AUDITS OF SECONDARY COOLING SYSTEMS IN EXISTING CASTERS AS A METHOD TO ENHANCE PRODUCT QUALITY AND PRODUCTIVITY

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Abstract

Over the life span of a continuous casting machine the requirements in terms of production output, product quality and the range of steel grades may change significantly. Consistent production of prime quality over the extended steel grade range requires an increased operational and maintenance flexibility which can be missing from existing casters. The secondary cooling system is a key technology area and its modification can greatly contribute to increased production, quality and flexibility.

A caster secondary cooling audit is a systematic and structured approach to determine how an existing secondary cooling system, operational practices and process automation data, impact on quality and productivity. The scope of an audit can vary from simply increasing nozzle capacities to a complete redesign of a secondary cooling system.

Secondary Cooling Audit

An audit consists of: -

- Benchmarking existing conditions.
- Diagnosing problems.
- Providing solutions.
- Proposal and plan on how to implement process, operational and maintenance improvements so that the required objectives are achieved.

The complex process of continuous casting requires a thorough understanding of the process technology and the environment of a steelmaking plant. Tools such as mathematical solidification models, complete check lists for data collection and standardised audit procedures are essential for efficient project planning.

Benchmarking of Existing Conditions

Establishing and benchmarking existing operational, performance and quality data is at the heart of the audit and provides the foundation from which recommendations can be made. A site survey is generally performed and detailed information is collected to enable a computer aided analysis to be performed. The comprehensive information required for this analysis includes: machine configuration, mould heat removal, support roll layout and cooling arrangement, cooling zone and nozzle layout, nozzle performance curves, steel grades and casting speeds, cooling practices and both quality and operational problems. This benchmarking analysis ensures that the computer models give a true representation of the actual caster. A typical result of this analysis in the form of a strand surface temperature and solidification profile is shown in Figure 1.

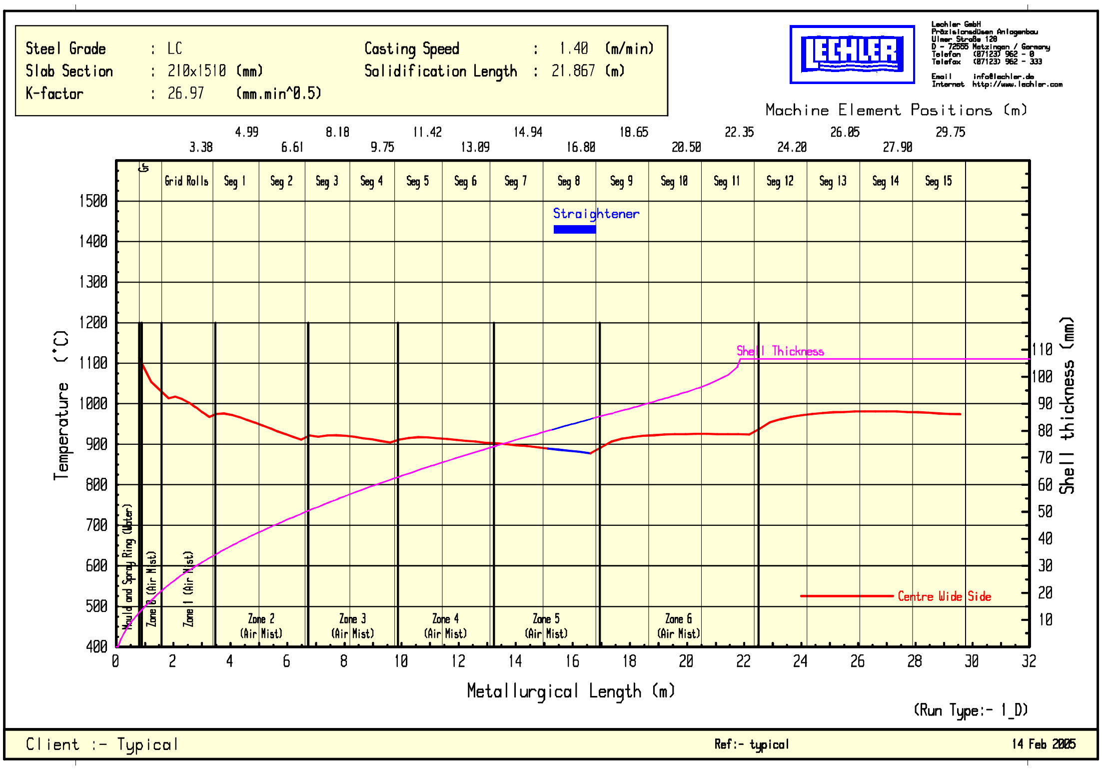

Figure 1 – Strand surface temperature and solidification profile.

