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Analysis of the Energy Process of a Radiant Tube for Heating a Flat Material Using a CFD Model

Šimon Staško[1] ● Róbert Dzurňák[1] ● Ján Kizek[2] ● Peter Demeter[1] ● Augustín Varga[1] ● Gustáv Jablonský[1]

[1]Technical University of Košice, Faculty of Materials, Metallurgy and Recycling, Institute of Metallurgy, Letná 9, 042 00 Košice, Slovak Republic, simon.stasko@tuke.sk, robert.dzurnak@tuke.sk, peter.demeter@tuke.sk, augustin.varga@tuke.sk, gustav.jablonsky@tuke.sk
[2]Technical University of Košice, Faculty of Manufacturing Technologies with a seat in Prešov, Department of Process Technique, Bayerova 1, 080 01 Prešov, Slovak Republic, jan.kizek@tuke.sk

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Abstract : In Reducing energy consumption and increasing energy efficiency have long been very important issues affecting all sectors of energy consumption, including the industrial sector. Industrial furnaces have a significant energy consumption that needs to be optimised, but before that an analysis of the energy situation is necessary. This article discusses the energy state analysis of a burner system, which was performed using CFD model. Specifically, the analysis of the combustion process in a radiant tube, for which a 3D model of this tube was created. The analysis also addressed the subsequent heat transfer from the surface of the radiant tube in the power range of 50-109 kW. Input parameters and model conditions were defined based on the parameters of the real burner system. The CFD modelling performed showed that as the fuel consumption increased, the radiant tube power increased and at the same time the flue gas temperature also increased. The heat flux from the tube surface was slightly different on both sides of the tube, which was due to the flame tilt inside the radiant tube.

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1 Introduction

Burners are technological devices that are used for combustion processes in devices such as boilers or industrial furnaces. In a burner, the incoming fuel is mixed with the combustion air and then the combustion of this mixture takes place, releasing the energy stored in the fuel. These process devices are required to be stable in the combustion process or reliable in the combustion of the fuel [1,2].

Burners can be classified according to several aspects, for example [3,4]:

- by type of combusted fuel,
- by the method of mixing the fuel with air,
- by length of flame,
- by application,
- by burner pressure,
- by burner construction.

Depending on the individual aspects, the way in which the fuel is combusted in the burner is different. These aspects also influence the temperature distribution in the working space of the furnace in which the burner is located. They also affect the way in which heat is transferred from the burner to the material to be heated and also the composition of the flue gases. Radiant burners are one of the types of burners used [4].

Radiant burners are characterised by the transfer of heat by radiation. As the fuel burns, the surface of the burner is heated, and this surface then transfers heat to its surroundings. The surface temperature of this type of burner can vary, for example, depending on the amount of fuel burnt [1,5].

Radiant tubes are one type of radiant burner. This type of radiant burner is used in cases where it is not technologically acceptable for the flue gases from the burner to come into contact with the heated material. Inside the radiant tube, the combustion process takes place and the heat released by the combustion of the fuel heats the walls of the tube, the surface of which can reach temperatures of up to 1200°C. The heat is then transferred from the surface of the radiant tube to the furnace space, thereby heating the material or the insert and the furnace walls. This description of the heat transfer of the radiant tubes is written in the Table 1 [6].

Table 1 Description of heat transfer in the furnace [7]

Heat transfer between			Method of heat transfer
the flue gases in the radiant tube	and	the wall of the tube	by radiation
			by convection
radiant tubes	and	heated material	by radiation
radiant tubes	and	furnace walls	by radiation

Such indirect heating usually takes place in the presence of a protective atmosphere which, for example, protects the heated material from oxidation. This protective atmosphere is also heated from the burner surface [8].

The heat flux density of radiant tubes is in the range of 20-50 kW.m^{-2} and their thermal efficiency is in the range of 0.5-0.6. If a recuperator is used, part of the heat energy of the outgoing flue gases is used to heat the combustion air fed to the burner, thereby increasing the thermal efficiency of the radiant tubes to 0.65-0.8 [4].

