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ADVANCED CONTROL OF SPRAY COOLING HEAT TRANSFER IN LONG PRODUCT CASTING

Abstract

The main challenges in long product casting are currently the increasing demand for high quality products in combination with a wide range of steel grades and section sizes as well as higher casting speeds. This creates a challenge for the secondary cooling technologies of these processes.

The solidification process driven by the cooling intensity on the strand surface requires precise control to achieve high quality standards of the product. The heat transfer in the secondary cooling is affected by the liquid distribution on the strand surface. Conventional air-mist full cone nozzles either show an unstable spray angle with varying water pressure or a limited water turndown range.

A new generation of full cone air-mist nozzles has been developed as a response to these limitations providing dedicated cooling and stable spray patterns for all operation conditions thus allowing operators to control the extracted heat on the strand surface in order to meet the individual cooling requirements for the varying products and casting speeds.

This paper presents new features for control of liquid distribution and heat transfer on the strand surface in secondary cooling zones.

Keywords

Continuous Casting, Secondary Cooling Control, Heat transfer

1. Introduction

Long product continuous casting processes have become more demanding in the last decade. While productivity and quality have remained fundamentals, requirements regarding flexibility in product dimensions and steel grades have increased. A wide range of steel grades and section sizes are being cast on one caster, with a wide range of casting speeds and a demand on high quality for all products. These demands are a challenge for the solidification process.

While the mould is a very important area in this process as it controls the initial solidification, the secondary cooling is also influencing the solidification and hence the quality of the product.

2. Secondary Cooling and process control

A secondary cooling system of a long product caster typically consists of multiple cooling zones. Each Zone ideally has only one nozzle type installed. The nozzle layout is usually identical for at least one section size and all grades. Therefore one nozzle type has to provide a high cooling turndown in order to meet the varying demands of the process. High carbon and micro-alloyed grades are cast at lower casting speeds with soft secondary cooling to avoid casting defects such as surface and internal cracking. The required heat extraction to achieve the soft cooling is low compared to low and ultra low carbon grades, which are typically cast at high speeds requiring hard secondary cooling to avoid bulging and breakouts. The heat extraction needs to be much higher for these conditions.

The heat extracted from the surface is mainly controlled by the nozzle water flow rate. To meet the requirements of both soft and hard cooling each nozzle has to provide a high range of heat extraction, hence a high water turndown range. The water turn down range is defined as the ratio of the recommended maximum and minimum flow rate of the nozzle.

The flow rates and pressures applied in the cooling zones on modern casting machines are controlled by sophisticated online software that dynamically defines optimum cooling based on computer modeling. However, the cooling control data is often defined by offline thermal models.

Thermal models calculate the temperature field and solidification profile based on theoretical heat extraction. The heat extraction in the secondary cooling zone controlled by sprays is derived from heat transfer coefficients (HTC). HTCs are usually a function of a theoretic surface spray density derived from the sprayed area and the nozzle flow rate. For air-mist nozzles the air pressure and flow rate should be taken into account as well since they have an impact on the spray kinetics and hence the HTC. An example of the effect of the air pressure on the heat transfer and a comparison between air-mist and single fluid nozzles is shown in Figure 1 [1]. Some models use the droplet size and velocity to calculate the HTC, which are depending on water and air-flow rates and pressures.