Diagnosing Problems

A key to the success and quality of a caster audit and the subsequent proposal for improvements is the investigation of the problem areas through benchmarking. Here the input of the operators, the maintenance personnel together with the investigation of metallurgical quality and defects is required. Actual strand surface temperature measurement data also helps to analyse and benchmark the existing situation.

Following the benchmarking, a detailed computer analysis of the caster performance with regard to steel grades, casting speeds and secondary cooling is normally performed to identify problems areas and distinguish between defects connected with the secondary cooling system or those caused by other effects.

Typical Examples of Problem Diagnosis

If a crack defect is detected in a slab at 40mm depth below the surface, then according to the shell thickness growth shown on the right hand axis of figure 1, this defect can be attributed to a problem in segment 1 at a machine element length of approximately 4,5m.

A modern online temperature scanning device was used for monitoring the slab surface temperature on the casting bow prior to entry into the straightener unit. The output of this device indicated an uneven temperature distribution across the slab width. The temperature deviation was approximately 100^{o}C and was visible as stripes on the strand surface at the exit of the machine.

Subsequent analysis showed that the peaks in temperature coincided with the split roll bearing positions; this was confirmed by the computer analysis shown in Figure 2.

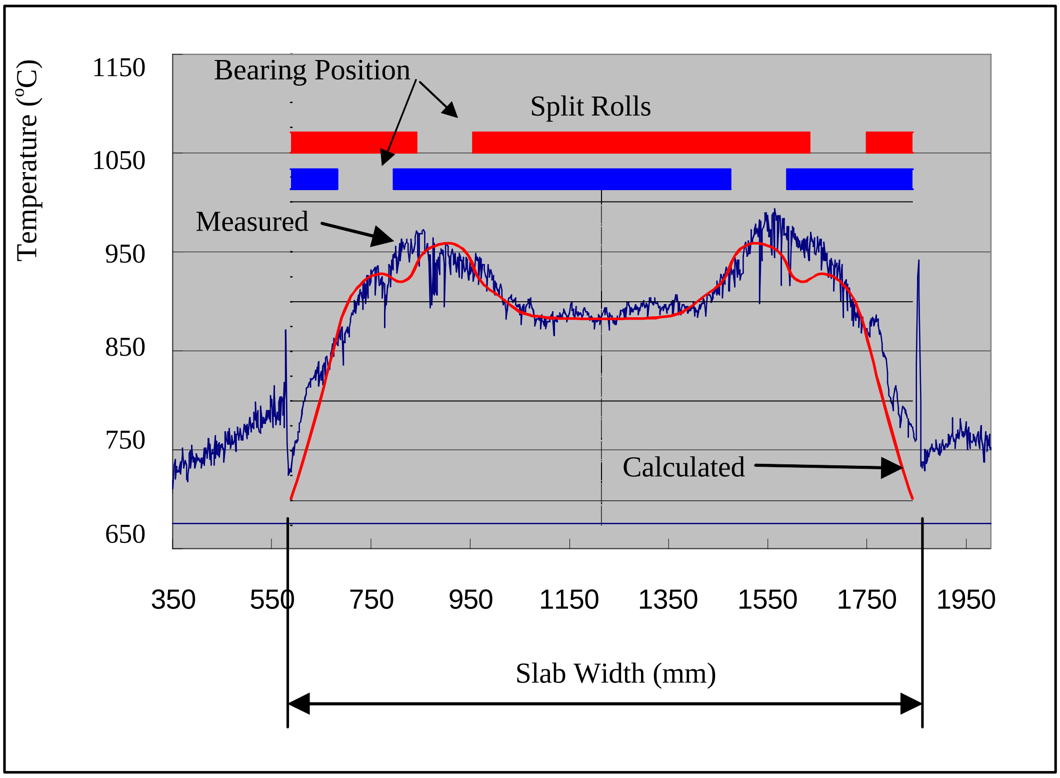

Figure 2 – Strand surface temperature measurement and modelling comparison.

