Comparison of Heat Transfer Power of the Cooling Panel with Square Cross Section and Circular Cross Section in Electric Arc Furnaces Steel-making by the Use of Computational Fluid Dynamics

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Abstract

Steel pipes with circular cross-sections are usually used in cooling panels of electric arc furnaces. In the present study pipes with square cross-sections under equivalent conditions were used to obtain more information on the possibility of increasing the heat transfer and cooling efficiency. The results showed increased efficiency of the square pipe compared to the circular cross-section pipes. This increase led to an increase in the cooling power and life expectancy under similar conditions. The fluid flow field and heat transfer were obtained using simulation. A comparison of the heat transfer and the energy of the circular and square cross-sections showed that the square cross-sections had a higher rate of heat transfer and work efficiency.

Keywords: Pipe; Arc furnace; Radiator; Computational fluid dynamics.

1. Introduction

Most steel productions employ electric arc furnaces and this method of steelmaking is increasing. Despite its vast application, about 70% of electrical energy consumed for steel production is used by the electric arc furnaces, which shows the importance of decreasing the energy consumption in these furnaces. However with the establishment of small steelmaking units the use of electric arc furnaces has been increased in the steel industry. Furthermore in the recent years the production expenses have been decreased considerably and the yield of steel has been increased, allowing electric arc furnaces to continue being an important method of steel production. Although the production expenses still needs to be decreased [1)].

Cooling panels used in the water cooling systems are the major component of electric arc furnaces and installed in the vessels and the ceiling of the furnaces [2)]. The panels transfer the heat surrounding the furnace by means of water flow through the panels. Since the water cooling panels of electric arc furnaces are exposed to considerable thermal, mechanical, and chemical stresses, they tend to crack and leak easily [3)]. A main concern of the designers and manufacturers of water cooling systems for electric arc furnaces is to achieve the maximum efficiency for the panels. Increasing the useful life and efficiency of the cooling panels decreases the repairing time and the time needed for exchanging parts, therefore it increases the tonnage of productive fusion, saves time and expense and the cost of producing expensive new panels [4)]. Extensive research has been already carried out to determine the factors affecting the efficiency of the panels in laboratory and in electric arc furnaces [5)].

Steel pipes with circular cross-sections are generally used in panels to cool electric arc furnaces. These pipes are produced worldwide. The quality of the raw materials used to make the panels, their design, arrangement of the panels (water inlet and outlet, fittings and the height of the structures), thickness and the diameter of the pipes, water hardness and impurities present in the water, speed and the input rate of the water are factors which effect on the efficiency and lifetime of the panels.

In the present study for the first time, cooling pipes with square cross-sections have been invented and compared the heat transfer, in cooling pipes with square and circular cross-sections under similar con-

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ditions. For this reason the described system was modeled using computational fluid dynamics. The simulation results showed that the heat transfer in a square shaped pipe is greater than in circular pipes under similar operating conditions. This increased the efficiency of the square pipe and its cooling capacity compared to that of the circular pipes. The simulation results were compared with empirical measurements and the computational model was validated.

2. Research Method

2. 1. Physical model

Fig. 1 shows the geometry of the cooling panels with circular and square cross-sections. The pipes in the cooling panel were manufactured using an ST 45.8 steel. Analysis of the ST 45.8 steel has been described by the DIN [6] standard and its mechanical properties are as Table 1 and Table 2:

2. 2. Initial conditions

The following assumptions were considered for modeling the heat transfer in the cooling panels of an electric arc furnace:

1- The flow of the fluid inside the pipes is unstable.
2- The type and composition of the used materials are similar to both circular and square cross-sections.
3- The thickness of both pipes is equal to 11 mm.
4- The cross-section area of both pipes is the same.
5- The working conditions of both types of pipes are the same.
6- The rate of the input water was fixed at 20 $\frac{m^3}{h}$.
7- The input water has a temperature of about 15 ºC.

