COOLING WATER INFLUENCE IN TEMPERATURE PROFILE OF CONTINUOUS CASTING MOLD

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Abstract. One of the most important process parameters in the determination of the final quality of the steel is its superheat degree in the mold. Thus, the cooling of the mold becomes a relevant factor in the process of continuous casting. The thermal resistance in the mold-metal interface influences the heat transfer in the mold substantially. This interfacial thermal resistance increases with the increase of the thickness of the film of the melt, during the casting process. This resistance is a result of a combined flow of convection and radiation. In the external mold surface is important the control of the cooling water flow, because, a not uniform heat transfer in metallic mold affects the production process and the quality of the final product. This work analyzes the effect of the water-cooling flow in temperature profile of continuous casting mold. With the results it's possible to control the cooling water flow to obtain improvement in the superficial quality during the continuous casting process.

Keys words: Continuous casting, thermal resistance, mold temperature profile.

1. Introduction

The problems of superficial quality in the continuous casting of steel are quite affected for the heat transfer through the layer interfacial in the air gap between the solidification of the film of steel and the metallic mold. In the process of continuous casting of steel the heat transfer among the liquid steel in solidification and the metallic mold, in front of solidification, has an important paper in the formation of superficial cracks in the final product, affecting the evolution of the solidification. The thermal resistance in the interface between the film of the metal and the mold influences the mechanism of heat transfer substantially. This interfacial thermal resistance increases with the increase of the thickness of the film of the metal, during the casting process, resistance this, associated to a combined flow of convection and radiation (Cho, et al., 1998). For Cho and Shibata (2001) the interfacial resistance thermal acts more than fifty percent of the global thermal resistance for the transfer of close heat of the position of the meniscus in the mold.

During steel solidification in the continuous casting the resistance to the heat transfer in the metal-mold interface depends on many factors, such as, contact pressure, oxides in the surface, rugosity of the surface, material coating, coating thickness, top surface turbulence (Kim and Lee, 1997; Santos, et al., 2001). Another important factor is the air gap development between copper mold and change phase material, due to deform solidification and crystallization of the metal (Cho and Shibata, 2001). In accordance with Stone and Thomas (1999) one of the functions more critics in heat flux mold is the heat transfer control through this interfacial gap. Liquid mold flux enters this gap at the meniscus intermittently during each oscillation cycle. It solidifies in the cold side of the gap into layers that may contain either crystalline or glassy phases, depending on the composition and local cooling history. These flux layers govern heat transfer across the gap, Fig. 1. The final surface of the product is created during the initial stage of steel solidification against the water-cooled copper mold at the meniscus. In the external mold surface is important the control of the cooling water flow that affects the heat transfer coefficient directly.

In the interface metal-mold is put a powder that serves as lubricant and it avoid the metal sticking in mold. He also controls the heat conduction rate through the interfacial gap, Fig. 1. In accordance with Stone and Thomas (1999) the mold flux is added as a powder to the top surface, where it insulates the molten steel from both heat losses and atmosphere contamination. The powder sinters and melts to form a layer of liquid that floats on the surface of molten steel.

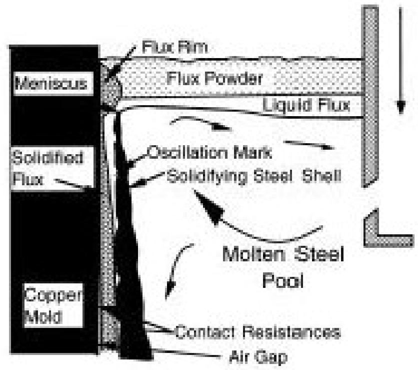


Figure 1. Scheme of the process of continuous casting showing the layers in the interface mold-metal.
Source: Stone and Thomas, 1999.

The literature contains a great number of works presenting analytical models and experimental studies (Huespe et al., 2000; Martorano and Capocchi, 2000). However, to contemplate the whole process is necessary include more complex factors, as the thermal interaction in interface mold-metal, becoming the numeric analysis an indispensable tool (Krishnan and Sharma, 1996; Huespe et al., 2000).

