Energy Efficiency in Secondary Cooling – New generation of hydraulic nozzles with increased water turndown ratio and cooling efficiency for slab casting processes

J. Frick, R. Wolff, Lechler GmbH, Germany;
R. Conte, A. Carboni, Danieli & C. Officine Meccaniche, Italy

Contact data

Robert Wolff, Lechler GmbH, Germany
Phone: +49(0)7123-962423, Email: robertwolff@lechler.de
Riccardo Conte, Danieli & C. Officine Meccaniche S.p.A., Italy
Phone: +39(0)432-1958658, Email: r.conte@danieli.it

Summary

Modern slab casting machines utilize air-mist secondary cooling systems which provide dedicated cooling performance in terms of liquid distribution, cooling efficiency and cooling flexibility. Decades ago, the air-mist nozzles installed in such systems were designed to overcome the shortcomings of hydraulic nozzles. These nozzles have been optimized to meet today's secondary cooling system demands.

Lechler and Danieli are now cooperating on the development of an innovative and purely hydraulic secondary cooling technology. The nozzle types provide improved cooling performance whilst maintaining dedicated liquid distribution on the strand surface. The hydraulic solution requires no compressed air for spray atomization. The new Hydrospray technology is the result of this cooperation.

The Hydrospray represents a quantum leap in secondary cooling technology. The removal of compressed air required for air-mist nozzles leads to a significant energy saving, together with CO_2 emission reduction and lower OPEX. Moreover, the on-board and interconnecting piping are simplified, giving two advantages: the spray width control is enhanced through a finer resolution and the installation time and costs are cut. The Hydrospray technology package, operated by Q – COOL closed loop control system, offers the opportunity to achieve outstanding performances in secondary cooling through high-resolution temperature control.

Extensive testing of the spray characteristics in terms of spray appearance, liquid distribution, impact pressure, pressure-flow rate and cooling efficiency has been conducted and compared with existing state-of-the-art air-mist nozzle solutions. The Hydrospray has shown better performance than state-of-the-art air-mist secondary cooling systems, offering the opportunity to steel makers to take advantage of a breakthrough technology which also contributes to energy efficiency and cost savings.

Key Words

Continuous Casting, Secondary Cooling, Energy Efficiency

Introduction

State-of-the-art slab casting machines utilize air-mist cooling technology in secondary cooling. The air-mist nozzles installed in these systems provide two major advantages compared to the previously utilized water cooling systems:
A large cooling control range as a result of the increased water turndown ratio and increased cooling efficiency as a result of the atomization of the spray water by compressed air.

The major disadvantages of this technology are the consumption of compressed air resulting in energy costs and the additional required piping and instrumentation for compressed air supply and control.

Lechler and Danieli have jointly developed a new secondary cooling technology to address both disadvantages while maintaining the benefits of air-mist cooling.

The vision

A new secondary cooling technology has been developed with the aim of removing the compressed air consumption from the system. A purely hydraulic secondary cooling system for continuous casting is simpler and significantly reduces the costs related to the installation of big compressors, interconnecting piping, air pressure / flow control and related instrumentation. At the same time, on-board piping is reduced as well, making the segments less complex.
More importantly, savings are obtained when the system is in operation as electrical power consumption for compressed air supply is not required. These savings have been estimated to range between 170,000 and 350,000 € per year per strand for a typical conventional slab casting machine. Saving electricity

also contributes to the reduction of CO_2 emissions, which are estimated to be between 800 and 1,800 tons per year per strand.

There are several options available to achieve this goal. While pulse width modulation or flexible nozzle orifices are proven technologies in other industries, they are hardly appropriate in secondary cooling environments as they are maintenance-intensive.
Therefore, Lechler and Danieli were focusing on the development of a simple, maintenance-friendly technology which can easily be fitted on existing and new casting machines.

One obvious option is to install multiple separately actuated nozzles which can easily accomplish the main objective. However, this would require an excessive amount of additional valves as well as additional piping and control instrumentation compared to existing machines. Based on this simple approach, more sophisticated solutions have been created, optimizing nozzle design and comprising pipe design as well as valve technology. These measures are taking this simple concept to a new level of secondary cooling control technology.

This basic concept is called Hydrospray and consists of three major components:

- A pneumatically actuated valve block controlling multiple nozzles or complete cooling zones depending on the secondary cooling design
- A dedicated piping and connecting system
- A nozzle unit consisting of a tailor-made multi nozzle head and the nozzle block and pipe. This unit provides the required spray water amount and cooling efficiency with optimized liquid distribution.

