IOP Conf. Series: Materials Science and Engineering **393** (2018) 012099 doi:10.1088/1757-899X/393/1/012099

Nozzle arrangement effects and cooling water pressure study for the improvement of the thermal transfer coefficient, in the secondary cooling of continuous steel casting

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Abstract. The paper analyses the effect of the nozzle arrangement on the continuous steel casting, depending on its shape and dimensions. At the same time, the work analyses the effect of cooling water pressure on the contact with the cast in order to improve the heat transfer coefficient at boiling. The present research in that, more specifically, disposed cooling water injection nozzle during the continuous casting method for arranging the nozzle for spraying cooling water to the cast surface to cool the play cast steel during the continuous casting of a continuous cooling water jetting nozzle alignment during casting It relates. An injection nozzle arrangement method during continuous casting is provided to evenly inject cooling water onto the surface of a continuous cast steel slab in a secondary cooling zone during the continuous casting.

1. Introduction

Most metallurgical plant and machine builders are already organized and active globally. Process optimizations, along with new technologies, enable production capacities to be permanently increased and the product quality of the metals produced to be further improved. Nozzles and nozzle systems play an important role here in all production stages. Cooler crystallizer is technologically the most important part of the continuous casting machines (Figure 1). [1]

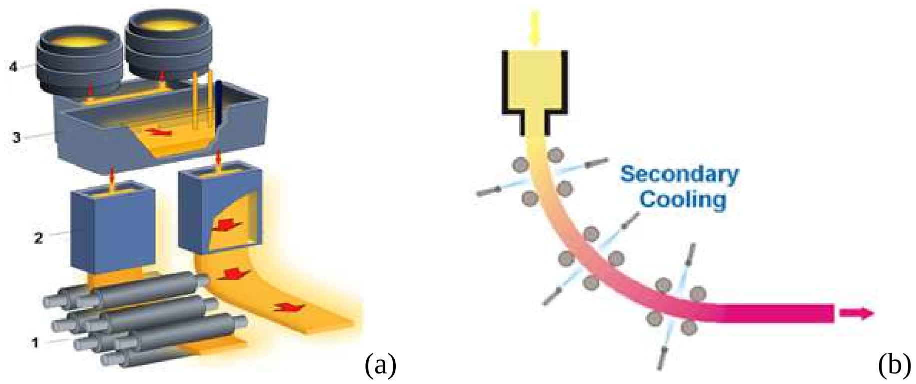

Figure 1. Feeding the cooler crystallizer from the tundish [1]. a – the cooler crystallizer: 1 – feed roller; 2 – cooler crystallizer; 3 – tundish; 4 – foundry ladle; b – the secondary cooling zones.

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Their construction, thermal conductivity, machining and assembly precision play an important role in achieving maximum productivity, superior quality of the semi–finished products, as well as a large removal of the semi–finished products. The main purpose of secondary cooling – Figure 2 is to continue cooling the thread after it has left the crystallizer and completely solidify the cross–section of the cast steel wire. [2]

Figure 2. Secondary cooling zone [2].

However, advancing solidification is limited by some natural restrictions, such as:

- thermal conductivity in the cast steel wire crust;
- cooling efficiency;
- quality considerations of the semi–finished product.

In order to complete the solidification and guide the wire in good condition, the secondary cooling zone is arranged. This cooling is carried out by direct spraying with pressurized water – Figure 2 through nozzles, able to pass through the steam formed by evaporation and to ensure continuous and permanent contact with water – metal.

The efficiency of secondary cooling is determined by both the water flow rate used (proportional to the casting speed) and the distribution of water on the surface of the metal. Spraying should ensure continuous cooling, consistent with a constant temperature drop from 1200–1300°C at the outlet of the crystallizer at 700–900°C at the end of the secondary zone [2].

The secondary cooling zone follows immediately after the crystallization and generally extends over 30 to 50% of the length of the liquid core. It is divided into sub areas, which are individually controlled. The cooling medium, which is water or a mixture of air and water, is sprayed through nozzles at the surface of the cast steel wire and is controlled so that the surface temperature of the cast steel wire decreases uniformly in the direction of casting. The temperature should be uniform on the wire circumference.