This work presents a numeric study of the heat transfer in the metallic mold accounting the external convection with the cooling water and the thermal interaction with the metal-air gap. It is studied the water-cooling flow influence in temperature profile of mold. With the results it can, besides optimizing the consumption cooling water, to obtain improvement in the superficial quality of the steel during the process of continuous casting, because, a not uniform heat transfer in metallic mold affects the production process and the quality of the final product.

2. Methodology

In this work it is studied the temperature profile in the wall of the mold of a process of continuous casting, Fig. 2, being observed the influence of the control of the cooling of the mold in its external surface.

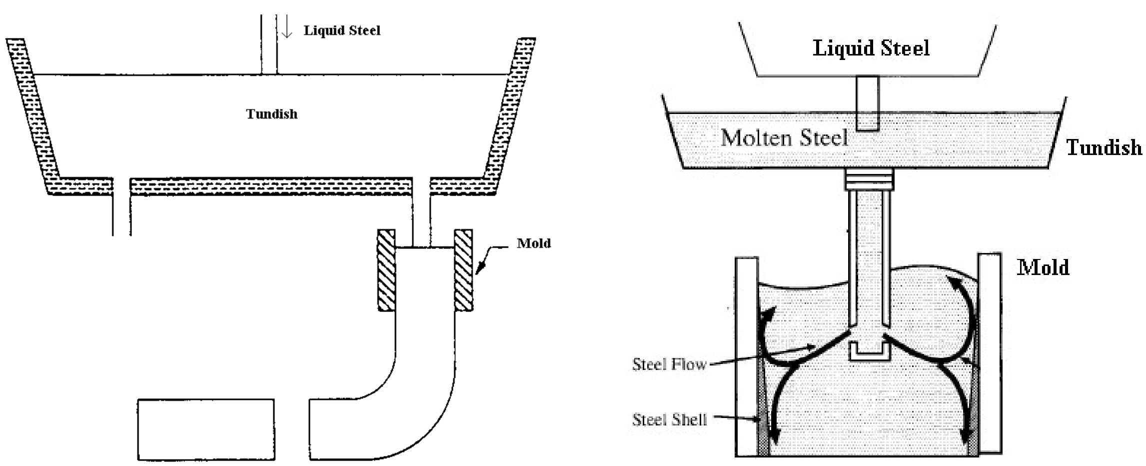


Figure 2. Scheme of the process of continuous casting.

2.1. Formulation of the model for the heat transfer in the mold

The mold is considered as a duct of square section, Fig. 3. The bottom and top surfaces of the mold are insulated, Fig. 3. Besides these surfaces it is also had part of the internal surface of the mold, in the top, with the condition of null flow. The initial condition is of uniform and same temperature the 25 ^{0}C.

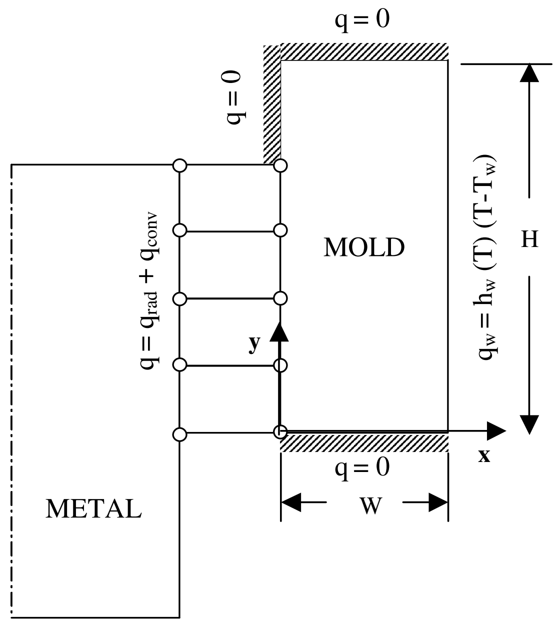


Figure 3. Coordinates system and boundary conditions in the mold.