As the actuation is pneumatic, no electronics are required close to the segment. Hydrospray can also be installed in existing air-mist secondary cooling systems without major mechanical modifications.

The technology

A sketch of the Hydrospray principle with its three major components is shown in Figure 1. However, this is just one possible design as the number of nozzles, position and size of the valve block as well as the piping design will be tailor-made for each cooling system.

Valve block
The pneumatically controlled valve block is the heart of the Hydrospray. It is designed to fit the secondary cooling system condition and the requirements of individual machines and control a given number of nozzles simultaneously. The installed valves are simple ON/OFF valves. Pneumatic control has been chosen to keep the electrical components in a safe area, free from water and steam.

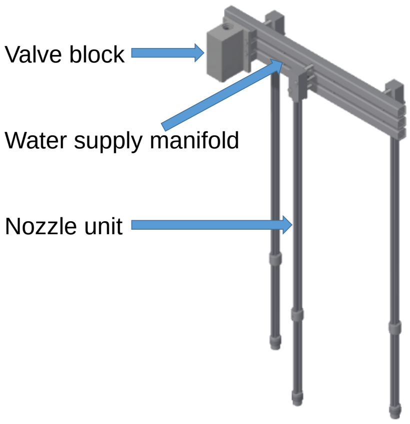

Figure 1: Schematic Hydrospray Principle

Water supply manifold
The water supply manifold connects the valve block with the nozzle unit. It mainly consists of multiple water pipes. Thanks to the optimized design the dimensions are similar to the existing air-mist secondary air and water supply manifold.

Nozzle Unit
The multi nozzle head is the component defining the spray and cooling performance of the Hydrospray system. It consists of multiple tailor-made nozzles, each one providing the required liquid distribution to the slab surface for individual water flow rate ranges.

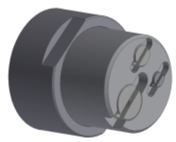

Figure 2: Multi nozzle head design example

The nozzle block and pipe connect the nozzle head to the water supply manifold and have dimensions similar to the existing air-mist nozzle components.

Q-COOL closed-loop control
Thanks to Q-COOL, a step forward in secondary cooling is taken with precise temperature control across the slab width, with the goal to increase the surface quality of the cast product.
Q-COOL enables an accurate control of the solidification process. Through a detailed real-time simulation of the strand in the mold and in secondary cooling, Q-COOL is able to compute the surface temperature and the shell thickness. Moreover, the secondary cooling flow rates are set and tuned to fulfill the surface temperature and shell thickness profile requested for the specific steel grade.

By setting the flow rate and selecting the proper number of active orifices of the Multi Nozzle Head, Q-COOL is able to provide a wide variety of corner / edge cooling strategies. The combined use of Hydrospray and Q-COOL offers the opportunity to finely control the temperature and solidification profiles, thanks to an increased turndown ratio and a simplified spray width control capability. The synergistic application of Hydrospray and Q-COOL increases operational flexibility and allows the reduction of CAPEX and OPEX.

The benchmark

In order to evaluate the secondary cooling performance of the new Hydrospray System, Lechler and Danieli conducted extensive measurements. For this task, a state-of-the-art air-mist nozzle taken from an operational secondary cooling system was used as a benchmark. An equivalent Hydrospray nozzle unit was designed to provide the same or improved cooling flexibility. The basic performance data is shown in Table 1.

	air-mist nozzle	Hydrospray nozzle unit
Water Flow Rate (l/min)	1.7 - 16	1 - 20
Water pressure (bar)	0.5 - 7	1 - 8
Spray angle (°)	100	100
Spray height (mm)	200	200
Atomizing Air flow rate (m^3/h)	max. 13	-

Table 1: Comparison of basic data for air-mist nozzle and Hydrospray nozzle unit

Both the Hydrospray nozzle unit and air-mist nozzle were examined in terms of liquid distribution, impact pressure and heat transfer for various flow rates in typical secondary cooling operating conditions.

Tests were carried out using a two-spray configuration, spray height and nozzle pitch were set according to the area of the continuous casting machine selected for the benchmark. Thus, it's possible to establish a comparison between Hydrospray and air-mist spray, both in the overlapping and non-overlapping areas.

An example of liquid distribution across the spray width at a minimum water flow rate of 1.6 l/min is shown in Figure 3. The corresponding impact pressure distribution is shown in Figure 4.

While liquid distribution and local spray density are very similar, there is clearly a difference in the spray impact pressure distribution. At this flow rate, the uniformity is improved with the Hydrospray system.

