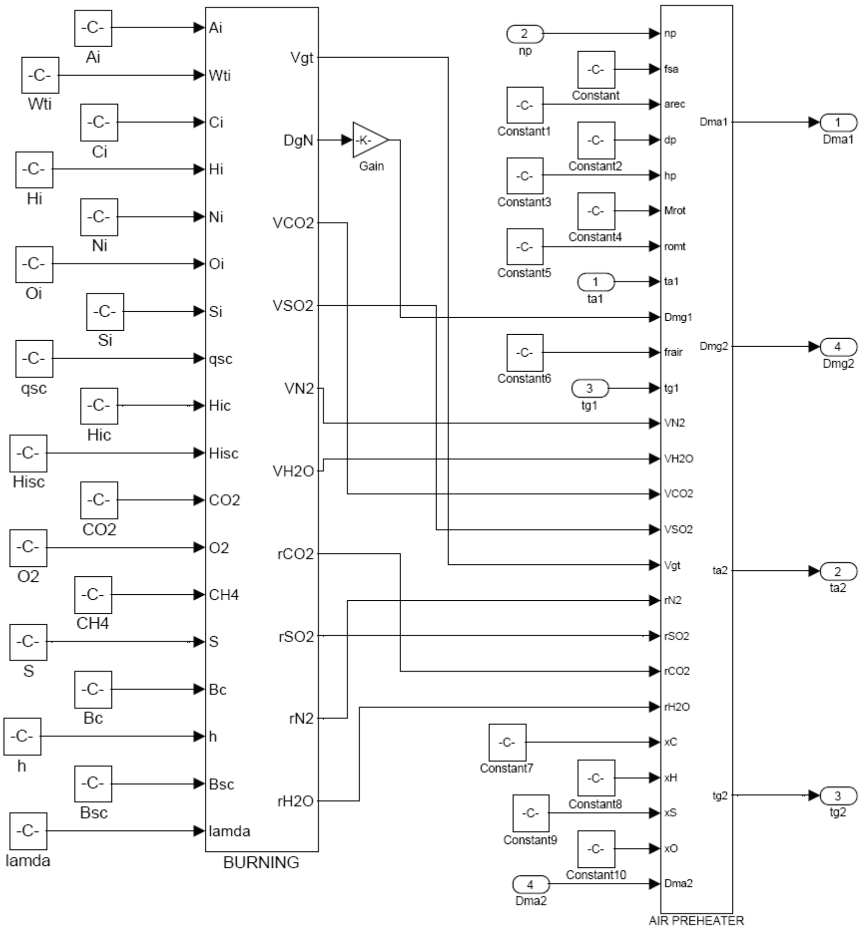

Fig. 14. Block diagram for calculating the air preheater

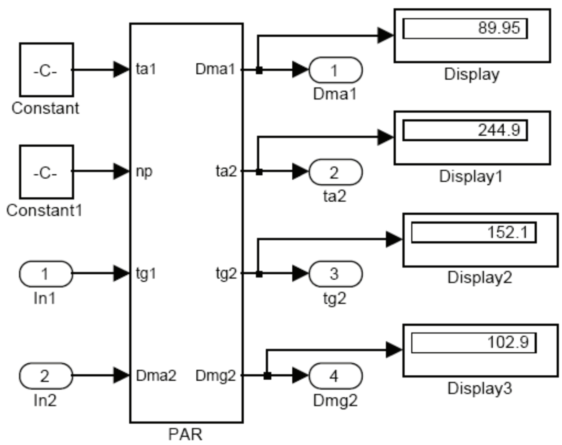

Fig. 15. Block diagram with external variables

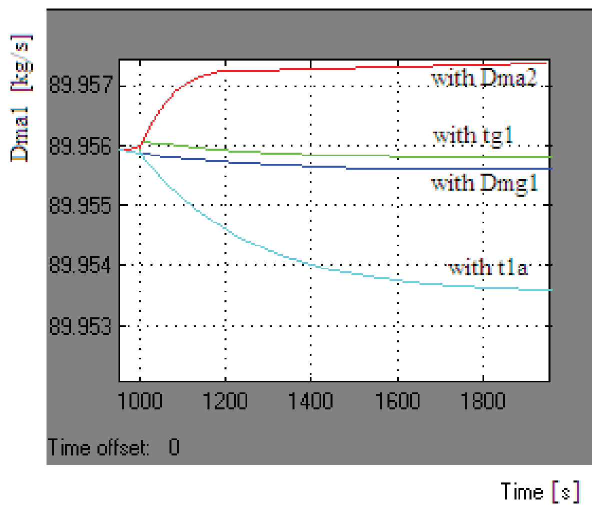

Fig. 16. The mass flow of air to the input

In the same time, the unknown variables are the flue gas temperature at the outlet, the temperature of the pre-heated air needed for de combustion process in the furnace - which becomes input data for the furnace calculation block, Fig. 14 and Fig. 15.

The mass flow of air to the input increases significantly with the mass flow of air to the output, very slow with the flue gas temperature at the entrance and decreases with the air temperature to the output.

IV. CONCLUSIONS

The model responds to the values taken as a basis for develop this work. Thus, studying the dynamic behavior of the regenerative air preheater to the step variation for each input data may be made the following comments: the mass flow of air to input is modified very fast, less than 5 seconds. It significantly increases to the variation of mass flow of air to output, decreasing with the temperature preheated air. The air temperature to the output decreases with mass flow of preheated air and increases with air temperature to the input. The model eliminated from the equations of heat transfer the coefficients empirically determined, they was replaced by the values calculated in real time. Due to the iterative calculation model is slower than the one given in the literature.

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