The transport problem, in the wall of the mold, is two-dimensional and in transient regime, as the resultant equation shown in the Eq. (1),

$$\frac{\partial}{\partial x}\left(\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\partial T}{\partial y}\right)=\frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{1}$$

with the auxiliary conditions as shown in the Fig. 4. In the external surface of the mold, in x = L, is had, as in Eq. (2),

$$-k_m\left(\frac{\partial T(x,t)}{\partial x}\right)_{x=L}=h_e(T)[T(L,t)-T_e] \tag{2}$$

where h_e, the external convective coefficient, it can be evaluated by the relationship presented in the Eq. (3),

$$h_e(T)=\frac{k_f(T)}{D_H}\left[0.023\,\mathrm{Re}^{0.25}\,\mathrm{Pr}^{0.4}\right] \tag{3}$$

and the boundary condition in the internal surface of the mold, it takes into account the change of heat for radiation, with the surface of the metal plus the change of heat for convection, through the air gap formed between surface of the mold and the metal, Eq. (4),

$$(h_i(T)+h_c(T))[T_i(t)-T(0,t)]=-k_m\left(\frac{\partial T(x,t)}{\partial x}\right)_{x=0} \tag{4}$$

The coefficient h_i represents the coefficient associated to the process of change of heat for existent radiation among the surface of the metal that is formed along the casting process and the surface of the mold through the air gap that is formed and it can be given by the relationship shown in the Eq. (5),

$$h_i(T)=\varepsilon\sigma[T_i(t)+T(0,t)]\left[T_i(t)^2+T(0,t)^2\right] \tag{5}$$

The coefficient h_c represents the coefficient associated to the process of change of heat for convection through the air gap that is formed between the metal and the mold and it can be given by the relationship, Eq. (6),

$$h_c(T) = \frac{k_g(T)}{l_g} \tag{6}$$

where k_g is the thermal conductivity of the gas and l_g is the thickness of the air gap.

2.2. Numeric approach

The method of finite differences is used for description the resulting equation, Eq. (1). A semi-implicit scheme is adopted in temporal evaluation with a non-uniform 50x100 grid. As the boundary condition besides the gas and water are temperature dependent of respective mold walls, it becomes necessary an iterative procedure in its calculation. The convergence solution is reached when the residue of the equation description goes smaller than 10^{-6}.

3. Case studies

A mold can be modeled as a duct with 190 mm width and 1 m height. The mold copper wall thickness has 12 mm and is covered by a chrome layer of 0,12 mm. The cooling water flow considered here, varies of 135 l/min to 450 l/min, with entrance and exit temperatures of 25 ^{0}C and 35 ^{0}C, respectively. The channel thickness of cooling water has 3,25 mm. A linear profile is admitted for the temperature of the cooling water flow. The medium thickness of the air gap is considered to be of 25 μm.

Figure 4 shows the evolution of global Nusselt number with the water-cooling flow (Nu_este). When the water-cooling flow increases, the heat transfer coefficient, h_w increases too.

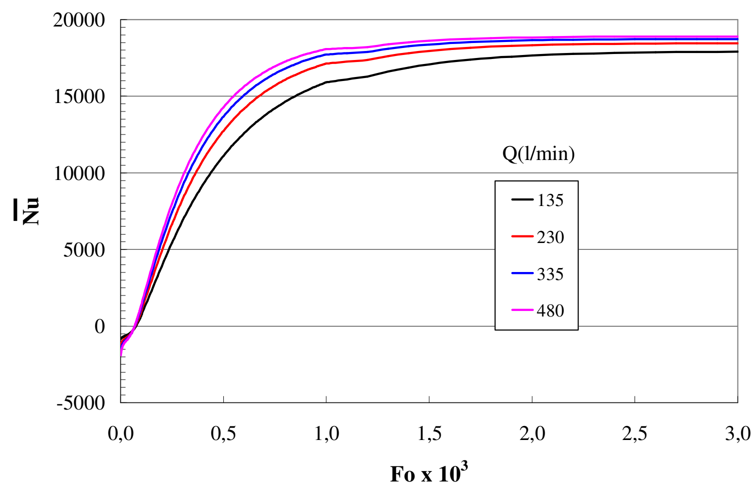


Figure 4. Global Nusselt x Fourier in function of the water cooling flow in external surface

here, the global Nusselt and Fourier numbers are defined as:

$$\overline{Nu} = \frac{1}{A}\int \frac{hH}{k}\,dA \tag{7}$$

$$Fo = \frac{t\alpha}{H^2} \tag{8}$$

The global Nusselt number in mold-water interface increases with your increase, more strongly during the transient regime than in steady state. This happens in function of the high existent temperature gradients in the beginning of the leak of the metal.

