Schäfer & Urbach

Report

"Innovative solutions for descalers"

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Sophisticated solutions for descalers

by

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Summary

Scale formation during hot rolling is affected by the temperature, steel grade, surrounding atmosphere and the exposure time. This paper gives the basics in descaling technology and their application in slab casting lines, heavy plate mills and hot strip mills. There are two kinds of scale relevant in casting plants and rolling mills: Sticky and dry scale. Sticky scale can be removed most effectively by using high pressure systems up to 450 bar. Dry scale can be removed from the surface by application of descaling systems with low distances of the descaling nozzle to the material. In praxis rolling speed, heat losses and ski-formation has to be taken into account. Appropriate combination of scale nozzle type and descaling distance guarantees no loss in descaling efficiency and savings in descaling water. Further water savings are possible due to width dependent descaling. Hydraulic actuators provide a height dependent descaling especially for varying thicknesses of the incoming slab, heavy plate or strip. Slab descaling in slab casting plants on one hand side has the advantages of save slab transport using magnet-cranes, improved slab inspection in the slab yard due to better surface quality and principally on the other hand side of energy savings due to direct further processing in the rolling mill without inserting into reheating furnaces. The process chain can be shortened and ressource efficiently production can be realized.

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Fundamentals in hydromechanical descaling

Scale formation and types of scale. Scale is generated by formation of oxide nuclei on the steel material surface. At the beginning the oxide nuclei are sticky to the steel surface and without any pores. They grow homogeneous along the surface. With growing oxide layer the orientation of the nuclei is lost and pores are generated partly due to material transformation. The upper oxide layers will get less sticky.

Scale formation is influenced by the chemical composition of the steel material, the behaviour of time and temperature during the reheating and rolling process, the surrounding atmosphere as well as the surface condition before starting the reheating. Scale is generated by decomposition of iron oxide into wuestite and hematite.

During hot rolling there are three chemical processes between steel and oxygen starting with minimum temperatures of 570 °C. The iron oxides FeO (wuestite), Fe_3O_4 (magnetite) und Fe_2O_3 (hematite) are formed due to the equations

$$2Fe + O_2 \rightarrow 2FeO \text{ (1)},$$
$$6Fe + 4O_2 \rightarrow 2Fe_3O_4 \text{ (2)},$$
$$4Fe_3O_4 + O_2 \rightarrow 6Fe_2O_3 \text{ (3)}.$$

Iron oxides are formed under low oxygen pressures. Wuestite with temperatures of more than 570 °C is generated first and is from the thermodynamical point of view the most stable oxide. In dependence of the pressure on the phase boundary the higher oxides are formed instead of the lower oxides [1].

All oxides are stable during hot rolling of hot strip and heavy plate material because the temperatures are in between 800 °C and 1150 °C. I.e.: Principally scale is generated on the steel material surface in the hot rolling process.

Regarding quantitative analysis of scale formation the velocity of oxide growth is determined by gravimetric measurement. During oxidation the probe absorbs oxygen, the increase of mass is evaluated by a sensitive balance.

Kinetics of scale formation.

Scale formation during hot rolling is given by the parabolic equation

$$s^2(t) = 2 \cdot k' = k_{p,l} \cdot t \text{ (4)}.$$

In the equation s indicates the scale layer thickness, $k_{p,l}$ the parabolic/linear scale formation constant and t the time. The descaling law is known since the beginning of the 20th century and was derived from the kinetics of solid diffusion [1]. Linear scale formation is dominant at the beginning of the process up to a critical scale layer thickness which is determined by the quotient of the parabolic and linear scale formation constant. When the critical scale layer thickness is reached further scale formation is performed by the parabolic law.

The scale formation coefficient is dependent on the steel materials temperature.
S. Arrhenius gave the empirical equation

$$k_{p,l} = A_H \cdot \exp\left(-\frac{Q}{R_{gas} \cdot T}\right) \text{ (5).}$$

In the relationship A_H means the frequency factor, Q the activation energy, $R_{gas} = 8,31451 \frac{J}{mol \cdot K}$ the gas constant and $T[K]$ the absolute temperature of the steel material.

The dependence of temperature during linear oxidation is influenced by the kinematic viscosity and the binary diffusion coefficient of the gas. There is only little dependence of temperature for the corresponding values which results in low activation energy values [1]. During parabolic oxidation there is a strong dependence of temperature for the scale formation coefficient caused by diffusion of iron ions through the oxide layer. The magnitude is further dependent on the chemical composition of the steel grade.