The radiant tubes can be made of chromium or chromium-nickel rolled steel, for example in a ratio of 20% Cr and 80% Ni, or also of ceramic material. These tubes can be made in several shapes, 3 of which are shown in the Figure 1 [4].

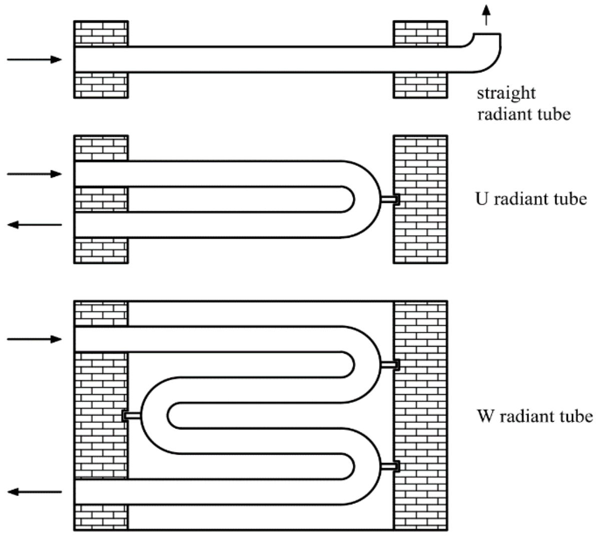

Figure 1 Types of radiant tubes [9]

One of the applications of radiant tubes is the heating of material in heat treatment, such as the heating of a steel strip in continuous annealing lines. The Figure 2 shows the heating of a steel strip in a continuous annealing line in two views [7,10].

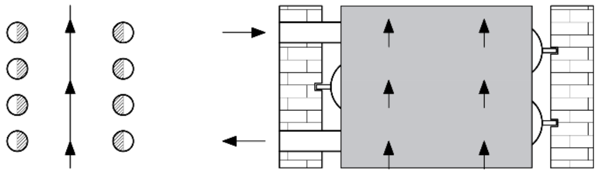

Figure 2 Heating the steel strip with a radiant tube

2 Materials and methods

Under the conditions of the research presented in this article, a 3D model of a W-type radiant tube was created, which is shown in Figure 3.

Figure 3 The 3D model of a W-type radiant tube

The Figure 4 shows the geometry of the inlet of the radiant tube.

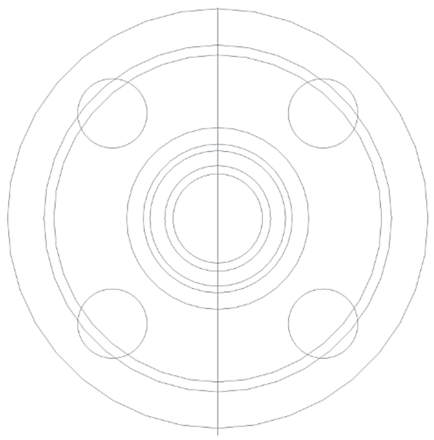

Figure 4 Radiant tube inlet geometry

Dimensions of the radiant tube:

- tube diameter = 12.7 cm,
- gas nozzle diameter = 2.7 cm,
- air nozzle diameter = 2.1 cm,
- number of air nozzles = 4.

2.1 CFD model conditions

The radiant tube in the modelling conditions was positioned parallel to the heated flat material, which was positioned on two sides of the tube, as shown in the Figure 5.

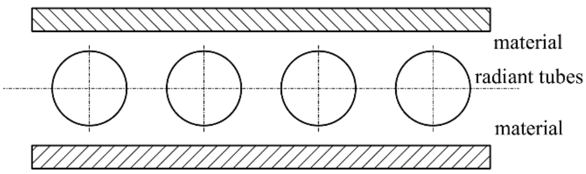

Figure 5 Positioning the radiant tube between the heated material

The input conditions and model parameters were based on the parameters of the actual radiant tube and the results of the heat balance.

Fuel:

- pure methane,
- fuel temperature = 20°C.

Combustion air:

- calculation using combustion stoichiometry,
- temperature of combustion air supply to the radiant tube = 170°C,
- excess combustion air = 1.06,
- volumetric amount of oxygen in the combustion air = 21%.