The extraction of heat in the crystallizer is mainly determined by the transition of heat from the surface of the wire to the wall of the crystallizer. In the secondary cooling zone, however, heat dissipation is especially dependent on the heat flow inside the crust of the yarn. Within certain limits, the heat transfer to the crust can be increased by increasing the temperature difference between the inside and the outside of the steel crust.

The temperature of the crust interior, for example the solid–liquid separation surface, is more or less invariant. As a result, the outside surface temperature of the crust, besides the crust thickness, will determine the solidification rate and hence the length of the liquid core of the cast steel wire; a low outside temperature means a large temperature difference inside the crust. However, the possibilities of achieving a short time of solidification by intense cooling of the spray are limited by the low thermal conductivity of the steel crust.

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Very intense cooling does not result in a gradient that steadily descends inside the crust, but a sudden drop in the crust temperature curve to the outer surface. It causes local thermal stresses in the crust and consequently internal and surface cracking in the wire. Some high–strength steels are particularly sensitive in this regard.

Spray cooling is split into loops and individually controlled areas. In general, the flow rate of sprayed water should drop from the crystallizer in the direction of casting. Spray water flows should be higher at the top of the casting machine in order to achieve the rapid growth of the yarn crust and thus improve the hardness of the crust according to the effort. Decreasing the cooling intensity in the direction of casting must prevent the surface temperature from becoming too low in the straightening points [1,2].

2. Heat transfer at boiling – steam influence

Boiling is the process of transforming the liquid at saturation temperature into vapor. Boiling is an isobar and isothermal process. For a given fluid boiling may occur between the three–point coordinates and those of the critical point [3].

Boiling according to the location of the process may be:

- surface heating – vapor formation is done on a heated solid surface with which the liquid comes into contact;
- boiling in the volume is carried out throughout the mass of the liquid, usually by expanding (reducing its pressure).

Depending on the movement or absence of fluid flow, boiling may be:

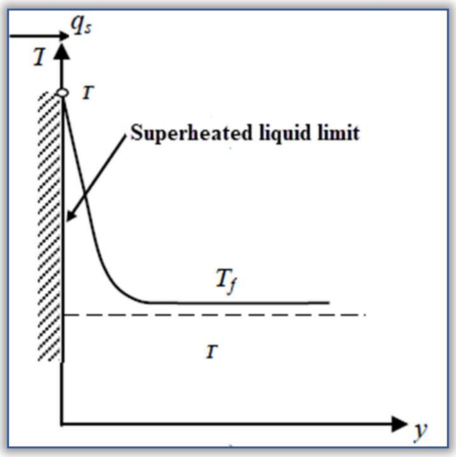
- high volume (free convection) boil;
- forced convection.

Depending on the boiling process mechanism it is distinguished:

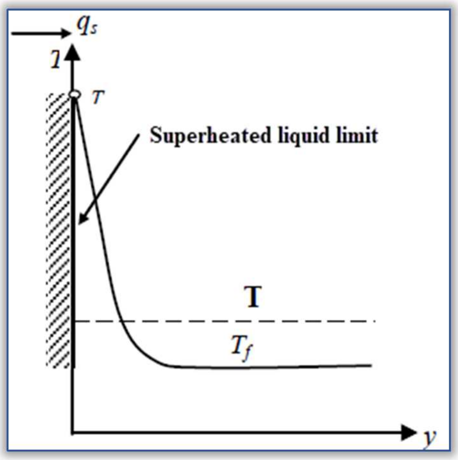
- the nucleus boiling on the heat exchange surface forms boiling buoys that grow, detach from the surface and move into the fluid mass, the heat transfer being very intense.
- the surface boiling on the heat transfer surface forms a vapor film.

Depending on the temperature in the limiting layer, boiling may be:

- at saturation – the entire volume of liquid is at saturation temperature (Figure 3.a);
- subcooling – the boiling occurs only in the boundary layer near the wall, where the temperature exceeds the saturation temperature, the temperature in the rest of the liquid being lower than the saturation temperature (Figure 3.b).



(a)



(b)

Figure 3. Boiling in the limiting layer according to temperature [3]: a – saturation boiling; b – boiling at subcooling.

The processes of formation, growth, detachment and displacement of the bubble influence the transfer of heat through three main processes:

- thermal conduction through the side surface of the bubble from the liquid overheating;
- evaporation to the surface of the microsphere under the bubble;
- free convection on surfaces not covered by vapor bubbles.