Figure 1 gives by example the scale layer thickness for the austenitic steel grade AISI 304 as function of time. For the calculation a temperature of 1150 °C was assumed. This temperature corresponds with the discharging temperature of the slabs from the reheating furnace during hot strip and heavy plate rolling. There a thicknesses of the scale layer up to 150 microns possible.

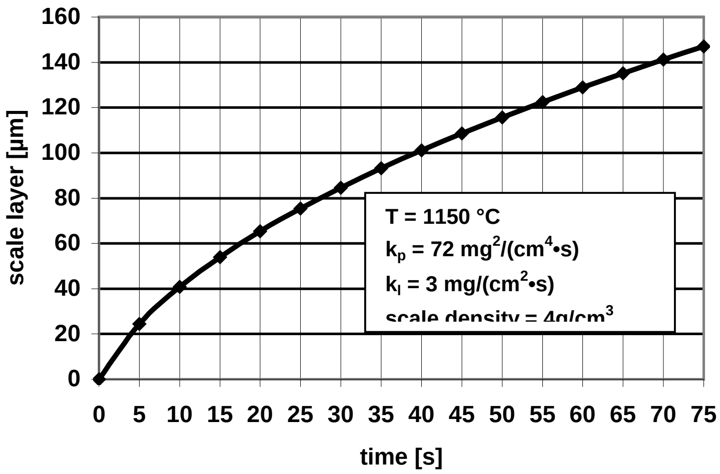

Figure 1: Scale formation during hot rolling – Austenitic steelgrade AISI 304

During hot rolling there a three kinds of scale possible: primary scale, secondary scale and tertiary scale. Primary scale is formed during the reheating process of the slabs in the pusher type or walking beam furnace. Secondary scale is formed during the rolling process in the roughing mill area and tertiary scale within the finishing mill and cooling train.

Scale formation and product quality. In **figure 2** the surface defect sticky scale is shown. This kind of surface defect is caused by rolled in primary scale from the reheating furnace or roughing mill area, which can appear as spot or in form of larger areas as well as trajectories on the material surface. The defect can be distributed irregularly over the length and width on the top and bottom side of the rolled material. Rolled in scale is very difficult to recognise on non descaled steel material. After pickling of hot strip the defect can appear as surface depression with non removed scale material [2].

Figure 2: Surface defect “Sticky Scale” (Rolled in primary scale) [2]

Design of descaling systems

Descaling nozzles. In descaling, the surface of the rolled material is impacted by high-speed water jets with a defined spray pattern. During descaling, a typical sequence of physical mechanisms takes effect, some of them in parallel.

Figure 3 gives the cracking and crushing of the scale layer by the kinetic energy of the water drops.

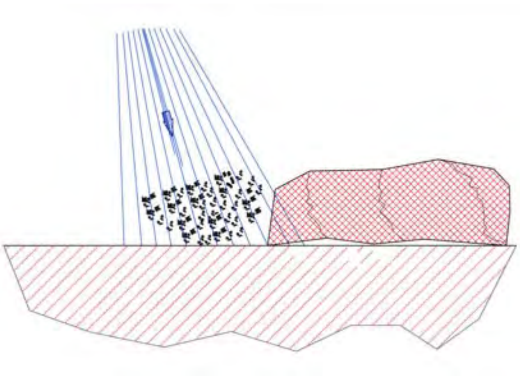

Figure 3: Hydromechanical descaling. Cracking and crushing of the scale layer by the kinetic energy of the water drops

Figure 4 shows the removement of the scale layer by different shrinking of steel and scale material due to water cooling.

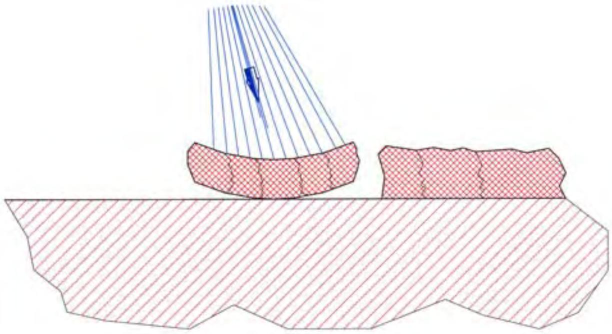

Figure 4: Hydromechanical descaling. Stress caused by different shrinkage of steel and scale material due to water cooling

Splitting off the scale is caused by explosion of water drops under the scale layer. The dissolved scale will be removed from the steel surface by the angled water jets of the descaling nozzle, **figure 5**.