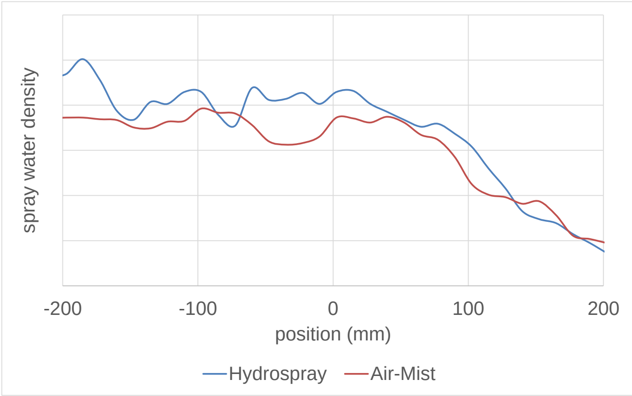

Figure 3: Liquid distribution comparison for minimum flow rate of Hydrospray nozzle unit and air-mist nozzle

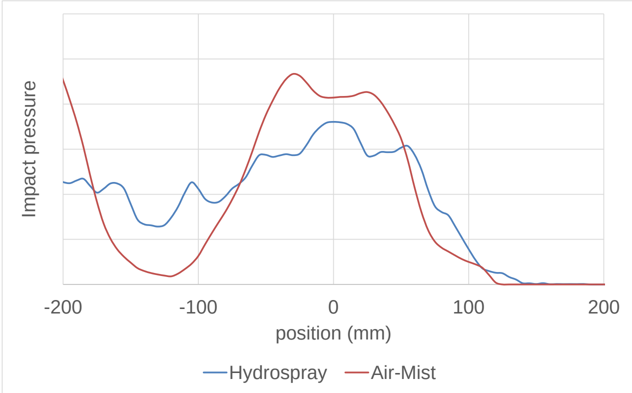

Figure 4: Spray impact pressure distribution comparison for minimum flow rate of Hydrospray nozzle unit and air-mist nozzle

An example of liquid distribution over spray width at a maximum water flow rate of 16 l/min is shown in Figure 5.

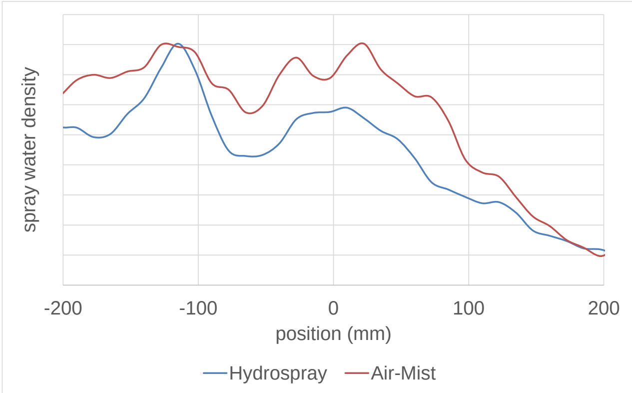

Figure 5: Liquid distribution comparison for maximum flow rate of Hydrospray nozzle unit and air-mist nozzle

In order to evaluate the actual effect on the secondary cooling performance of both nozzle types, heat transfer coefficient (HTC) tests were conducted under the same conditions.

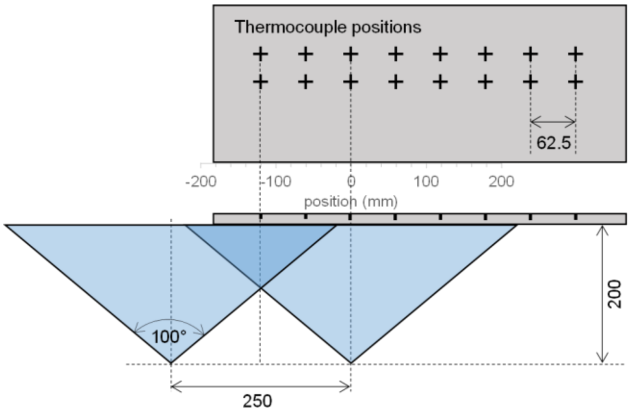

Figure 6: HTC test setup and thermocouple positions

The Heat Transfer Coefficient (HTC) was computed using the test setup indicated in Figure 6. A plate is heated up to 1200 °C. Several thermocouples installed on the plate measure the temperature. The measurements are processed and, by solving an inverse problem, the local surface heat transfer coefficient is computed. HTC results are available for each thermocouple row on the test plate. In order to evaluate the capability of the spray to withdraw heat from the strand, a synthetic parameter was chosen: the average HTC in the surface temperature range from 1200 °C to 900 °C.

