Title of the Paper :

Improved secondary cooling for continuous casting

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Synopsis: The demand for improved product quality and increased productivity has focussed attention on the need for more efficient systems of spray cooling during continuous casting. Nozzle characteristics must be investigated and test procedures developed to measure cooling patterns and heat transfer. Improved nozzle design and air/water systems gives in better water distribution and this reduces corner cracking and core segregation. There are also important operational benefits which enable expansion in the product mix.

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Many slab and bloom casters built in the 1970s and 1980s are still equipped with nozzle systems that require modification to provide the degree of control of modern machines. Since air mist spray nozzles were introduced about 20 years ago, casting technology and spray nozzle technology have been developed in parallel in order to meet stringent demands imposed on product quality and to increase productivity. The major criteria for selection of the spray nozzle is the heat transfer coefficient (HTC) which is determined by the spray pattern, liquid distribution (density), and volume must be economical both to manufacture and maintain. Accurate measurement of HTC is now possible and this allows investigation of all aspects of air mist cooling during continuous casting.

The use of modern air mist nozzle technology in existing continuous casting machines has helped to reduce the incidence of strand surface cracking and centre segregation, and bring down costs by incorporation of maintenance-friendly nozzle mountings and pipe designs. Larger nozzle control ratios are often necessary to match the various casting speeds for new formats and steel grades to be added to the product mix.

To summarise, the need for optimisation is mainly associated with the following:

- Large-scale modernization of the casting machine.
- Implementation of soft reduction or an electromagnetic stirring system

- Significant changes in casting operations due to widening of the product mix
- Elimination of quality problems attributable to the cooling process.

The most important of these reasons is usually the need to improve product quality. Often the demands cannot be fulfilled with the existing cooling system because of inadequate spray characteristics, clogging of the nozzles, and maintenance difficulties. These three problems often occur together.

The first step in an optimisation process is to analyse the existing cooling system and investigate each of the problem areas mentioned above, and to measure heat transfer coefficients. When investigating spray characteristics, it is necessary to verify the nozzle arrangement, to measure the uniformity of cooling water distribution, and to verify the turn-down or control ratios and air-water ratios of the nozzles. The turndown- or control ratio describes the ratio between the minimum and maximum water flow of a given nozzle. The air-water ratio describes the compressed air- versus water consumption in Nm^3/h against l/min.

Spray Nozzle Characteristics

In this section we shall consider some of the factors mentioned in the introductory paragraphs in relation to typical existing air mist cooling systems.

Cooling Water Distribution

In order to measure uniformity of water distribution nozzles are tested in the Lechler laboratories under conditions identical with industrial application at a specific site. That is, at the same spray height and nozzle pitch as in the caster machine. The measuring device shown in Figure 1 is used for this purpose in which the levels of water collected in an arrangement of glass tubes are measured by ultrasonics. Fig. 2 shows the results for an existing two-nozzle system at a water pressure of 1,2 bar and an air pressure of 2 bar indicating a very uneven liquid distribution. A concentration of water is evident at the edges that could lead to an overcooling effect at the edges of a slab. Hence it could be assumed that, in this particular case, the edge cracks and the core segregations experienced by the customer were at least partly caused by the spray characteristics of the existing nozzles.

Fig. 1

Liquid Distribution Measuring Device

Fig. 2

Existing cooling: Water distribution
nozzle arrangements at 1,2 bar water pressure