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In this case the casting bow is a ”one piece” design and although the split roll bearing are offset from roll to roll they are inline down the whole of the casting bow. The reduced heat extraction at the bearing positions produces the “striped pattern” shown for half the slab width in Figure 3. The darker line in the centre of the lighter stripe coincides with the roll overlaps.

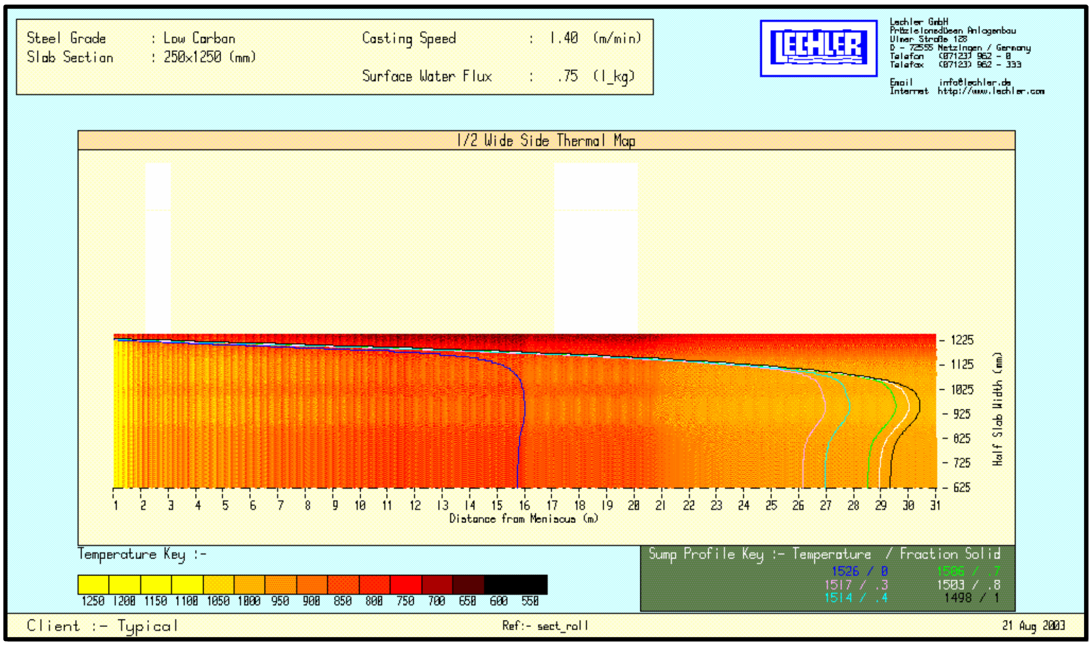

Figure 3 – Surface temperature map of solidification model showing only half of the strand wide side with typical W-Shape crater end.

Figure 3 also clearly indicates that a "W-Shape" crater end profile results from the high surface temperature areas associated with the roller bearings; if soft reduction would be applied for this steel grade then centre line segregation could be expected.

The vertical support girders of the casting bow interfere with the ideal nozzle positions and spray heights (Figure 4); this results in a reduced water density in the non optimal spray overlap area. The nozzle staggering does not completely compensate for this mechanical limitation. This contributes to the effect of the reduced heat removal in the roll bearing area and intensifies the strand surface temperature deviation.