In Fig. 5 the evolution of global Nusselt number with mold-air gap (Nu_west) it is shown. The results reveal that this increase does not change strongly, in the first time steps, this fact making believe that influence of the cooling water flow is not predominant in the formation of the final surface of the product.

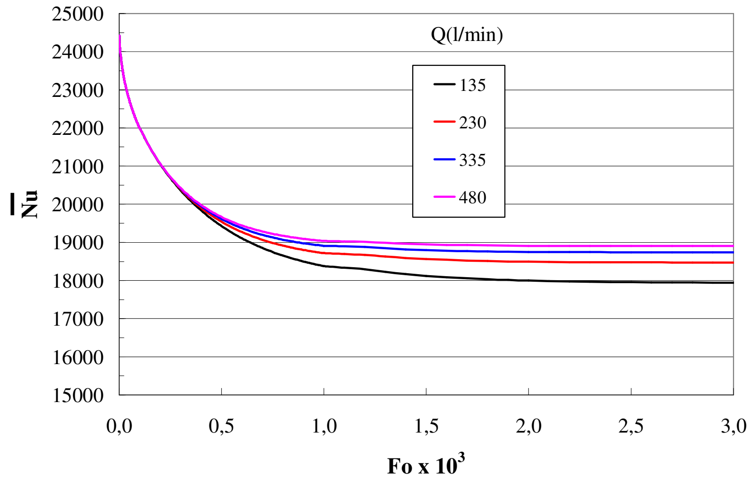


Figure 5. Global Nusselt x Fourier in function of the water cooling flow in internal surface

Now it is shown the results being considered the cooling water flow have value equal to 230 l/min. Figure 6 shows, qualitatively, isotherms for an area close to the top mold surface, illustrating the insulated boundary condition.

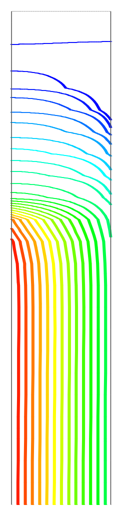
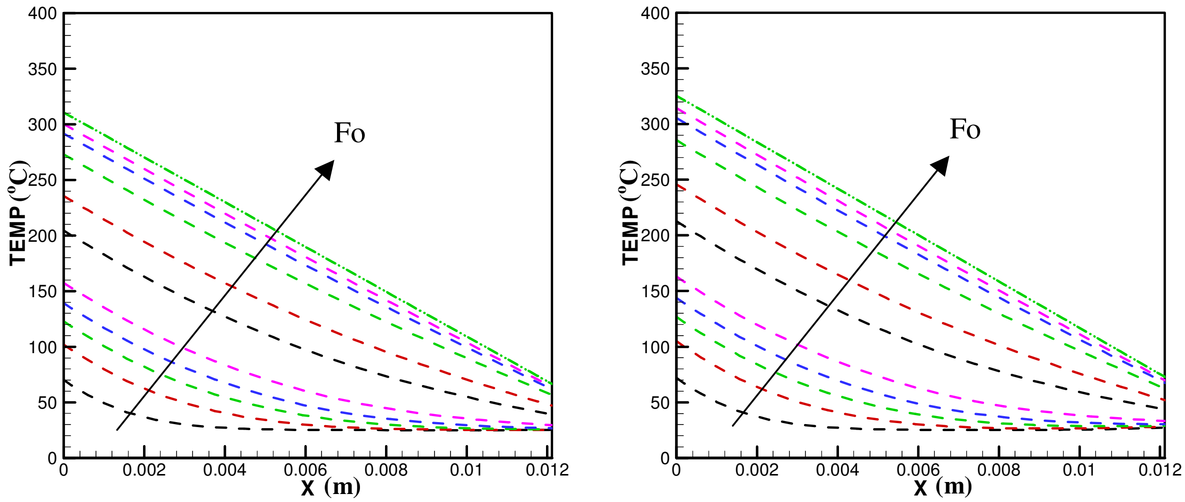


Figure 6. Isotherm – in the surface close of the top.