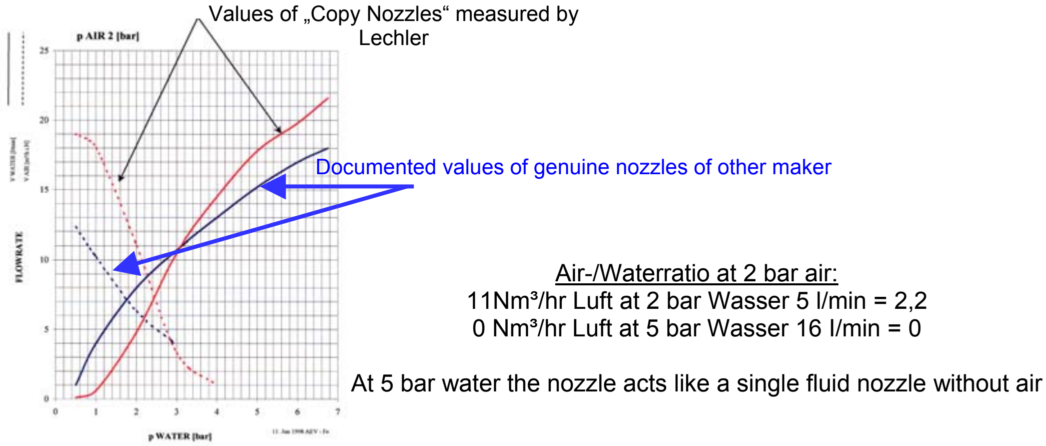
Maintenance

The ease of maintenance of an existing installation can also be investigated during the course of a site survey. Assessment is based on the effort required to assemble and dissemble the nozzles, pipes and headers; the alignment of the nozzles and the nozzle tips in relation to the target surface; and the rigidity of the piping system. Often many small diameter air and water pipes are not shaped and welded according to the original drawings, when they are replaced during maintenance. Pipes are often bent and may be out of position due to either thermal effects or mechanical impact. As a result the water jets impinge on the support rollers instead of the slab surface. To counteract the problem of misalignment, the alignment pins of the nozzle tips are sometimes removed which creates further misalignment difficulties. In some cases nozzle tips are misaligned with the spray jet hitting the rolls and not the slab surface. The likely result is a significant negative effect on the liquid distribution in many of the roller gaps.

Turn-down and Air/Water Ratios

In one investigation, the nozzles tested were locally made copies of the originals and since the machine was operating under different conditions from those initially specified, the turn-down ratio and the air/water ratio were both investigated. There were significant differences between the original nozzle specification and the nozzle in use. Furthermore, the nozzles showed a very steep pressure-flow characteristic which made fine tuning of flow very difficult (Fig.3).

Fig.3



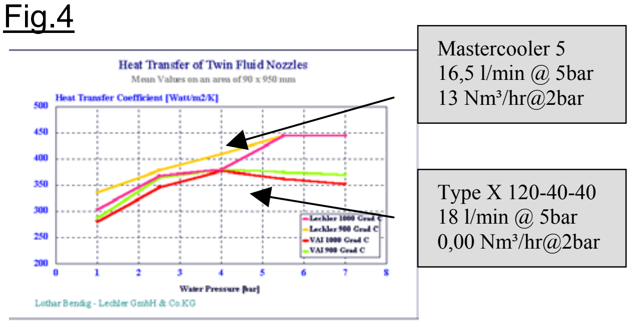
Existing cooling :
Pressure flow diagram nozzle 120/40-40

The most important result of this particular investigation was that the nozzle was operating beyond its designated control range and did therefore not consume any compressed air anymore beyond a water pressure of 4 bar so that the air/water ratio was zero. In fact, this particular nozzle could not be regarded as an air mist nozzle when it was operated at a water pressure of more than 4 bar.

Heat Transfer Coefficient

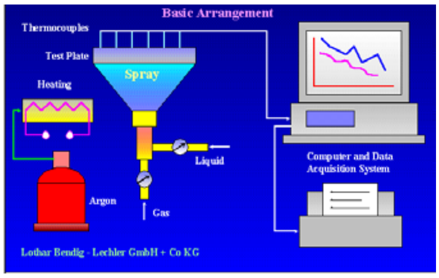
Because of the results of the pressure flow measurements additional heat transfer coefficient measurements were made with the existing locally made nozzles mentioned above. As expected, the nozzles of the cooling zone shows a stagnating HTC at a water pressure above 4 bar. (Fig. 4). The HTC does, in fact, exhibit a slight reduction at higher pressures. Due to the lack of compressed air the existing nozzle performed worse than a conventional single-fluid water nozzle. This explained why no increase in casting speed was possible with the existing cooling system despite increase in water pressure and flow.

Fig.4



Heat Transfer Comparison Measurements

Fig.5



HTC-Measurement Method

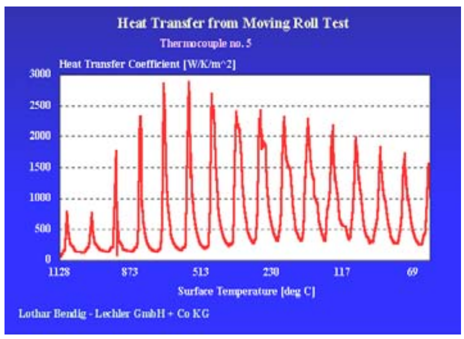
The heat transfer coefficient in this investigation was measured by the 'moving nozzles' test which is shown in Fig. 5. A steel plate with 24 thermocouples, embedded at a depth of 2.5 mm, is heated to a temperature of, for example, 1200°C in an atmosphere of inert gas. The top surface of the plate is isolated whereas the underside is cooled by the nozzle to be tested. The nozzle in the manifold is placed in a movable bed so that the nozzle moves parallel to the plate by means of a computer-controlled electric motor.