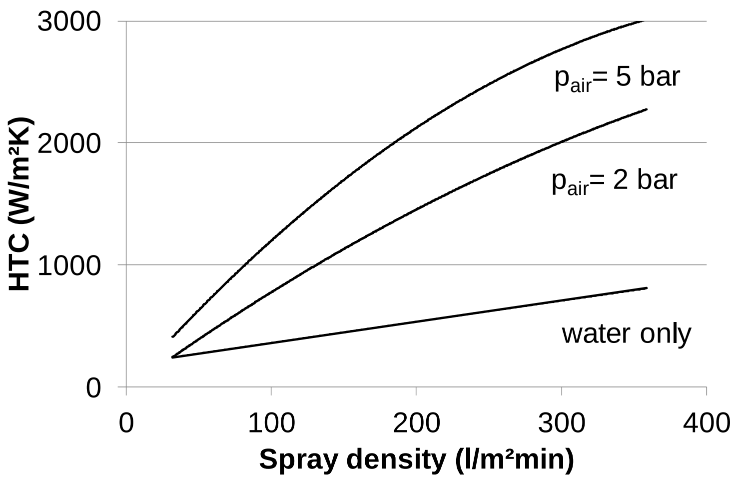

Fig. 1: HTC as a function of spray water density for water only and air-mist nozzles at varying air pressure above Leidenfrost temperature, after [1]

In long product casting mainly full cone and oval cone nozzle are installed in the cooling zones. Modern casters which require a high water turndown ratio are usually equipped with air-mist nozzles. [2]

The secondary cooling process design is based on idealised assumptions. Both a stable nozzle spray angle for all operating conditions and a homogeneous cooling, based on a constant even spray intensity throughout the sprayed area are being implied. Both assumptions are not realistic since spray angle and liquid distribution vary with water and air pressure for conventional air-mist nozzles.

The spray angle varies with water and air pressure. Conventional full cone air-mist nozzles show variations in spray angles over the water turn-down range. The liquid distribution is affected by the spray angle; it is also a result of the fluid dynamics within the cone spray, varying with different air-water ratios. Generally 3 types of liquid distribution profiles can be observed.

Figure 2 shows the relation between the local spray density (top and centre row) and the dynamically measured distribution (bottom row) for these typical profiles. The dynamic distribution results represent the total local spray intensity over the spray depth as a function of the strand width. The first column shows a centre-pronounced (High Centre, HC) distribution where most of the liquid is concentrated in the centre area of the spray cone. The second column shows a distribution profile, which concentrates more liquid to the outer area of the spray cone. Dynamic measurements results show an even (Flat Centre, FC) distribution for this condition. The third column shows a spray characteristic similar to a hollow cone. Dynamic distribution measurements show an edge pronounced (Low Centre, LC) distribution of the liquid on the surface.