2. 3. Governing equations

In order to predict the heat transfer of water circulation panels during cooling, the following governing

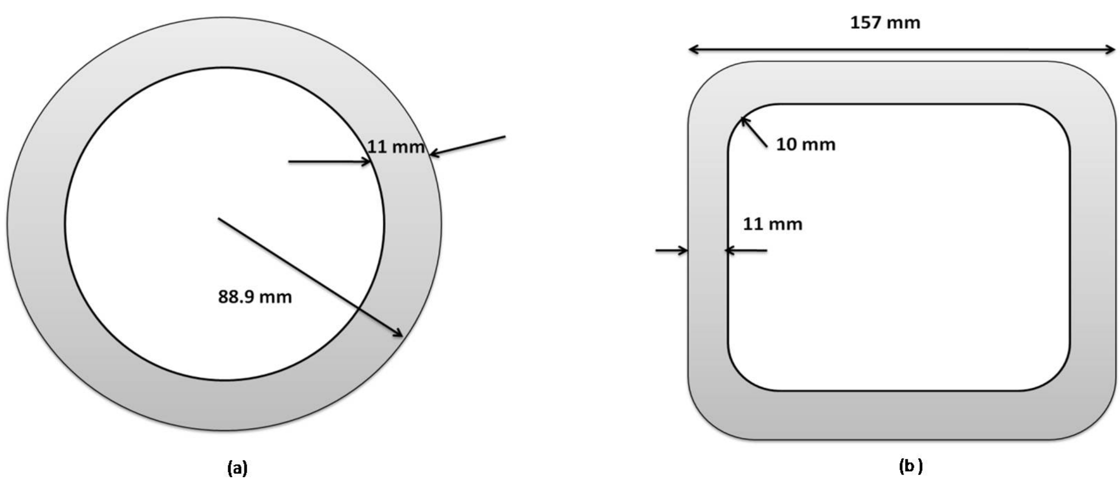

Fig. 1. Geometry of the cooling pipe: (a) circular cross-section; (b) square cross-section.

Table 1. Chemical analysis of the pipes [4].

Steel grades	wt. % (max)				
	C	Si	Mn	P	S
St45.8	0.21	0.10-0.35	0.40-1.20	0.040	0.040

Table 2. Mechanical properties of the pipes for elevated temperatures tested in room.

Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	*Hardness (HB)*
410-530	≥255	21	130-165

equation was used:

$$\frac{\partial(\rho c_p T)}{\partial t}+\frac{\partial(\rho u_x c_p T)}{\partial x}+\frac{\partial(\rho u_y c_p T)}{\partial y}+\frac{\partial(\rho u_z c_p T)}{\partial z}=$$
$$\left(\frac{\partial^2(k_{eff}T)}{\partial x^2}+\frac{\partial^2(k_{eff}T)}{\partial y^2}+\frac{\partial^2(k_{eff}T)}{\partial z^2}\right)+\dot{q}(x,y,z)$$

Eq. (1)

In Eq. (1), $k_{eff}=\frac{C_p\mu_t}{Pr_t}$ (heat conduction coefficient), Pr_t, μ_t and $\dot{q}$ are turbulent Prandtl number, turbulent viscosity and source term respectively.

The physical properties of the rod are a non-linear function of temperature and represents by the following equations [4)]:

$$k=1.1197\times10^{-7}T^3-0.0001365T^2+0.028133T+41.14$$

Eq. (2)

$$c_p=-5\times10^{-5}5T^2+0.2575T+429.47$$

Eq. (3)

2. 4. Boundary Conditions

The cooling panels were situated next to the fused steel making slag at constant temperature of 1620 ºC. The following equations are considered:

$$h_{total}=\bar{h}\left(\frac{\bar{h}}{h_{total}}\right)^{\frac{1}{3}}+h_r$$

Eq. (4)

In Eq. (4) h_{total} is the total heat transfer coefficient and $\bar{h}$ is the heat transfer coefficient with neglecting radiation and heat transfer coefficient of radiation. h_r, is:

$$h_r=\frac{\sigma_{SB}\,\varepsilon\left(T_w^{\;4}-T_s^{\;4}\right)}{\left(T_w-T_s\right)}$$

Eq. (5)

In Eq. (5) σ_{SB} and ε are Stefan-Boltzman constant and emissivity coefficient respectively.