To simulate movement of the strand from one roller gap to another, the computer actuates the removal of a deflector plate in order to start the cooling process. The nozzle then moves from left to right with the deflector open and then in the opposite direction with the deflector closed. The temperature of the water and the plate are measured simultaneously until the plate attains the same temperature as that of the water (Fig.6)

Fig. 6

„Moveable Spray Nozzle" & Roll HTC-Test

Fig. 7



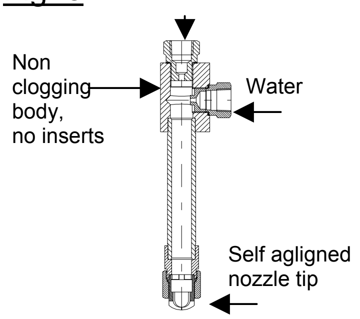
Heat Transfer from Moving Roll Test

The temperature history records and information on the nozzle position in relation to the plate are stored in a data logger. These data are then used as for evaluating the heat transfer conditions and for computation of heat transfer coefficients (Fig.7)

Nozzle Arrangements

In the machine which was investigated it was not possible to modify the existing water pumps or compressors because of cost. In order to reduce the volume of compressed air the original air mist nozzles of the foot roll zone were replaced by conventional single fluid, flat jet nozzles (Fig.8). The volume of compressed air that became available from this zone was added to the air in the remaining zones so as to increase the air/water ratio. These zones were then equipped with Lechler Mastercooler air mist nozzles. In the lower cooling zones the nozzles were staggered from one roller gap to the next in order to avoid edge overcooling and to optimise uniformity of the cooling along the strand radius.

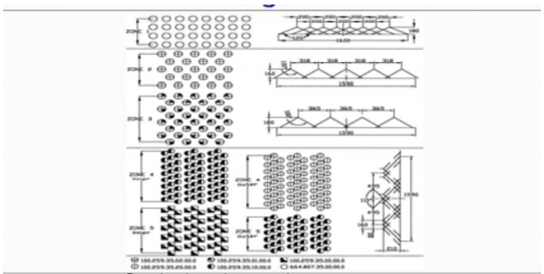
Fig. 8



Diameters of body, pipe, tip inlet and tip shape carefully computer designed (computer prof.) for :
- **High HTC values**
- **Stable spray angle at all pressures & flows**
- **Uniform water distribution**

Mastercooler

Fig.9

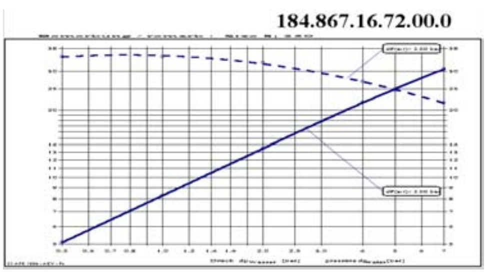


Optimized nozzle arrangements

Modern Air Mist Nozzles

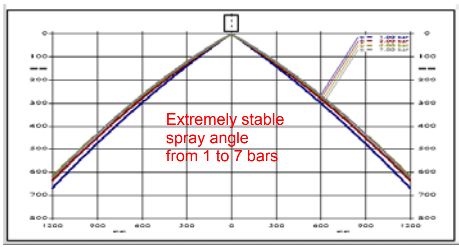
The essential features of modern air mist nozzles such as the Lechler Mastercoolers or Slabcoolers are the mixing chamber, extension pipe, water and air inlet adapters and their internal geometries, as well as the geometry of the nozzle tip. These components must be precision designed with the aid of a computer model to assure a high heat transfer coefficient, stable spray angles and uniform liquid distribution (Fig. 9). The pressure flow curve of the Mastercooler is rather flat and this makes it possible to fine tune the cooling system (Fig.10). Furthermore the typical nozzles of the Mastercooler offer large free passages and hence advantageous non-clogging characteristics. There are no vanes or deflector pins or any other wear parts in the mixing chamber for air and water. The spray width of the Mastercooler is very stable within a range of water pressure of 1 and 7 bar. The constant and uniform spray characteristics that are obtained with this system are shown in Fig. 11. Computer-profiled nozzle geometry is employed to ensure the high stability of these characteristics.