The nucleation process can be divided into several stages:

- forming the first bubbles in nucleation centers at the heat exchange surface – the minimum size of the bubbles at the time of their formation is characterized by the critical radius (R_k).

$$R_k = \frac{2 \cdot \sigma \cdot T_s}{c \cdot \rho_v \cdot (T_p - T_s)} \tag{1}$$

where:

≡ σ – surface tension of the liquid;
≡ T_p, T_s – the wall temperatures and the saturation temperature;
≡ c – latent heat of vaporization;
≡ ρ_v – the vapor density.

- if $R > R_k$ increases bubbles – the parameter that determines the rate of bubble growth is Jacob's criterion

$$J_a = \frac{c_p \cdot \Delta T_e}{r} \tag{2}$$

where:

≡ c_p – heat–absorption capacity of the liquid.

- the bubble thus formed increases you to a critical d_0 diameter, at which it deviates (Figure 4) – d_0 is determined by the balance of forces acting on the bubble (adhesion force, archimed force and weight force).

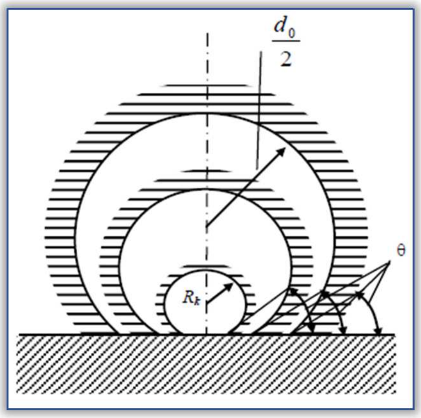


Figure 4. The simplified bubble growth scheme.

$$d_0 = 0{,}0208 \cdot \theta \cdot \sqrt{\frac{\sigma}{g \cdot (\rho_l - \rho_v)}} \tag{3}$$

where:

≡ θ – the boiling watering angle.
≡ ρ_l – the liquid density.

The intensity of heat transfer to nucleation can be explained by three mechanisms (Figure 5):

- increasing heat transfer due to turbulence induced by vapor bubbles (Figure 5.a);

- vapor–liquid exchange – characterized by the pumping effect, which raises by raising and detaching the bubbles the hot liquid layer next to the wall, allowing the cold place to remain cool (Figure 5.b);
- increasing thermal transfer due to the evaporation process of the liquid microstratum under each bubble (Figure 5.c).

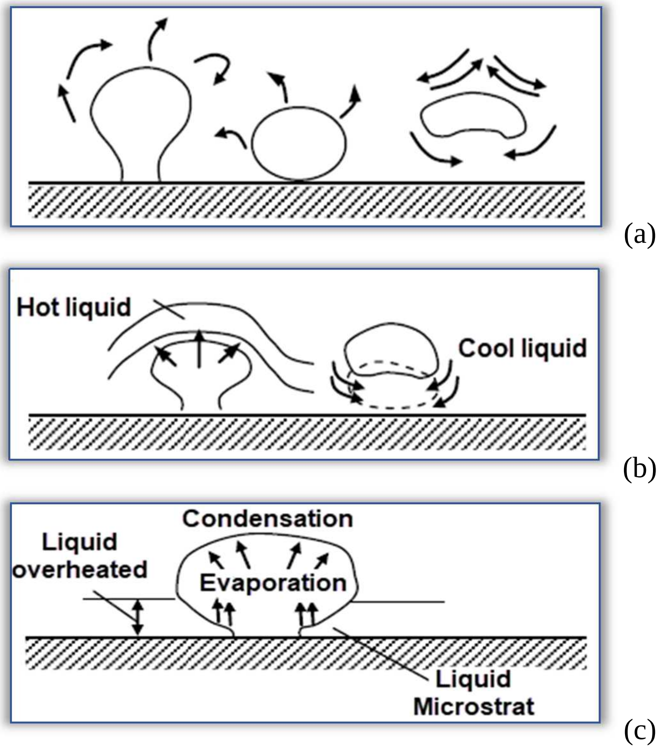


Figure 5. Mechanisms of heat transfer to nucleation boiling.