Equations (1) was discretized with a finite volume method (FVM) in a 2D cylindrical coordination. A first order upwind differencing implicit approach is used and the discretized equations, have been solved with TDMA algorithm in an iteration method. The program was solved by Fluent V12 software.

3. Results and Discussion

3. 1. Computational model validation

The temperature of the input water was maintained at 15, 20, 25, and 30 °C and the output water exiting the cooling panel was measured and recorded to validate the computational model. The temperatures recorded for the output water using experimental measurements were compared with the results of the computational model. Fig. 2 shows the results of the output water temperature from the experimental measurement and the computational model. The figure indicates that there was satisfactory agreement between the results of the experimental measurement and the modeling results.

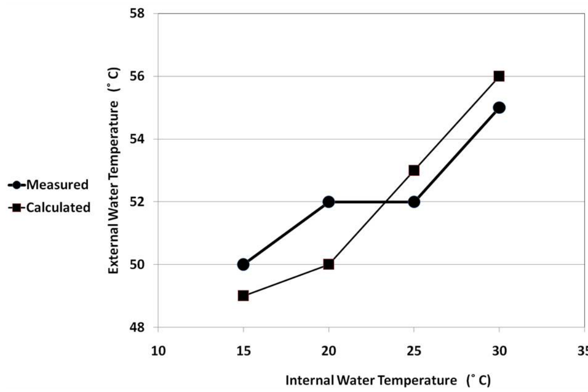

Fig. 2. Comparison of the output water temperature results obtained by experimental measurement and the computational model.

3. 2. Comparison of the temperature in circular and square pipes

Fig. 3 shows the heat transfer results obtained from the computational model for the two types of panels after 10, 20, and 35 s. At 35 s the conditions have stabilized and no further change was observed.

The thermal contours in Fig. 3 indicate that the water inside the square shaped pipe has warmed more quickly compared to the circular pipe. For example as shown in Fig. 3 after 25 s the temperature of the water inside the circular shaped pipe has increased to about 35 °C while at some parts of the square shaped pipe the temperature has reached about 42 °C. The temperature of the surface of the circular shaped pipe reached about 100 °C whereas for the square shaped pipe the temperatures were less than 100 °C except at the corners which were around 100 °C.

Fig. 3(e) shows that the temperature of the water inside the circular pipe was less than 40 °C at most parts, except those close to the surface of the water. The temperature at the surface reached about 100° after 35 s. The temperature of the water in the square shaped pipe exceeded 45 °C at most parts after 35 s and the temperature at the surface was less than 100 °C.

It is evident that the square shaped pipe offers a greater heat transfer compared to the circular shaped pipe when the quality and size of the cross- sections and the rate of water inside the pipes were held constant. Fig. 4 demonstrates that the heat transfer in the square shaped cross-sections were greater than the circular cross-sections under constant conditions; it transmits more energy in less time and is more efficient.