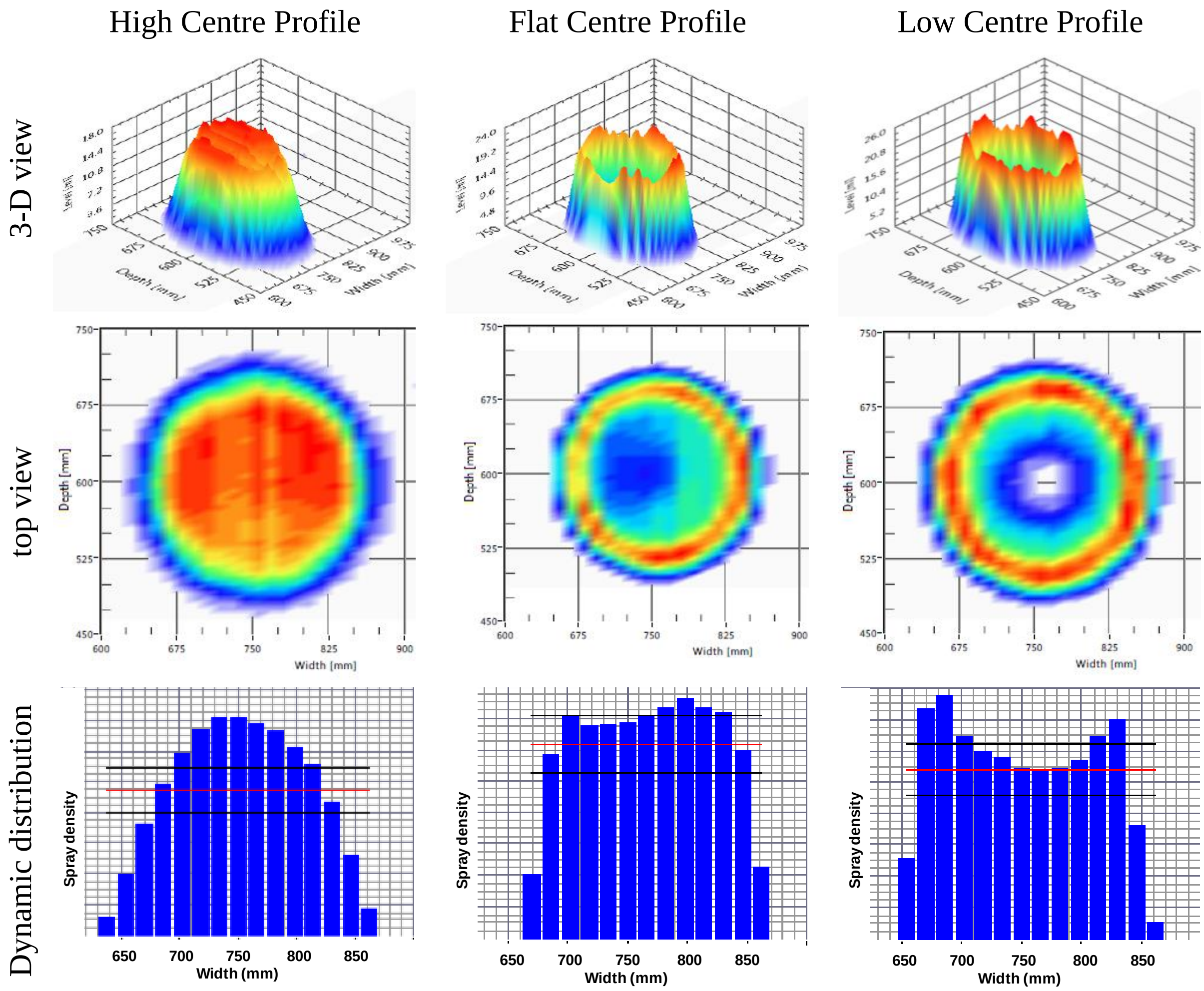

Fig. 2: Different methods of measurement analyses for varying liquid distribution profiles; top row: 3-D view, Centre row: top view, bottom row: dynamic distribution; left column: “high centre” distribution profile, centre column: “flat centre” distribution profile, right column: “low centre” distribution profile

The resulting temperature profile on the strand surface is depending on the local heat transfer. The heat extraction is a function of the applied spray characteristic and is varying with spray angle and liquid distribution. Hence local cooling can become uneven if the spray characteristic is not controlled properly.

Conventional air-mist nozzles do not give the option to control the liquid distribution profile, which can lead to uneven cooling on the strand surface. Figure 3 shows a strand of a round billet in a lower cooling zone at a low casting speed. The nozzle is operating at a low water flow rate and pressure. The spray characteristics show a reduced spray angle and a high centre (HC) liquid distribution. As a result the strand is locally overcooled beneath the nozzle centre. This condition can lead to surface and internal defects, having the potential of reducing the quality of the semi product. This is a typical problem for many billet and bloom casting machines.

The opposite situation exists at low casting speeds where corners are often overcooled due to the naturally increased heat extraction in that area. In this case a high centre liquid distribution of the nozzle is preferable at low operating pressures in order to keep the corners at high temperatures.

