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INFLUENCE OF ROTATIONAL SPEED UPON HEAT TRANSFER IN A ROTARY REGENERATIVE HEAT EXCHANGER

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ABSTRACT
Ljungström air preheater is a regenerative heat exchanger which is mainly used in steam boiler plants for preheating of the combustion air. The hot gas and cold air ducts are arranged in such a way to allow both to flow simultaneously through the machine. The hot flue gas heats the rotor material and as the rotor rotates, the hot rotor section moves into the flow of the cold air and preheats it. Simulations of regenerative heat exchanger described in open literature are mainly based on the empirical approach where some of the effects to the process are simplified or neglected. Although this may give reasonably good and in many cases acceptable results, a more comprehensive mathematical model based on differential equations of continuity, momentum and energy is applied here for analysis of the flow and heat transfer in such a device for better understanding of its process features. Using that, an effective procedure was developed for calculation of processes in rotary heat exchanger for optimisation of its parameters, which can be used either in research and development purposes or in the common industrial practice. An analysis based on such a mathematical model is applied in this paper to allow rotational speed to vary and quantify its influence upon heat transfer in the rotary air preheater to show hat optimal conditions exist for which the heat transferred passes through its maximum.
Keywords: heat transfer, rotary heat exchanger, optimal rotation speed

1. INTRODUCTION
A successful design and use of rotary heat exchangers requires a full appreciation of the fluid flow and heat transfer within these complex devices. The simple calculation of heat transfers between the hot combustion products and solid material on the one side and the cold air and solid body on another side, as described in [1] can be used to estimate the pre-heater performance sufficiently well, however, a more precise and accurate calculation must be used to determine precise influence of the input design and operation parameters upon the process. For this purpose more comprehensive models are required.

The goal of research activities, which part is described in this paper, was to enhance understanding of fluid flow and heat transfer in Ljungström rotary air preheaters that will contribute to improvement of total efficiency of an air pre-heater, and a steam boiler plant as a whole. The research was concerned with numerical and experimental characterization of air flow and flow of flue gases. Results of the investigation show that there exists optimal rotational speed for which the heat transfer has its highest value. This is then recommended for operation of the heat exchanger.

2. CALCULATION OF FLUID FLOW AND HEAT TRANSFER IN ROTARY PREHEATER

The one- and three- dimensional numerical models of heat transfers between the hot combustion products and solid material on the one side and the cold air and solid body on another side is used here to estimate the pre-heater performance. More details are given in [2], where the methods used and the applied numerical and experimental techniques were described and a full set of calculation and experimental results and their comparison were presented. One-dimensional two-fluid model consists of three energy balance equations, two for the gas phases and the other one for a solid body. The three-dimensional two fluid and one solid body model is described by a set of differential transport equations of continuity, momentum, energy. The space conservation equation, as well as the turbulence transport equations and equation of state complete the model. For more details, [3] may be consulted.

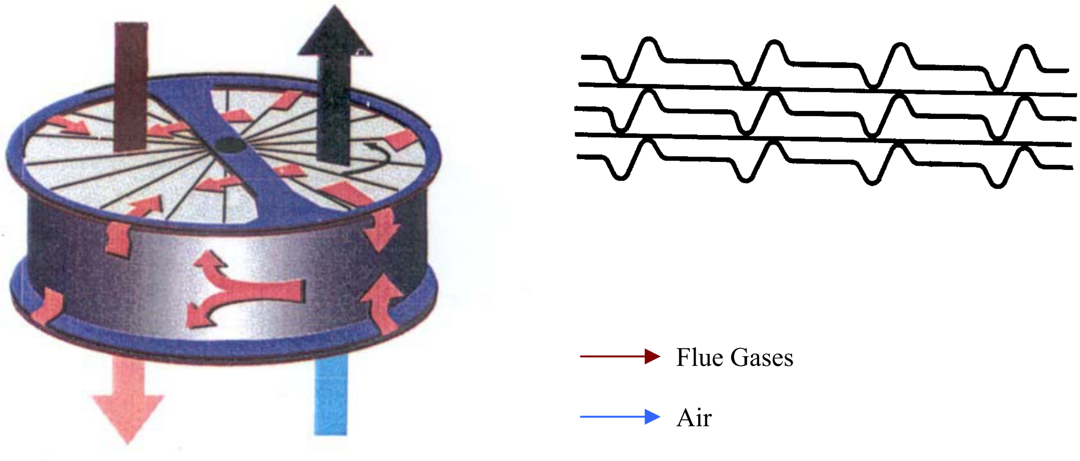

Figure 1. Ljungström air preheater, Left Schematic diagram, Top right Heat transfer surface