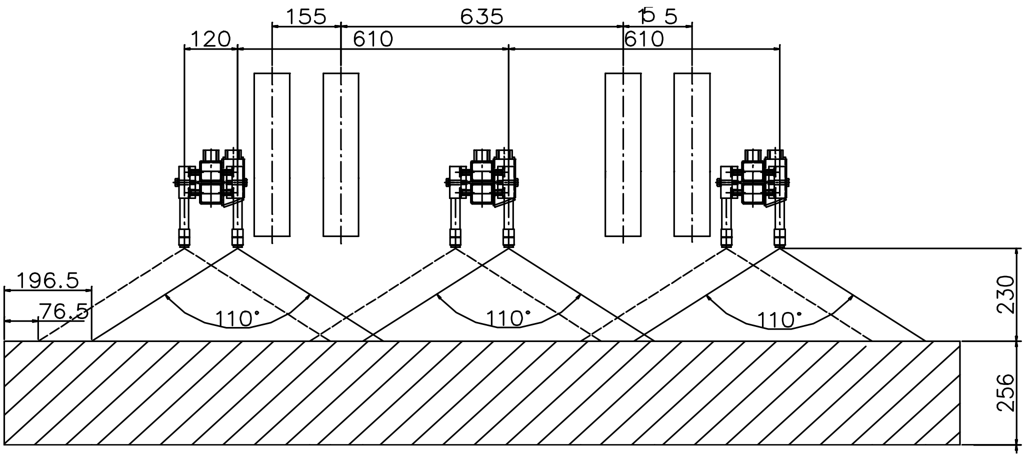

Figure 4 – Nozzle and girder positions.

On Site Plant Survey

The initial step of a caster audit, before the benchmarking takes place, is to obtain an accurate picture of the real situation by conducting an on site machine survey which includes:

- Physical measurements of existing nozzle positions and spray heights in all segments either, on the caster during stand still or, in the maintenance bay.
- Verification of the water flow tables of the secondary cooling control system for both levels 1 and 2.
- Measurements of the maximum available water flows and pressures of every cooling zone.
- Measurements of the maximum available air flows and pressures.
- Investigation of the cooling water supply temperature.
- Investigation of water and air control instrumentation, filtration and pipe dimensions in segments and machine.
- Investigation of existing emergency water tank and exhaust fan capacities.
- Investigation of existing water treatment, pump and compressor capacities.

In most cases experience has shown that any existing documented data is not usually reliable since changes and modifications may have been made over the life span of a machine. These changes have often been made without updating the documentation.
Observation of events, unexpected behaviour, minutes from interviews and meetings as well as digital photographic recordings are also a part of the on site survey. In Figure 5, misaligned and off position air mist nozzles can be seen, the sprays are colliding with support roll so reducing their cooling efficiency.

Figure 5 – Misaligned and off position air mist nozzles.

Off Site Analysis

The next step of the audit is to analyse and further verify the collected data, an action that is performed off site.

Water flows and in the case of air mist, compressed air flows, together with their related pressures are always the centre of focus. If documented and measured data contradicts, then potential error sources are identified by specific calculations. These include pressure drops, location of bottlenecks caused by instrumentation components or additional fittings and incorrect flow table values in the secondary cooling control systems.

Samples of all existing nozzles are measured in the nozzle laboratory and actual pressure flow diagrams are established for comparison with the plant data. In the case of multi nozzle arrangements, water spray distribution measurements are performed over the entire control ratio (minimum to maximum water flows) under plant conditions in terms of spray height and nozzle pitch.

Figure 6 shows a poor spray water distribution resulting from an excessive (too large) nozzle pitch in the centre of a four nozzle per roll gap layout. Here the headers were not manufactured as per drawing and modifications had also been made to the segment without reference to the nozzle positions.