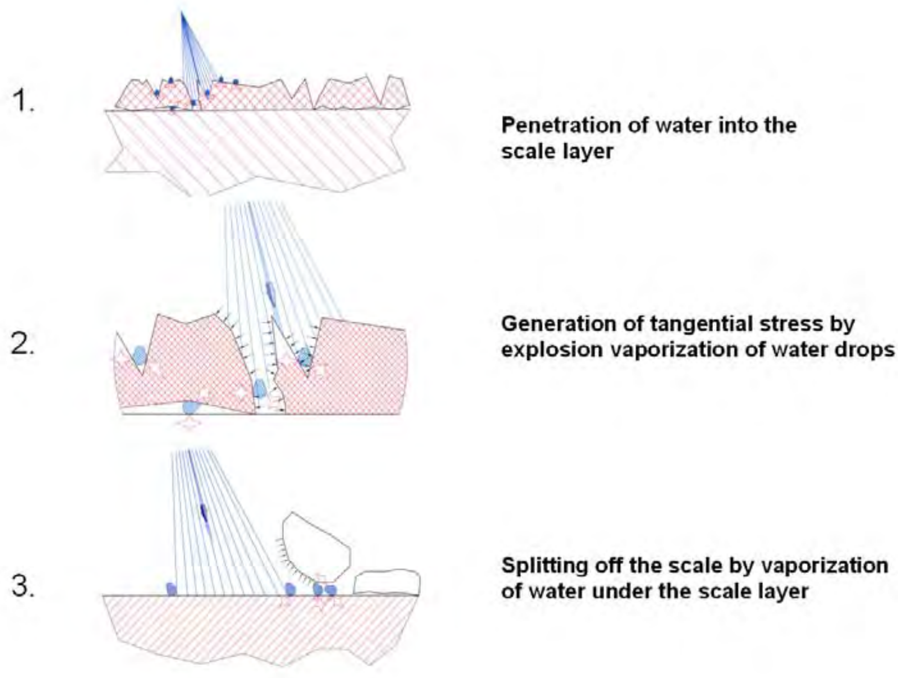

Figure 5: Hydromechanical descaling. Separation of scale layer from steel substrate by explosion of water vapour

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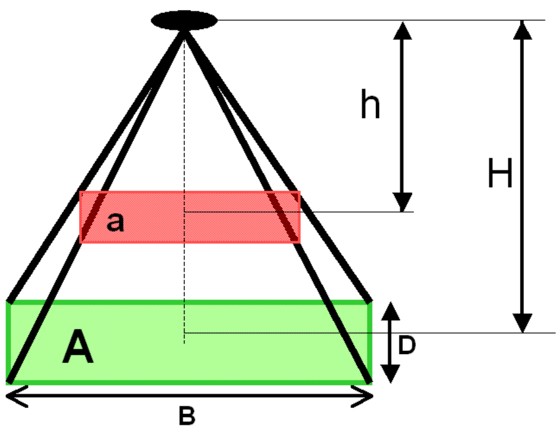
The characterising descaling parameter is the impact, which is expressed as the quotient of spray force and area of coverage in N/mm^2. The impact depends on the

- type of descaling nozzle,
- spray angle,
- volume flow rate,
- spray pressure on the steel surface and
- spray height.

Spray pressure, nozzle size, spray angle and volume flow rate are linear in their effect on impact; spray height has an exponential component, **figure 6**.



There is:
Reduction of spray height by a factor 2 results in an increase of impact by a factor of nearly 4

Variation of spray height gives an influence on spray width B and spray depth D and therefore an influence on the impacted area

Figure 6: Impact and parameter spraying distance

When spray height is varied, then – independent from the spray angle – two dimensions are influenced simultaneously due to geometry: spray width and spray depth. Spray height is therefore the most effective parameter. Halving the distance between nozzle and material surface increases impact by a factor of roughly four.