Figures 7, 8, 9 and 10 show the evolution of the temperature, to cooling-water flow equal a 230 l/min, in the mold with increase of the number of Fourier. In these figures, the dimensionless instants (Fourier) shown are $1x10^{-5}$, $3x10^{-5}$, $5x10^{-5}$, $7x10^{-5}$, $1x10^{-4}$, $2x10^{-4}$, $3x10^{-4}$, $5x10^{-4}$, $7x10^{-4}$, $1x10^{-3}$, $3x10^{-3}$, and $5x10^{-3}$.



(a) In the base of the mold.

(b) In the center of the mold.

Figure 7. Temperature profile in the mold.

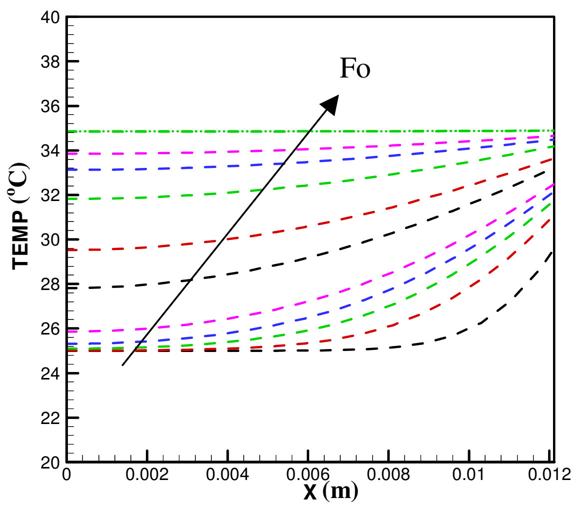
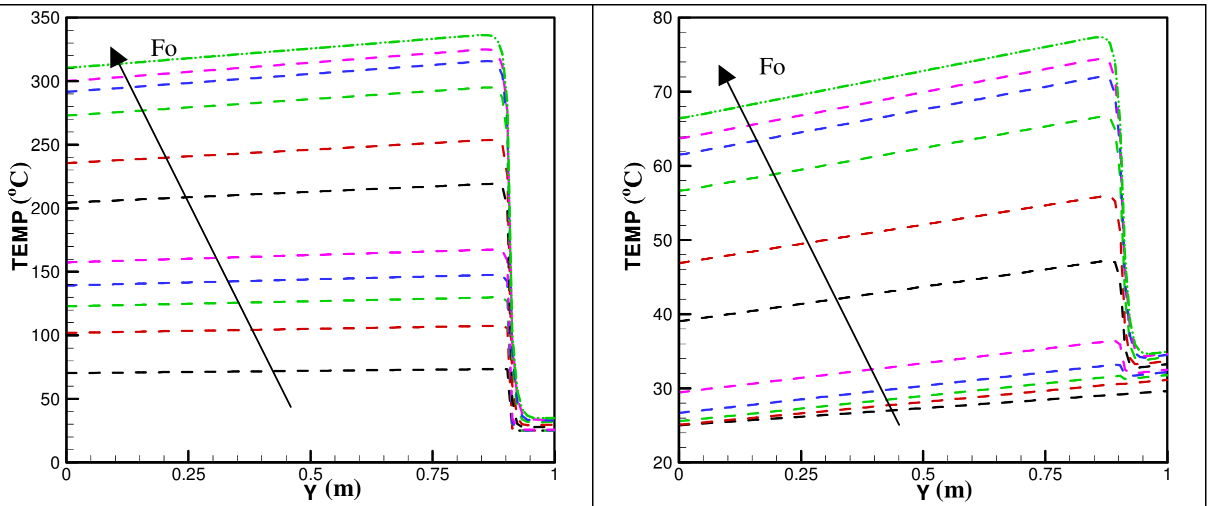


Figure 8. Temperature profile in the top of the mold.