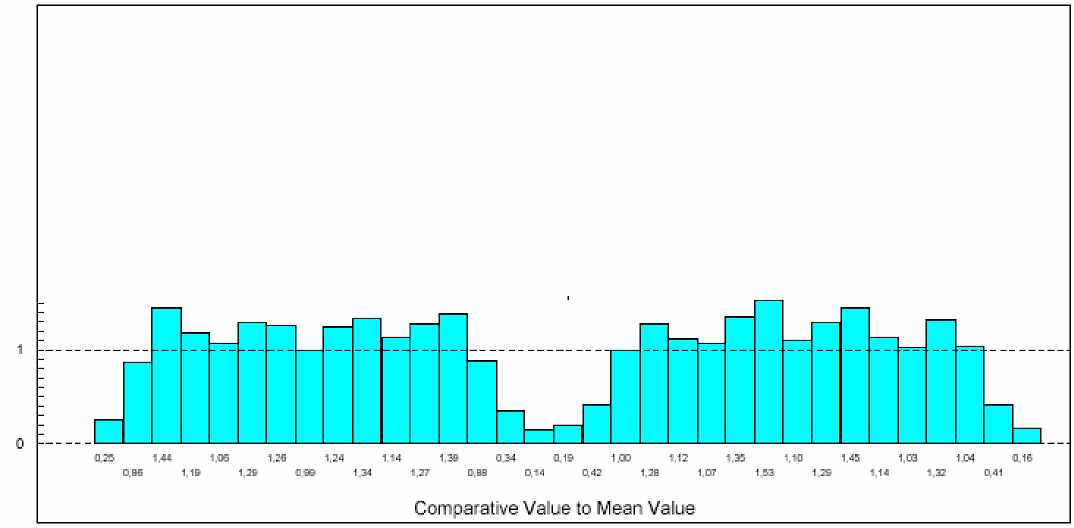

Figure 6 – Poor spray water distribution caused by false nozzle pitch in the centre.

The problem of transverse surface and corner cracking associated with Micro Alloyed Steels is often found in older slab casters which have single nozzle arrangement installed in a roller gap. This arrangement always sprays with a constant spray width irrespective of slab width. Depending on the spray characteristic of the installed nozzle, either the strand corner or the centre is overcooled. The cracks are created during bending and straightening when the strand surface temperature is (partly) in the critical low ductility temperature region between 700°C and 950°C (Figure 7). In these casters corner cracking occurs mainly when casting narrow width slabs.

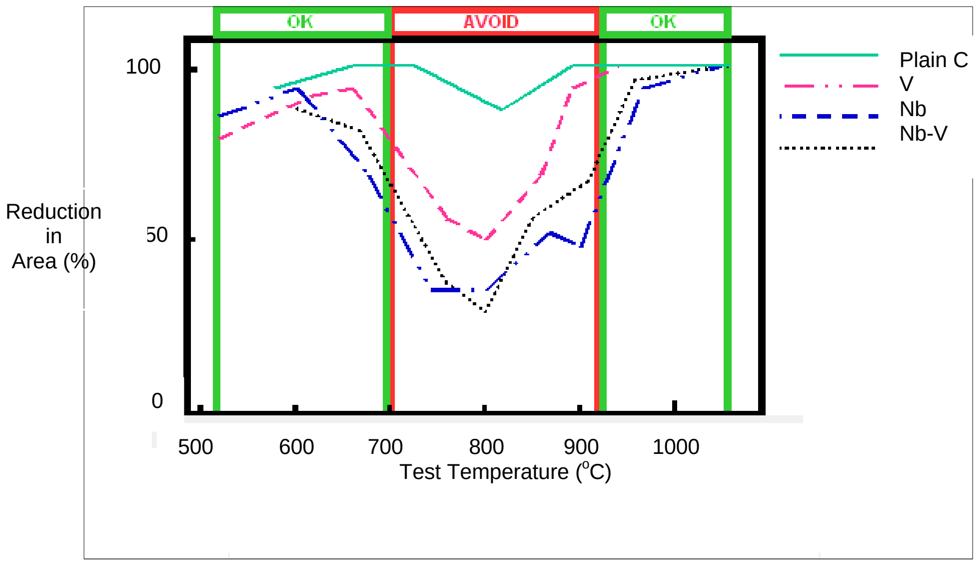

Figure 7 – Steel grade temperature related ductility curves Micro Alloyed Steels.

In an attempt to solve nozzle clogging problems, a twin or a multi nozzle arrangement is sometimes replaced by a single nozzle in a roll gap. This increases the single nozzle size and hence the free internal passages. However, due to the increased spray height which becomes necessary in order to cover the same strand width, the spray footprint on the surface widens and can result in spray collision with the support rolls as shown in figure 8. This reduces the heat transfer significantly because:

- The water flow available to cool the strand surface is reduced.
- The increased spray height reduces the spray impact.
- The wider spray angle reduces the spray impact.