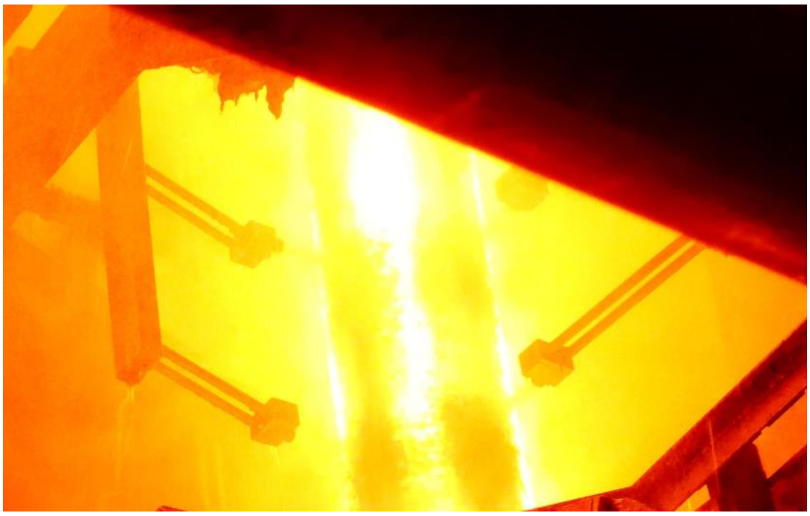

Fig. 3: “Black stripes” on round billet as a result of non-uniform spray nozzle cooling

3. New Features for Secondary Cooling Control

A new generation of air-mist full cone nozzles has been developed as a response to these challenges to allow advanced liquid distribution control on the strand surface maintaining the advantages of a stable spray angle and a high water turndown range.

These new nozzles of the Billetcooler Flex series show a constant spray angle of 60° for typical spray heights from 100 up to 200 mm and cover a water flow rate (V_w) range from 0.3 - 8 l/min (Table 1).

Table 1: New Types of Billetcooler Flex, flow rates at 2 bar constant air pressure

Nozzle Size	Spray angle	min V_w (l/min)	max V_w (l/min)
0.8	60°	0.3	3
1.25		0.5	5
2		0.8	8

The comparison of spray characteristics (Figure 4) between the Billetcooler Flex and a conventional full cone air-mist nozzle shows the improvements in terms of spray homogeneity and spray angle stability. Both nozzles have the same nominal spray angle and a similar minimum and maximum flow rate. The operating air pressure was set at 2 bar constant.

These improved characteristics also have an impact on the liquid distribution on the strand surface which is not affected by the dynamic spray angle for the new Billetcooler Flex. Therefore the liquid distribution profiles can be controlled by adjustment of the operating pressures and flow rates maintaining a constant sprayed area.

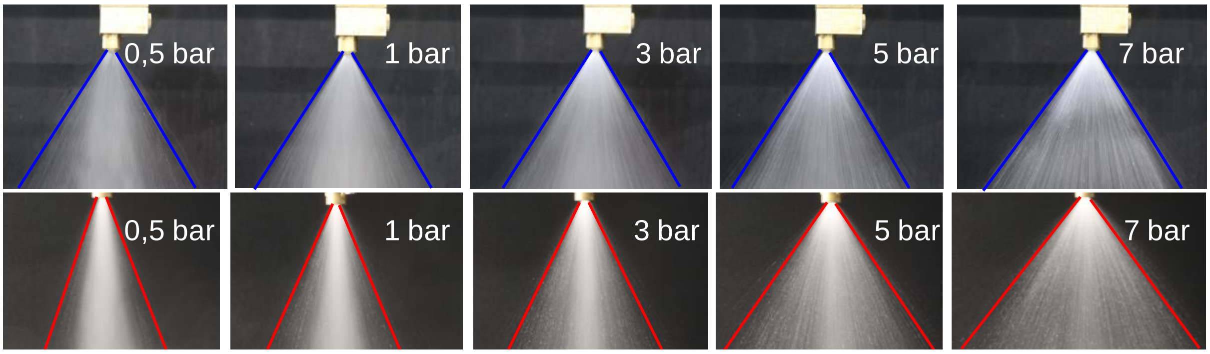

Fig. 4**:** Spray characteristics of new Billetcooler Flex (top row) compared to the conventional air-mist nozzle (bottom row) at varying water pressure (bar) and 2 bar constant air pressure

Figure 5 shows the flow rate diagram for a medium size nozzle of the Billetcooler Flex. The top and bottom dashed frame lines represent the flow rates at maximum and minimum design air pressures of 4 and 1 bar respectively. The left and right dashed frame lines describe the flow rates at minimum and maximum water pressures of 0.5 and 7 bar respectively.