One of the first relationships for calculating the convection coefficient at volume nucleation was proposed by Kutadeladze:

$$q = 22{,}2 \cdot p^{0{,}54} \cdot (T_p - T_s)^{3{,}33} \quad (4)$$

where:

≡ p – the pressure expressed in the bar.

Biphasic flow involves the presence of the two phases: liquid and vapor, which move together and interact with each other, the flow hydrodynamics and the heat transfer being interconnected.

3. Nozzeles effects about the secondary cooling zone

The essential operating data of spray nozzles are [4]:

- flow rate;
- spray angle;
- liquid distribution;
- spray impact;
- droplet size.

Flow rates and spray angles are dependent on feed pressure and viscosity of the liquid to be sprayed. The spray angle is determined right at the nozzle's orifice. The indications given on spray widths and coverage diameters are more useful at larger distances from the orifice. Air friction losses and ballistic phenomenon's influence the spray behavior and the size of the impact area in dependence on the chosen service pressure.

The pressure (p) is the feed pressure above atmospheric, which is available at the liquid inlet into the nozzle. The spraying operation is performed under counter pressure, the flow rate is dependent on the differential pressure (Figure 6). Minimum and maximum pressures are adjusted to the required flow rates and the spray quality.

Air–mist spray nozzles for secondary cooling benefit from an increased spray kinetic energy which results in an increased heat extraction compared to single fluid nozzles for the same spray water intensity. Due to the spray kinetic resulting from the interaction between water and air the spray angle of an air–mist nozzle is generally more stable with varying water pressure and position compared to single fluid nozzles.

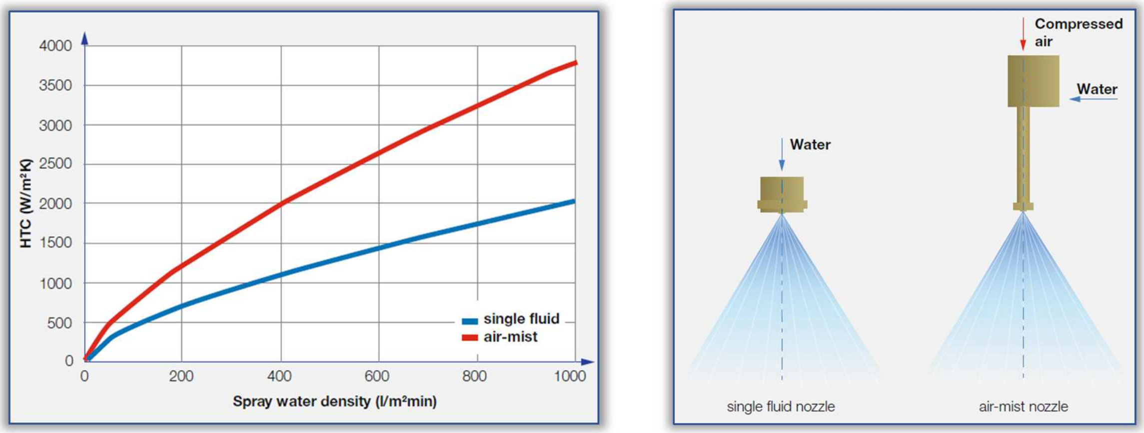


Figure 6. Comparison of heat transfer coefficient of single fluid vs. air–mist nozzle [4].

When using several flat spray nozzles on a manifold to provide an overall uniform coverage on a strand passing under the sprays, it is very important that all nozzles be oriented correctly in relation to each other.

4. Concluding remarks

— in the film–forming process on the heat exchange surface a vapor layer is generated that isolates the liquid from the heated surface;
— heat is transferred through conduction to the liquid–vapor interface where evaporation occurs. The coefficient of convection is influenced by the position of the surface (horizontal, vertical), the nature of the fluid and the excess temperature ΔT_e;
— low spray pressures are generated by full cone nozzles of wide–angle flat fan nozzles;
— high spray pressures are typical for flat fan nozzles with narrow spray angles (15–60°C);
— extremely high spray pressures are produced by solid stream nozzles;
— the effect of the spray water temperature on the heat transfer coefficient is reduced with air–mist nozzles;
— all the flat spray patterns should be aligned to ensure accurate coverage.

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