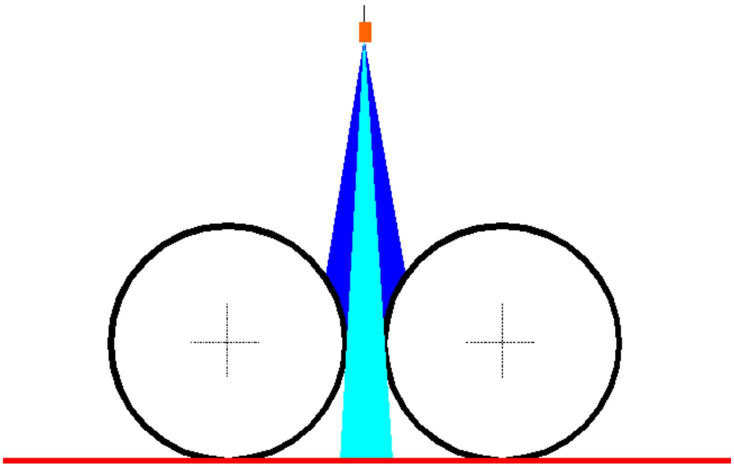

Figure 8 – Spray collision with support rolls.

Multi-nozzle layouts use nozzles with smaller spray angles which produce a more stable spray pattern over their operating range. However, poorly designed and arranged nozzles can produce uneven heat removal particularly in the overlap areas. Consecutive rows of such nozzles can produce “temperature stripes” on the strand surface, which can result in quality problems. See Figures 9 and 10

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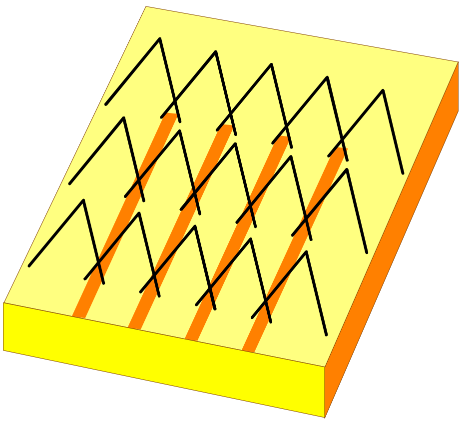

Figures 9 and 10 – “Inline” nozzle layout causing temperature striping.

Nozzle heat extraction capability reduces with increasing spray water supply temperature as shown in Figure 11 and can lead to both operational and quality problems.
Compensation factors which increase or decrease the spray water flow with respect to supply temperature can be used to eliminate these problems, but they can have a significant effect on the useable water turn down of the nozzle. Addition factors will increase the required maximum nozzle design flow and as such increase the achievable minimum flow, this effectively “over sizes” the nozzle. Water flow turndown during periods when the temperature factors are not applied will be reduced so increasing the risk of overcooling at low casting speeds. This situation becomes more critical for single fluid nozzles because of their inherently limited turndown.

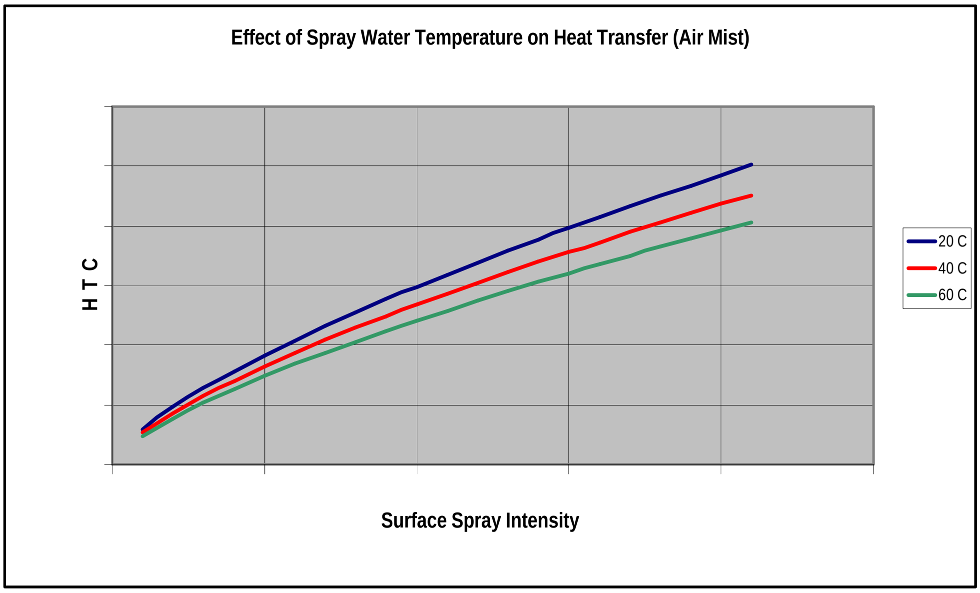

Figure 11 - Effect of spray water temperature on HTC (air mist nozzles).