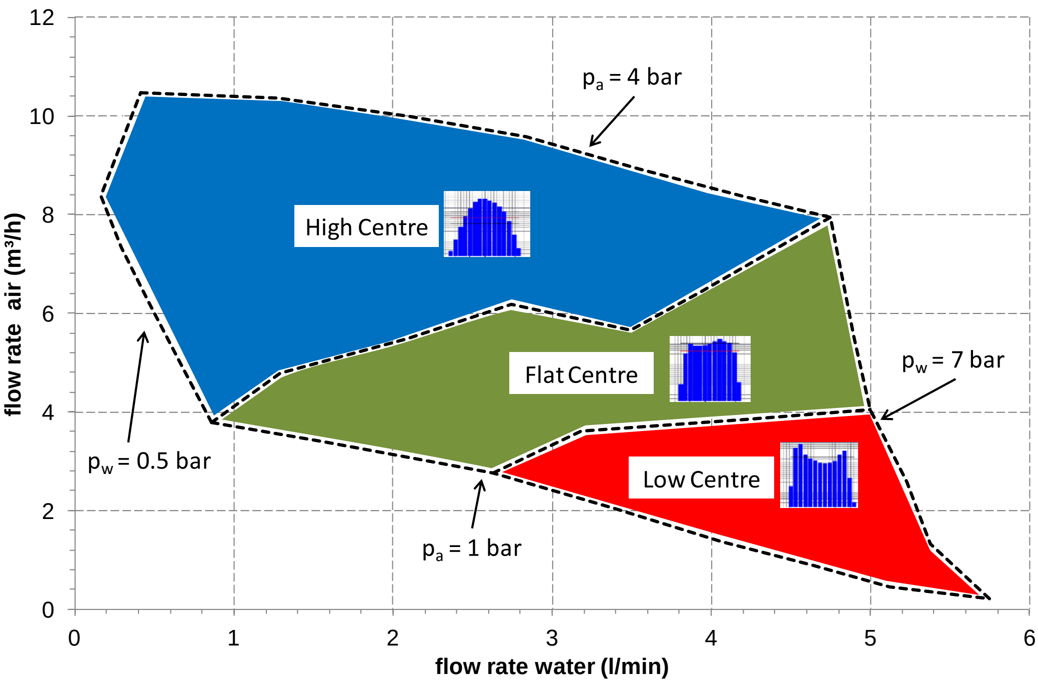

Fig. 5: Air and water flow rate diagram including liquid distribution control options for new Billetcooler Flex Size 1.25

The dashed lines between the colored areas indicate the transitions between the different liquid distribution profiles that can be controlled by adjustment of the operating pressures and flow rates. This characteristic provides the additional option to adjust the liquid spray distribution on the surface according to the requirements of the continuous casting process.

As shown in Figure 3 the liquid distribution determines the surface temperature to a certain extend. For the new nozzle generation HTC measurements for different air and water pressure set ups have been conducted in order to investigate the correlation between the distribution profiles and the resulting local heat extraction. For these measurements a typical spray height of 150 mm was chosen.

A dynamic measurement method was used with a moving HTC sensor passing underneath the spray and measuring the local heat extraction covering all areas of different spray intensities within the spray cone. Figure 6 shows the spray distribution measurement results and the positions for HTC measurement in the centre and 75 mm from the centre to evaluate the relation between dynamic spray distribution and heat transfer. The dashed lines show the measurement positions of the sensor.