Fig. 10



Mastercooler Flow Diagram

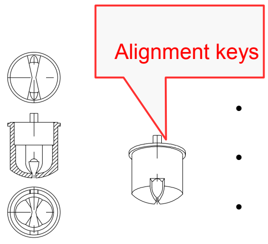
Fig. 11



Spray width diagram Mastercooler

An arrangement of two keys for automatic self-alignment of the tip is a standard feature of the design. It assures correct alignment of the spray jet against the strand surface and hence a high standard of operational safety (Fig. 12).

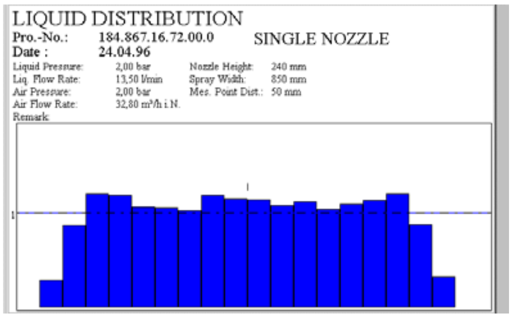
Fig. 12



- Computer profiled
- Self aligning
- Uniform water distribution
- Stable spray angle

Mastercooler & Slabcooler nozzle tips

Fig. 13



Mastercooler: Even water distribution

In order to optimise the nozzle arrangement, Mastercooler nozzles are tested under proposed installation conditions and the water distribution is determined. A high degree of uniformity is achieved across the entire width of the spray at water pressures as shown in Figs. 13 and 14. The HTC of the Mastercooler nozzles for the optimisation process can also be measured and documented as shown in the previous Fig. 4, too. This diagram demonstrates how the HTC rises continuously up to a pressure level of approx. 5.5 bar, whereas the HTC of the Type X nozzle tends to decrease beyond a pressure of 4 bar. Both the Mastercooler and Type X nozzles tested were comparable in size.

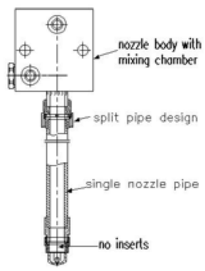
A higher specific water density is not the only factor decisive for the heat transfer coefficient. The air/water ratio must also be considered with compressed air providing the kinetic energy necessary for penetration through the steam layer above the strand surface. This is important at temperatures beyond 650^{0}C because of the Liedenfrost phenomenon.

The HTC value of an air mist nozzle which is not supplied with a sufficient amount of compressed air can not reach the values attained by a conventional single fluid nozzle.

Fig.14

Mastercooler : Optimised water distribution
2 nozzle arrangement at 4,0 bar water pressure

Fig. 15

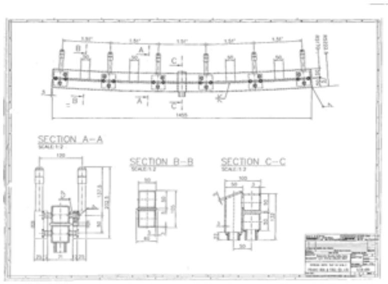


Mastercooler SMART
With split pipe design

In addition to the non-clogging characteristics of the modern Mastercooler nozzles, a maintenance-friendly vertical nozzle mounting design with a plate connection can be selected, the new Mastercooler SMART (Fig.15). This allows greater ease and faster disconnection of the nozzles; and also a much more rigid design of spray header with consequent reduction in the man hours required for maintenance and repair of the spray pipes(Fig.16). A split design of the nozzle's extension pipe is available. In case of a break out only the front end with the tip has to be replaced whereas the nozzle body can remain. This is another cost saving feature.

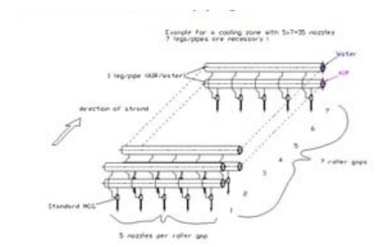
Moreover, with this design it is possible to reduce the number of nozzle feed pipes of a caster significantly. Fig. 17 shows a conventional horizontal piping with nozzle feed pipes routed parallel to the rollers along each roller gap. For a segment having 7 roller gaps on each side totally 7 horizontal pipe manifolds are required to supply the nozzles with air and water.