Heated material:

- it is a long flat material,
- material temperature = 750°C,
- material emissivity = 0.86.

CFD modelling was performed at radiant tube powers in the range 50-109 kW.

3 Results and discussion

The created CFD model was used to obtain information about the heating and heat transfer from the surface of the radiant tube.

The model results show that as the fuel consumption increased, the power of the radiant tube also increased. This dependence of radiant tube power and fuel consumption is shown in the Figure 6.

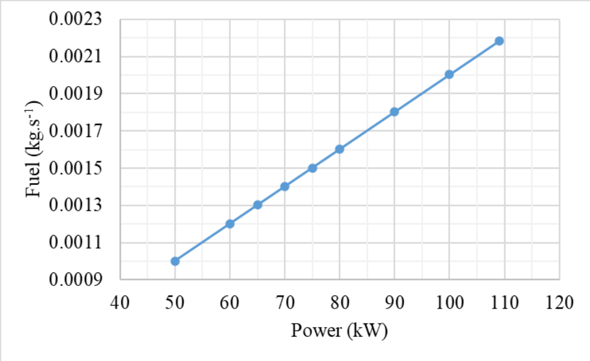

Figure 6 Dependence of radiant tube power and fuel consumption

The Figure 7 shows the dependence of the flue gas temperature at the outlet of the radiant tube and the power, while the temperature at the outlet of the radiant tube increases with increasing power of the radiant tube.

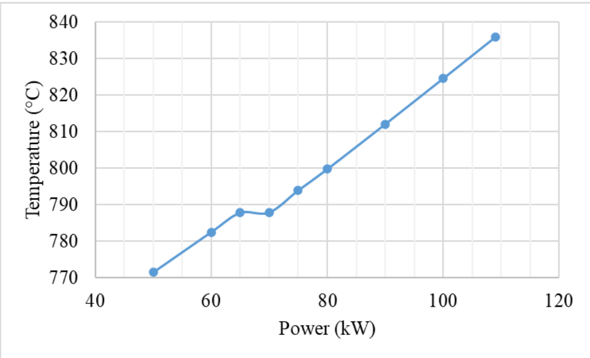

Figure 7 Dependence of flue gas temperature at the outlet of the radiant tube and power

Due to the fact that 1 radiant tube heats 2 materials at the same time, it was necessary to divide the tubes along the axis into 2 sides, which are marked with letters a-b, as shown in the Figure 8.

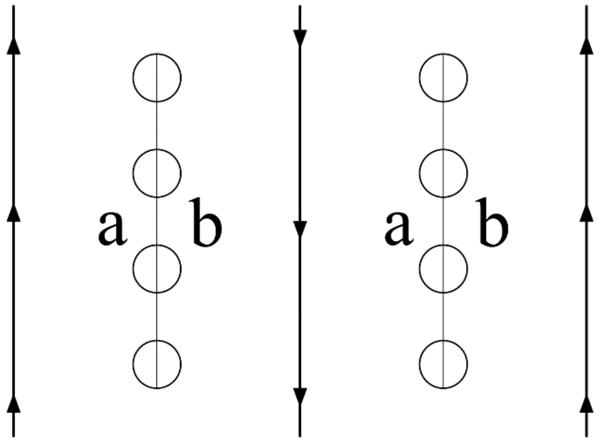

Figure 8 Division of the sides of the radiant tube

The heat exchange surface of one side of the radiant tube, or half of the tube, is 0.32856 m^2. The Figure 9 shows a 3D model of the half of the radiant tube, with the location of the largest heat flux or heat loss marked in blue.