A comparison of HTC distribution across the spray width for a minimum water flow rate is shown in Figure 7.

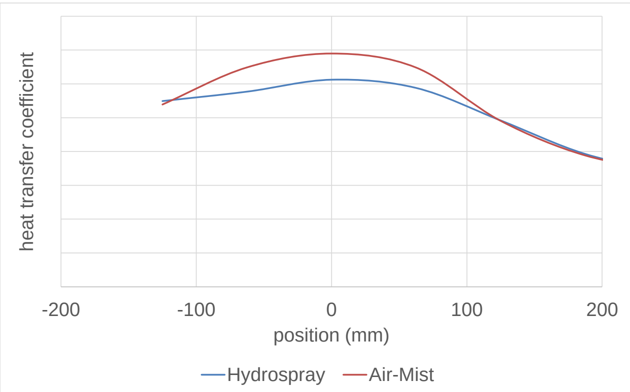

Figure 7: HTC distribution comparison for minimum flow rate of Hydrospray nozzle unit and air-mist nozzle

The HTC distribution and absolute values are on a similar level for both systems. The Hydrospray nozzle unit even provides reduced cooling efficiency at the minimum spray water flow rate.

A comparison of HTC distribution across the spray width for a maximum water flow rate is shown in Figure 8.

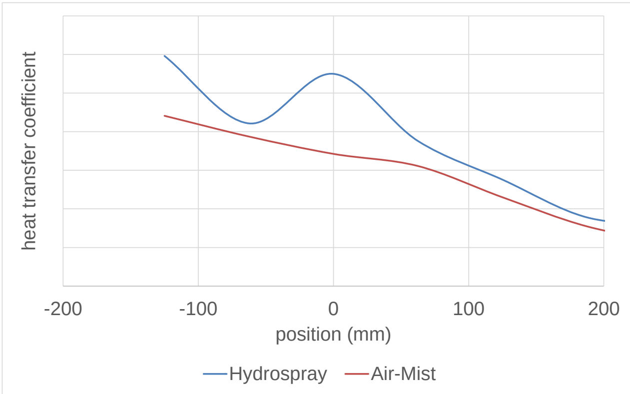

Figure 8: HTC distribution comparison for maximum flow rate of Hydrospray nozzle unit and air-mist nozzle

The HTC distribution and absolute values are again on a similar level for both systems. The Hydrospray nozzle unit even provides increased cooling efficiency at the maximum spray water flow rate.

In the graph in Figure 9, the average HTC is plotted as a function of water flow rate. A comparison between air-mist nozzle and Hydrospray is established and a very similar behavior is observed: even though compressed air has been removed, a properly designed multi nozzle head achieves even higher heat transfer coefficients at the maximum flow rate.
This benchmark proves that air-mist sprays can be replaced by Hydrospray systems without any downgrade in cooling efficiency and quality. Furthermore, since the turndown ratio is even higher, the cooling capability of the secondary cooling system is enhanced in terms of flexibility.

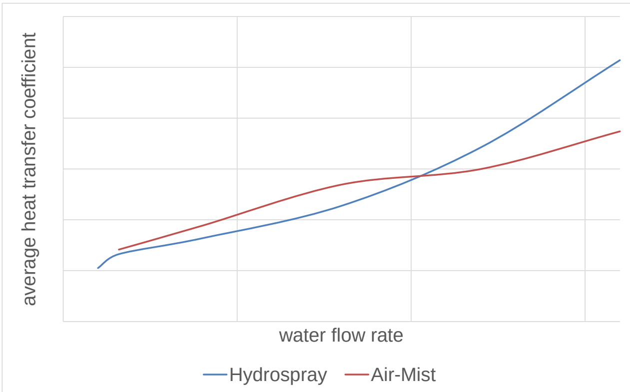

Figure 9: Comparison of HTC results as a function of water flow rate for air-mist nozzle and Hydrospray nozzle unit

Conclusion

A new secondary cooling technology was developed in order to eliminate the high compressed air consumption of existing air-mist systems while maintaining the same cooling flexibility and quality. Extensive testing has shown increased cooling efficiency of the Hydrospray over air-mist nozzles, making it possible to adopt Hydrospray in existing and new continuous casting plants. The same performance is achieved, taking advantage of an increased turndown ratio.

This simple and maintenance-friendly technology combined with the well proven Q-Cool automation software provides a huge energy-saving potential for compressed air consumption and associated energy consumption and CO_2 emissions.

The next steps

Hydrospray tests will be performed on a conventional slab casting machine in China in 2019.