The result are obtained in the form of instantaneous temperatures of air and flue gases, instantaneous temperatures of solid and mass flow of the air and flue gases for each point along the axial coordinate. Both, the fluid flow and structural behaviour of the solid parts in a regenerative pre-heater are fully described by the mass averaged equations of continuity, momentum and energy conservation which are accompanied by equations of the turbulence model and state. This mathematical scheme is accompanied by the boundary conditions for both, the solid and fluid parts to comply with form presented in [3].

The geometry of the Ljungström rotary exchanger, as presented in Figure 1 is transformed to a sequence of finite volume elements forming the preheater numerical configuration which is then used for unsteady calculations of fluid flow and heat transfer. Spatial domain of the pre-heater is replaced by numerical grid that contains discrete volumes. A boundary fitted and confirmed numerical meshes are generated for each part of both, the fluid and solid parts like, for example in [4]. The grid generation method is implemented in a pre-processor program developed by authors in order to produce a numerical mesh suitable for analysis of a rotary regenerator and to incorporate it automatically into the existing finite volume software.

3. INFLUENCE OF ROTATION SPEED UPON THE PREHEATER PROCESS

In this paper a calculation is made of the heat transfer process within the rotary air preheater for variable heat load of 200, 170 and 140 MW at one speed of rotation, of1.76 rpm, Table 1 and for different rotational speed for one fixed unit power of 200 MW, Table 2. The rotary preheater serving boiler 5 of Unit IV in Tuzla Power Plant is used as object of investigation. A numerical solution was obtained for a variety of working conditions for some of which the experimental results exist. The calculation and experimental results show good agreement, Table 3.

Table 1. Calculation results for Ljungström aipreheater, Unit IV, TE Tuzla, 200 MW at 1.76 rpm for three different plant loads

Plant load (MW)	Temperature of flue gas (^oC)	Air temperature (^oC)
200	161.8	260,1
170	159,4	257,2
140	158,8	254,1

The analysis of the influence of rotation speed upon the preheater process may start with two extreme cases. In the case of extremely low speed of rotation, practicaly there is no rotor movement and the heat transfer will be minimal if not zero. The both flows will maintain the same inlet temperature along the complete height of the regenerator and it will be the same at the preheater outlet. Contrary , if the rotation speed is extremly high, time of the surface expoure to the each fluid flow will be too short to change significantly the metal filling temperature and it will stabilise at certain level, similar to the exit temperature of a parallel flow heat exchanger. Then, the outlet temperature of both fluids will tend to the filling temperature.

Table 2: Calculation results for Ljungström air preheater, Unit IV, TE Tuzla, 200 MW for different rotation speeds

Rotation speed (rpm)	*Temperature flue gas -(^oC)*	*Air temperature (^oC)*
1.0	164.5	254.3
1.76	161.8	260.1
2.2	158.4	265.3
2.6	155.6	267.5
3.0	153.4	269.4
5.0	159.5	264,3
10.0	170	254
100	190	235

Table 3: Comparison of calculation and experimental values for Ljungström aipreheater, Unit IV, TE Tuzla, 200 MW at 1.76 rpm

	Temperature of flue gas (^oC)	Air temperature (^oC)
Model	161.8	260.1
Experiment	166.9	260.0

The results of the calculation are presented in Figure 2 and 3 for varying speed of rotation, between 0.5 and 5 rpm and between 0.01 and 100 on the logarithmic scale. The speed domain between 0,50 and 2,00 rpm is analised in detail with a 0.25 step in order to estimate the optimum value precisely. The optimal speed of rotation, which gives the maximum heat exchange, appeared to be at about 3.00 rpm. It is estimated that optimal speed value of 3.00 rpm gives approximately 3.2 % more heat exchanged comparred to 1.76 rpm. Such an optimal speed of rotation which is almost doubled means savings in process which can be achieved with very low investment. Obviously, the outlet temperatures of air and flue gases depend on rotor rotation speed and will be at their maximum and minimum values respectively.