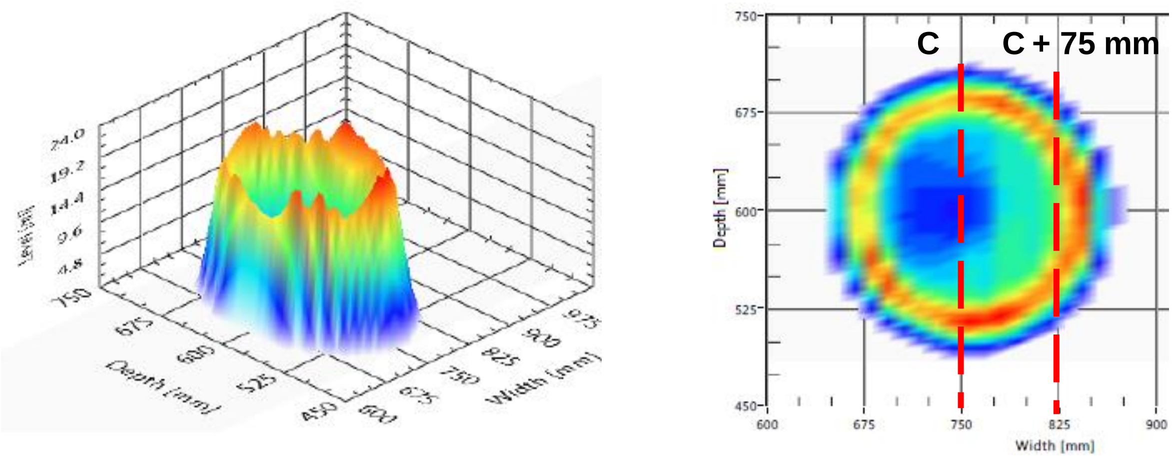

Fig. 6: 3-D view on liquid distribution of full cone nozzle (left) and top view including measurement positions in centre position C and 75 mm from the centre C+75 (right)

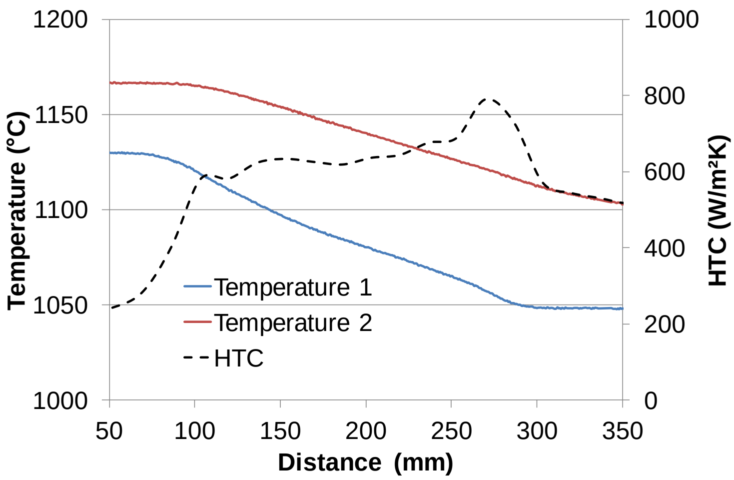

Fig. 7: Example of experimental temperature data for 2 positions inside the sensor and calculated local HTC data

The local HTC values have been derived from the surface temperature, materials properties and spray water temperature based on Fouriers equation. An example of the calculated HTC compared to measured temperatures inside the sensor is shown in Figure 7. An average value of the local HTC has been calculated over the sprayed distance for each operating condition. These values have been analysed for varying liquid distribution profiles and operating pressures (Figure 8). An overview of the analysed nozzle pressures for air (p_a) and water (p_w) and according flow rates (V_a,V_w) is shown in Table 2.