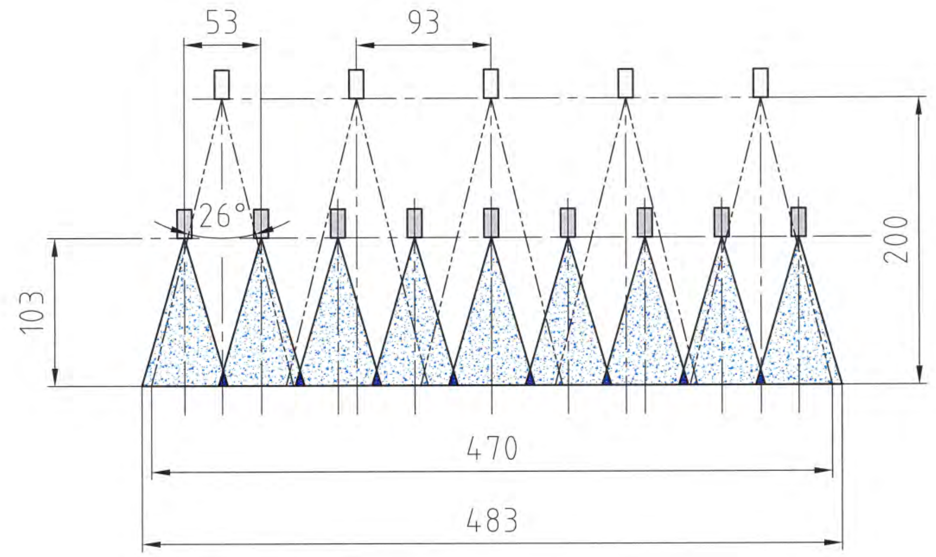
This means that to optimize cost-efficiency the spray distance should be as short as possible, although in practice heat loss, material speed and irregularities of the geometric form (ski-formation) have to be considered.

The design of the descaling system has to be based on the type of scale encountered. Most of the primary scale arises in the furnace. To allow furnace scale to be removed easily, the furnaces are operated with an oxidizing furnace atmosphere. The furnace operation practice and the inserted steel grade have a great influence on scale formation. A thick and dry scale layer is easier to remove than a thin, firmly adhering scale layer. If the scale is dry and thick, cooling produces differential shrinkage of scale and steel. Tangential shear forces occur at the boundary layer which cause the scale to crack.

With thin, firmly adhering scale the situation is different. This adhesive scale also occurs in oxidizing furnace atmospheres on high-alloy and low-carbon steels. Owing to the firm adhesion of the thin scale layer it is not easy to utilize shrinkage in scale removal. Breaking and flushing are required in this case, calling for higher impact and lower water coverage per unit area. This means the spray distance must be short and small nozzles must be used [3].

The descaling layout software provided by the nozzle manufacturer Lechler makes it possible to make reliable predictions of the properties of a descaling system. This program provides on-screen configurations of diverse nozzle layouts and operating conditions, together with graphics of spray patterns and calculations of all parameters. These are automatically recalculated after changes.

The physically induced convergence of the edge sprays means that different effective spray angles can be selected depending on spray height and spray pressure. This function is recorded in a large number of reproducible measurements and is implemented in the descaling software [3].



Nozzle:	**SCALEMASTER HP**	Nozzle:	**Mini SCALEMASTER HP**
Number:	5 pieces 682.766 each 82,02 l/min	Number:	9 pieces 642.606 each 32,53 l/min
Pressure :	200 bar	Pressure:	200 bar
Distance:	200 mm	Distance:	103 mm
Q_{total}:	410,1 l/min	Q_{total}:	292,7 l/min > **Saving 29%**
Impact:	064 N/mm²	Impact:	064 N/mm²

Figure 7: Impact and parameter combination of spraying distance and water flow

Figure 7 gives by example the design of a descaling system with the aim of reducing water flow amount while keeping impact constant. Reducing spray height, use of more nozzles and modification of nozzle type with less specific individual water flow rate results in reduction of water use while maintaining impact constant.
Descaling pumps. Descaling systems in hot rolling mills operate with plunger pumps as well as with centrifugal pumps. Plunger pumps, **figure 8**, have in comparison with centrifugal pumps, **figure 9**, the following advantages:

- The operating pressure for plunger pumps is up to 450 bar in opposite to 250 bar for centrifugal pumps. This means the descaling impact can be increased by a factor 1,8 when operating with plunger pumps.

- The efficiency factor for plunger pumps is 92 % and 75 % for centrigugal pumps. The resulting impact ratio due to the different efficiency factors is 1,23.