Fig. 16



Mastercooler SMART
Optimised piping

Fig. 17

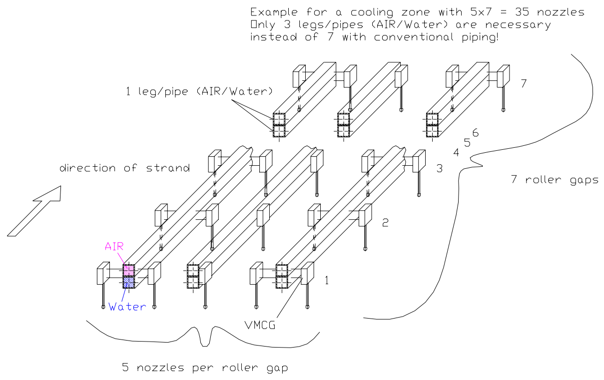


Conventional horizontal piping

An installation using Mastercooler SMART nozzles with the vertical plate connection only 3 pipe manifolds are required, provided the manifolds can be routed in the (vertical) strand direction as shown in Fig. 18. In such a case a staggered positioning of the nozzles is easy to achieve with only one pipe manifold required by simply welding staggering pipes between the nozzle feed pipes and the vertical nozzle connection plates .

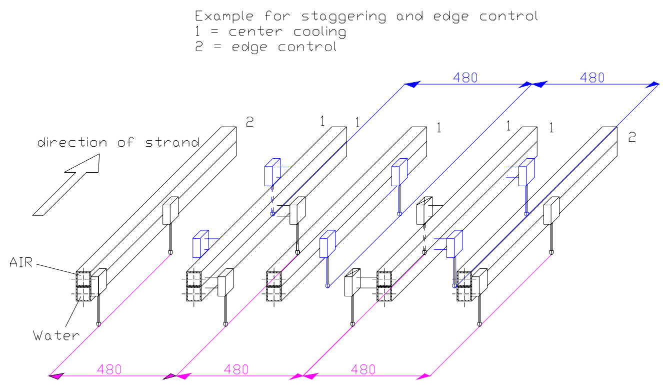
Spray width control (according to the slab width) is another option for which the Mastercooler SMART offers a much more economical segment pipe design. With the horizontal piping and the conventional nozzle mounting method 7 additional (hence 14 totally) manifolds become necesarry for a segment as described above if the outer nozzles need to be switched on and off. Only 5 manifolds (Fig.19) in total for each side of the segment must be installed when utilising the Mastercooler SMART and a vertical pipe design.

Fig.18



Vertical piping with Mastercooler SMART

Fig. 19



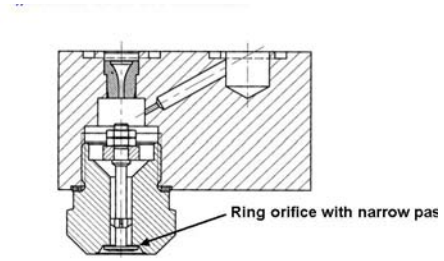
Vertical piping with MC SMART staggered nozzle arrangement and edge control

An additional feature is that the operational safety of the casting machine can be greatly improved since the positioning of the nozzles, nozzle tips and the spray header is always correct due to their greater rigidity. Reduction in the cost of the air and water pipe systems due to simpler design and ease of maintenance is another important benefit of the Mastercooler.