Setting the Objectives for a Revamp

There can be a number of reasons for conducting a detailed caster audit. The most common are:

- Identify product quality defects and to eliminate them.
- Improve maintenance friendliness and reduce costs.
- Increase production by increase of casting speeds.
- Change of strand formats and steel grades (product mix).

In most cases it is a combination of all four reasons that determines the objectives for a revamp of the secondary cooling system. It is important that these objectives are clearly defined so as to provide the audit party with a clear focus when preparing the final caster audit report and subsequently, the feasibility study for the revamp.

Providing Solutions

Using the previous analysis and the benchmarking as a basis, modifications to the secondary cooling system are proposed. These modifications are aimed at an economical and operable solution with the objective of achieving the new requirements; again computer analysis is applied to ensure the integrity of the modifications. If necessary the proposal can include modifications to supply pipe work, both on and off the caster, together with control instrumentation and control data.

Proposal and Plan

A comprehensive report is produced and submitted for further discussions and the derivation of an action plan. The report includes:

- Conclusions on existing casting conditions.
- Recommendations and observations with regard to the new objectives, together with proposals on the following areas:-
    - Secondary cooling layout.
    - Nozzle layout and capacities.
    - Maximum and minimum flow rates.
    - Secondary cooling control.
    - Supply pipe work.
    - Control instrumentation.
    - Secondary cooling control and control data.
- Conclusions and recommendations on operational and maintenance practices.
- All vital secondary cooling system utilities.

When proposing modifications which give the secondary cooling system the flexibility to maintain optimum casting parameters, it is necessary to pay careful attention to cooling zone layout and both nozzle positioning and selection. Cooling zone and nozzle layouts must be configured with respect to the steel grades, casting speeds and roll support geometry. In certain cases the actual casting machine segment structure will dictate the nozzle layout in which case the layout may not be ideal but more a compromise. Nozzle selection is dependant on both nozzle layout and the operational characteristics of the caster.

Cooling Zone Layout

An incorrect cooling zone layout can significantly affect caster operation, productivity and product quality.

Cooling zones that are high in the caster should be kept short in length so as to minimise the water pressure head differences within the zone; large pressure head differences will produce uneven cooling over the length of the cooling zone. This will be more apparent at slow casting speeds where generally the spray nozzles are operating close to their minimum water flows and pressures. Short cooling zones also allow better control of surface temperature and solidification in this critical area of the caster; long zones can lead to non ideal temperature profiles.

Micro alloyed steel grades can benefit from spray width control. This is where the actual sprayed width is automatically adjusted in line with the cast width so preventing over spraying of the strand and as such over cooling of the corners and edges. The result is hotter strand corners and edges, which during bending and straightening minimises the risk of corner and transverse surface cracking.

Nozzle Layout

A good nozzle layout is paramount in fulfilling the operational and production requirements of the caster. In designing a nozzle layout, it is not only important to consider the solidification and metallurgical requirements of the steel grades to be cast, but also the behaviour of the nozzles under operational conditions, the machine segment design and the roll support configuration. It is essential that nozzle arrangements produce an even heat removal across the strand while maintaining a stable spray pattern.

Conclusion

An audit as described and the subsequent feasibility study delivers a wide range of benefits by determining the improvements that can be obtained by an upgraded secondary cooling system with improved operation and maintenance practices. The thoroughly documented final report, containing collected and analysed data and a proposal for future improvements through a system upgrade, forms a comprehensive and indispensable tool for decision making and comparison with other plants. An audit also identifies problems and causes which were previously not recognised. The time, efforts and cost of such work is insignificant in comparison with the potential benefits of a properly executed audit which results in an optimised secondary cooling system.

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