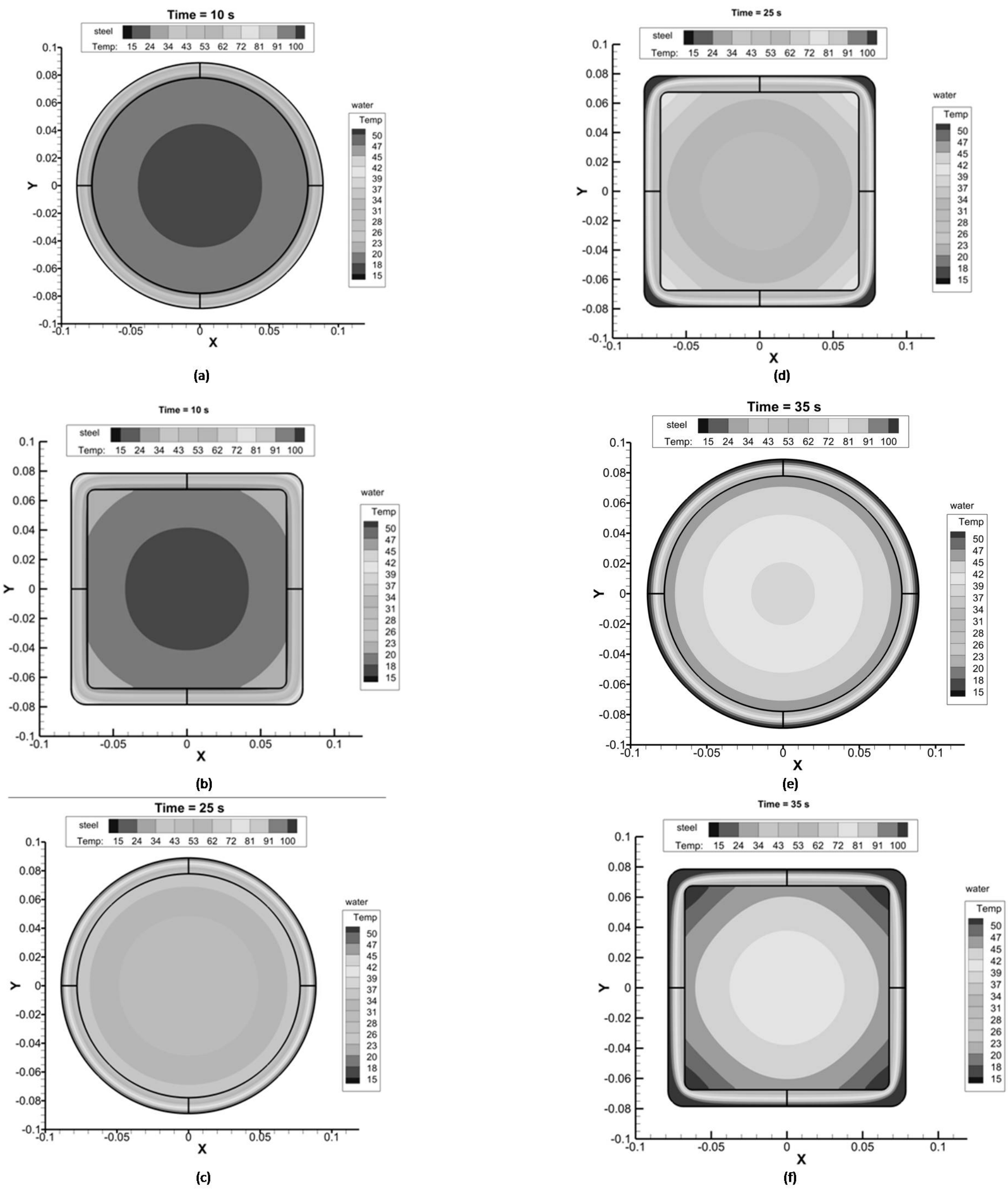

Fig. 3. Temperature contours: (a) and (b) 10 s, (c) and (d) 25 s, (e) and (f) 35 s.

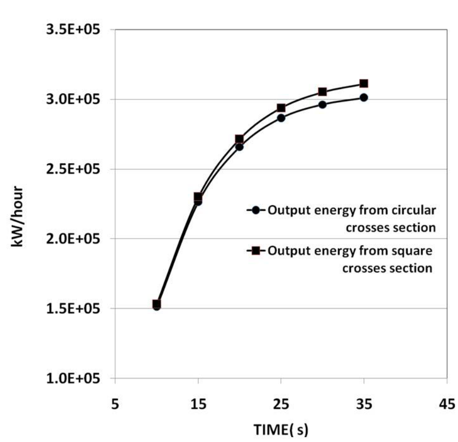

Fig. 4.Transfer energy variation of the different pipes versus time.

4. Conclusion Remarks

- A cooling panel system was modeled using computational fluid dynamics
- The simulation results showed that the heat transfer in a square shaped pipe is greater than in circular pipes under similar operating conditions.
- The temperature of the surface of the circular shaped pipe is more than square shaped.
- The square shaped pipe transmits more energy in less time and is more efficient compared to circular shaped pipe.
- Due to above results, the square shaped pipe has more lifetime and efficiency related to pipes under similar operating conditions.

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