Billet and Bloom Casters

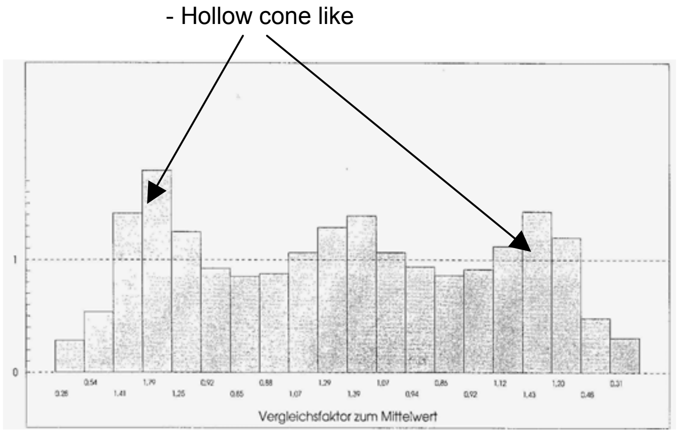
To match the highest demands on quality especially for special steels and stainless steel air mist secondary cooling becomes a must for many new billet- and bloom casters. Airmist full cone or oval cone nozzles are typically the choice for this machines. Frequent nozzle clogging and a liquid distribution causing corner cracks are common problems with the airmist full cone nozzles for billet casters (Fig.20) known as the block nozzles. The narrow ring orifice is easily blocked it produces rather a hollow cone than a full cone(Fig.21).The very high consumption of compressed air of this nozzle type is a further disadvantage.

Fig. 20



„Old full cone block nozzle“

Fig.21



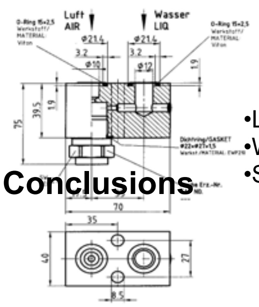
„Old full cone block nozzle“ Liquid distribution

Wherever air mist oval cone nozzles are installed clogging of the nozzle tip is often a problem, too. The cause are the multi slot tips with their extremely narrow free passages. Partially clogged slots lead to uneven cooling and the related surface and corner cracking.

The new Mastercooler MCGB for billet and bloom casters (Fig.22) features very large cross sections which are appr. two times larger than those of the common nozzle designs. An extremely wide turndown ratio (min. : max. water flow) of up to 1 : 14 (Fig. 23) so that an entire billet caster requires one nozzle type only throughout. Hence maintenance procedures and spare part management can be simplified. The full cone spray foot print with soft edges helps to avoid corner cracks (Fig 24). The compressed air consumption is up to 50% lower with new Mastercooler MCGB compared to the older designs. This means that costs savings are possible both on plant investment as well as during operation.

An Mastercooler MCGB with an oval cone having a large size circular orifice and a spray angle (width / thickness) of up to 90° x 60° is also available. This design allows to cover large billet or bloom areas with less nozzles.

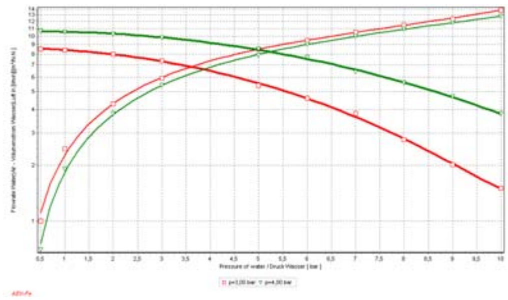
Fig. 22



•Large free passages
•Wide turn down
•Stable full cone

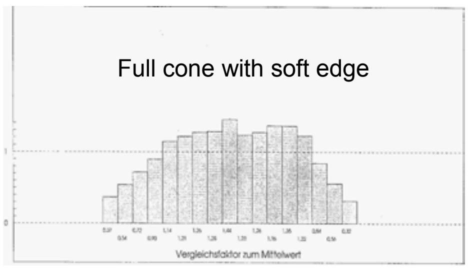
The new Mastercooler MCGB
for billets and blooms

Fig.23



The new Mastercooler MCGB
Pressure flow diagram

Fig. 24



The new Mastercooler MCGB Liquid distribution

Demands to improve both the quality of the product and the productivity of existing casting machines almost inevitably involve an investigation of the efficiency of secondary cooling. Regardless of whether an air mist cooling system is already installed, modern spray nozzles such as those in the Mastercooler, with their individual spray characteristics and with mountings specially designed for the requirements of each particular machine, have a number of important advantages. These include:

- Reduced incidence of surface and corner cracking and core segregation due to the improvement in liquid distribution and reduction in cooling-water flow.
- Enhancement of caster operating conditions for an enlarged product mix due to wider turndown ratio and optimization of air/water ratio.
- Significantly reduced maintenance and pipe costs due to simple and rigid nozzle mounting and spray piping.
- Improvement in operational safety due to perfect alignment of nozzles and spray piping and to reduction in nozzle clogging.

These benefits of the spray nozzles described in this article are now well established and can be readily achieved in those continuous casting plants producing blooms, slabs and thin slabs where it is required to optimise the secondary cooling system.