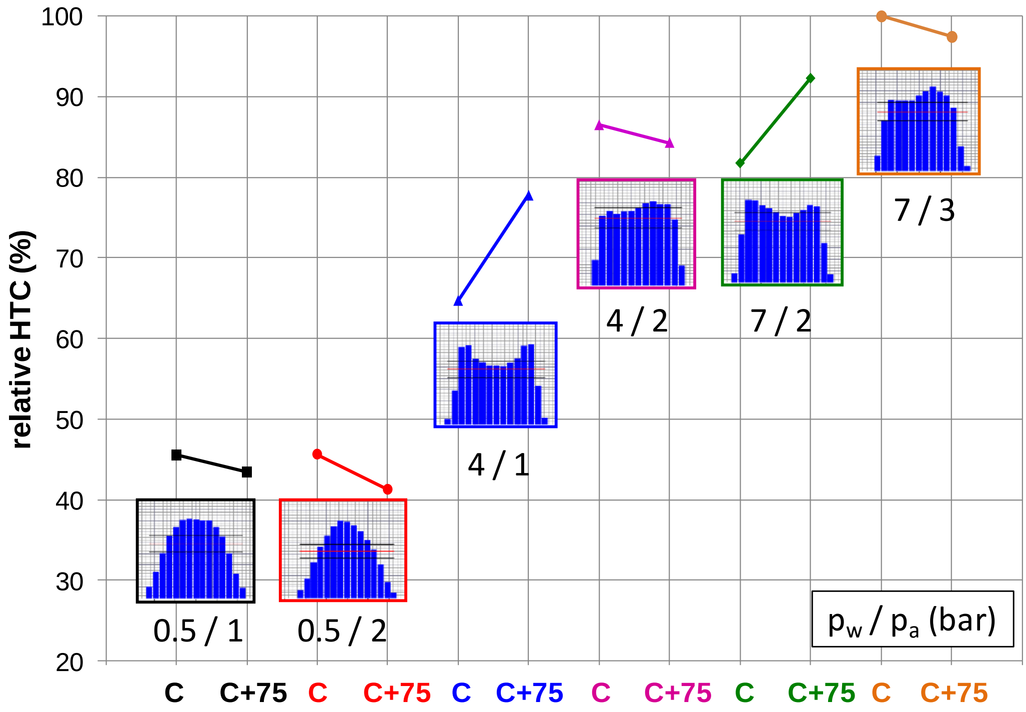

Fig. 8: HTC results for different liquid distribution profiles of Billetcooler Flex Size 1.25 in centre position C and 75 mm from the centre C+75, p_w/p_a in bar

Table 2: Analysed operation conditions of new Billetcooler Flex Size 1.25

#	p_w (bar)	V_w (l/min)	p_a (bar)	V_a (m^3/h)
1	0.5	0.4	2	6.3
2	0.5	0.8	1	3.6
3	4	3.6	2	4.1
4	4	4.1	1	1.1
5	7	5.2	2	2.25
6	7	5	3	5

The results confirm the correlation of the dynamic liquid distribution and the heat extraction. The high centre profiles at lower water pressures show the highest HTC in the centre position while the low centre profiles show higher HTC values in the off centre measurement results. This heat extraction characteristic will be beneficial for long product casting processes as it provides the option to provide dedicated cooling to the required areas and helps to reduce quality problems related to local overcooling of the strand corner or centre.

In order to use these benefits for product quality enhancement the caster control needs to be adjusted taking into account the liquid distribution profile as a function of the air and water flow rates.

4. Summary

The increased demand for flexibility and high quality in modern long product casting processes creates a challenge for secondary cooling technologies. The control of the local heat extraction is an important factor which is limited due to conventional nozzle characteristics. A high water turndown ratio in combination with a stable spray angle is required. Conventional air-mist nozzles cannot provide both at a time. These limitations can cause defects in the semi product.

A new generation of air-mist full cone nozzles, the Billetcooler Flex, has been developed providing additional options to control the local heat extraction still maintaining a stable spray angle and a high water turndown ratio. The heat extraction can be controlled by the liquid distribution profile which can be either high centre (centre pronounced), flat centre (even) or low centre (edge pronounced). HTC testing has been conducted to verify the correlation between dynamic liquid distribution and heat extraction. These tests confirmed the flexibility in terms of local heat extraction of the new nozzle type and show the potential for long product casting process improvements.

References

[1] F. Puschmann and E. Specht, Atomized Spray Quenching as an Alternative Quenching Method for Defined Adjustment of Heat Transfer, Steel Research int. 75 (2004), p.283

[2] R. Boyle and J. Frick, Modern secondary cooling technology in continuous casting of steel, la metallurgia italiana 1/2005, p.49