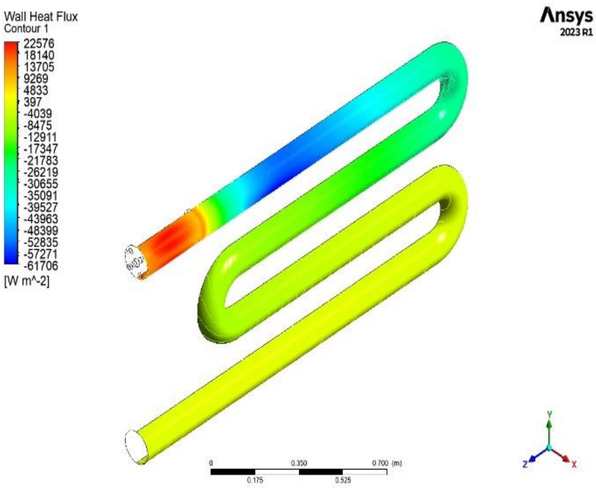

Figure 9 The 3D model of half of a radiant tube

The Figure 10 shows the dependence of the average value of the heat flux on the surface of the radiant tube and the power, this figure also contains the regression equation.

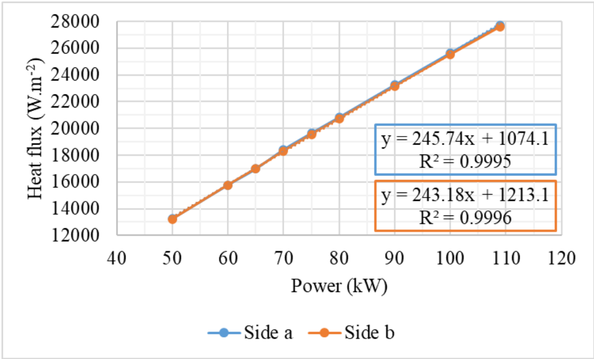

Figure 10 Dependence of the average value of the heat flux on the surface of the radiant tube and the power

The CFD model results showed that the heat flux on sides a - b was slightly different, and these differences in heat flux on sides a-b were due to the tilted flame in the radiant tube.

The Figure 11 shows a schematic of the radiant tube from CFD modelling at a power of 50 kW.

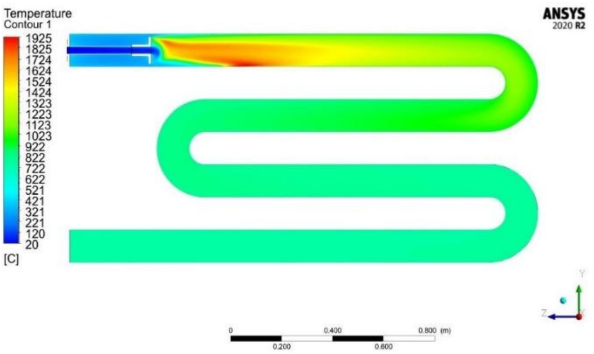

Figure 10 Schematic of the radiant tube at 50 kW

The Figure 12 shows a schematic of the radiant tube from CFD modelling at a power of 109 kW.

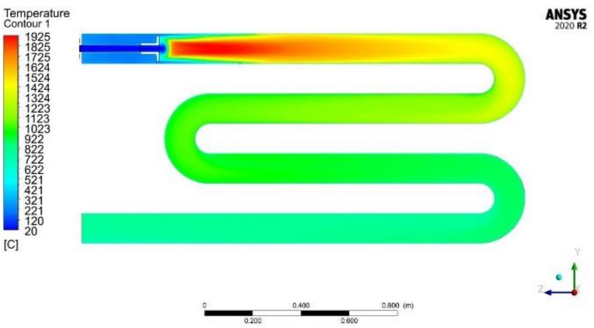

Figure 11 Schematic of the radiant tube at 109 kW

It can be seen from Figures 11 and 12 that at lower power the flame in the radiant tube is downwards and, conversely, at the maximum power of 109 kW the flame is located in the centre of the tube.

4 Conclusion

Energy status analysis is an important step in achieving energy efficiency. In this paper, an analysis of the combustion process occurring in radiant tubes has been performed using CFD modelling. The input parameters and model conditions were based on parameters from a real burner system. A 3D model of the radiant tube was created and modelled at power outputs of 50-109 kW. The power variations were performed by adjusting the fuel consumption. This model showed the temperature field distribution on the tube surface and also the heat flux from the radiant tube surface. The results showed the influence of the radiant tube power on the flue gas temperature and a slight difference of the heat flux on the two sides of the tube was found. The results also include the heat flux regression equation and the effect of radiant tube power on the flame tilt in the tube.

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