It is observed in the presented curves, in the Fig. 7 e 8, an accentuated gradient of the temperature, close of the top of the surface, in function of the insulated condition. The temperature profile in the mold is characterized by a lineal profile in the steady state regime.



(a) In the interface mold-air gap

(b) In the interface mold-cooling water

Figure 9. Temperature profile in the mold.

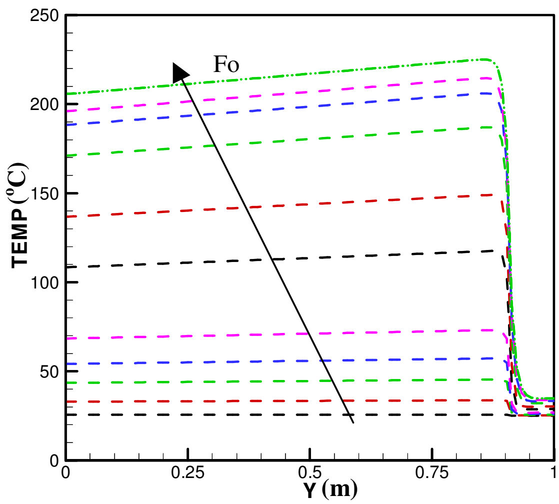


Figure 10. Temperature profile in the center of the wall of the mold.

In the Fig. 11 the evolution of the number of global Nusselt is shown, Eq. (7), in the two surfaces of the wall of the mold, with the objective of characterizing the convective coefficient, in the side in contact with the water of cooling and the combined coefficient of radiation and convection in the side of the interface with the metal. For numbers of Fourier above 3 x 10^{-3} the solution tends to steady state.

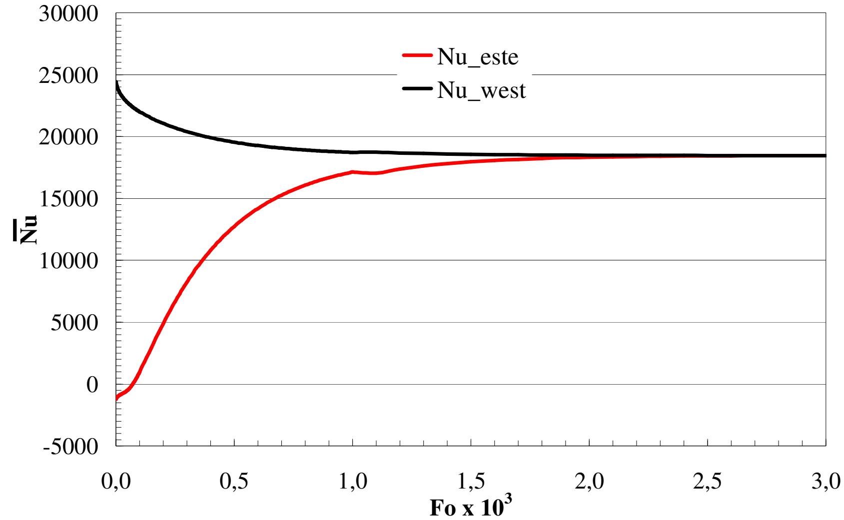


Figure 11. Global Nusselt x Fourier

4. Final considerations

A numeric study of the heat transfer in the metallic mold being taken into account the external convection with the water of cooling and the thermal interaction with the metal, on the internal side, through the air gap formed among mold and metal is presented. The results of this work show the temperature profile in the mold being taken into account profiles of lineal temperature in the metal and in the water of cooling for the calculation of the heat transfer coefficient. It is still admitted a small variation of the air gap. It is observed that the influence of the cooling water flow is not predominant in the formation of the final surface of the product.

The numerical method used for the problem of the transport of heat in the mold of the process of continuous casting, with a transitory two-dimensional approach, show to be an efficient tool that it allows to evaluate the flow of heat in the mold. Although some analytical models have been proposed, the numerical analysis is an indispensable tool when there is the necessity to include complex factors as the influence of air gap besides the influence of cooling water.

New results should be worked so that it can quantify of the thickness of the air gap formed between mold and metal.

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