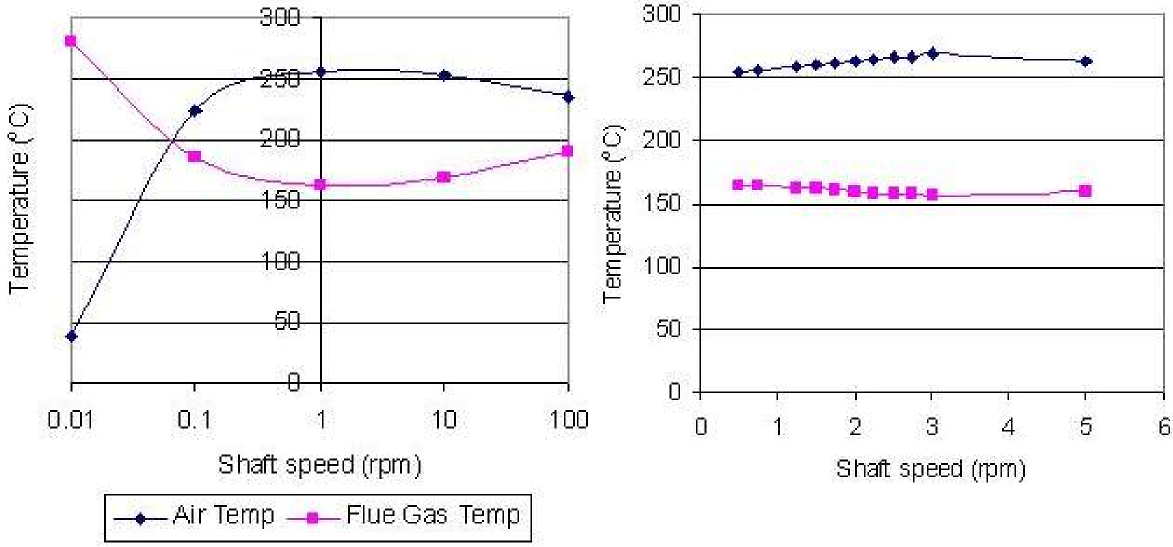

Figure 2. Outlet temperatures of air and flue gas for variable speed of rotation

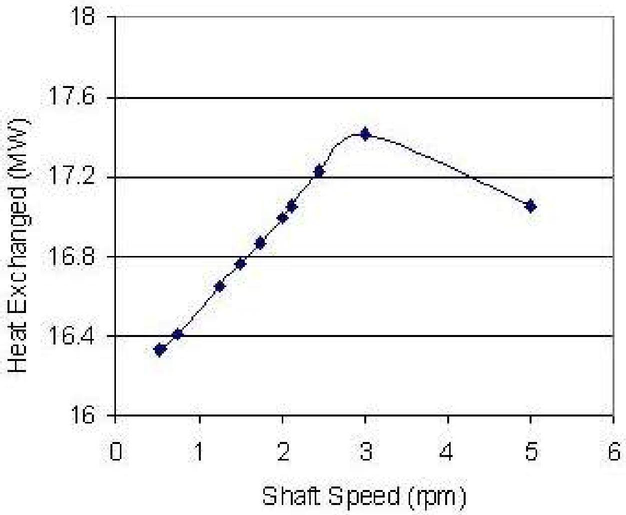

Figure 3. Heat exchanged at variable speed of rotation

4. CONCLUSION

On the basis of the analysis described in this paper it is concluded that efficency of the rotary regenerative exchangers pass through a maximum while the shaft speed varies. The most efficient heat transfer for the preheater in question was achieved at 3.00 rpm which is almost twice the current speed. Unfortunately, the increase of rotation speed enhances mixing of hot and cold fluids which would require additional studies before it is implemented.

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