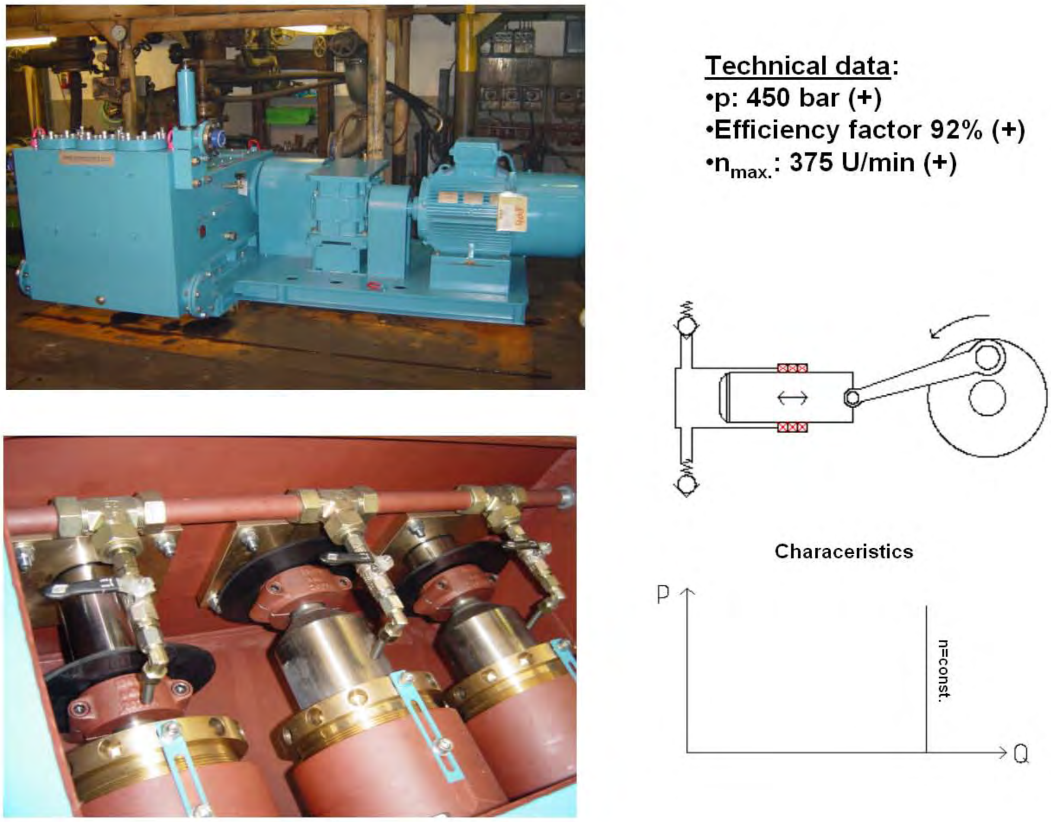


Figure 8: Lay out of descaling systems – plunger pumps

Under consideration of the higher operating pressures and the higher efficiency factor there is an increase of descaling impact by a factor 2,2 possible when operating with plunger pumps instead of centrifugal pumps while keeping all other parameters constant.

The more than one magnitude lower number of revolutions for plunger pumps result in positive manner on system service life time.

Centrifugal pumps are used in descaling systems if great water volume amounts are needed when applying low system pressures.

Plunger pumps are used if low water volume amounts are to be raised when applying high system pressures.

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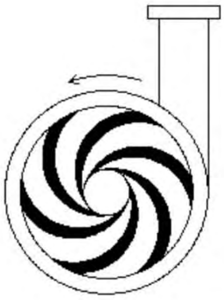
__Technical data__:
•p: 250 bar max. (+/-)
•Efficiency factor 75% (-)
•$n_{max.}$: 5.000 U/min (-)



Characteristics

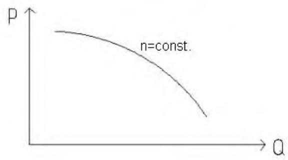


Figure 9: Lay out of descaling systems – centrifugal pumps

Further characteristics of plunger and centrifugal pumps are described in the following.

For high pressure plunger pumps no special design is essential. High pressure centrifugal pumps have to be constructed multiple-staged with axial balances in dependence of the applied volume flow.

When operating with plunger pumps the volume flow rate is proportional to the number of revolutions; centrifugal pumps have a further dependency from counterpressure.

The step-down of plunger pumps is a conventional low cost straight differential. For the step-down of centrifugal pumps special high cost turbo gears are essential.

The solids content in the water descaling system is maximum 50 mg/l for both types of descaling pumps.

Plunger pumps operate independent from the system pressure if the number of revolutions will be kept constantly, i.e. the total volume flow can be used for the descaling process. When applying centrifugal pumps the volume flow varies with the system pressure.

Plunger pumps are easier to maintain in the rolling mill than centrifugal pumps.

Width dependent descaling. Width dependent descaling in hot strip mills can be implemented in two steps by separating the water cycle system for strip widths up to 1.500 mm and larger, **figure 10**. The spray header has to be divided in two sections for the large widths and one section for the smaller widths. The spray headers are fed by one high pressure water conduit, which supplies the middle and exterior part of the spray header. When rolling small strips the exterior part of the spray header can be cut off from descaling by use of water contact valves. This procedure provides reduction of water consumption.

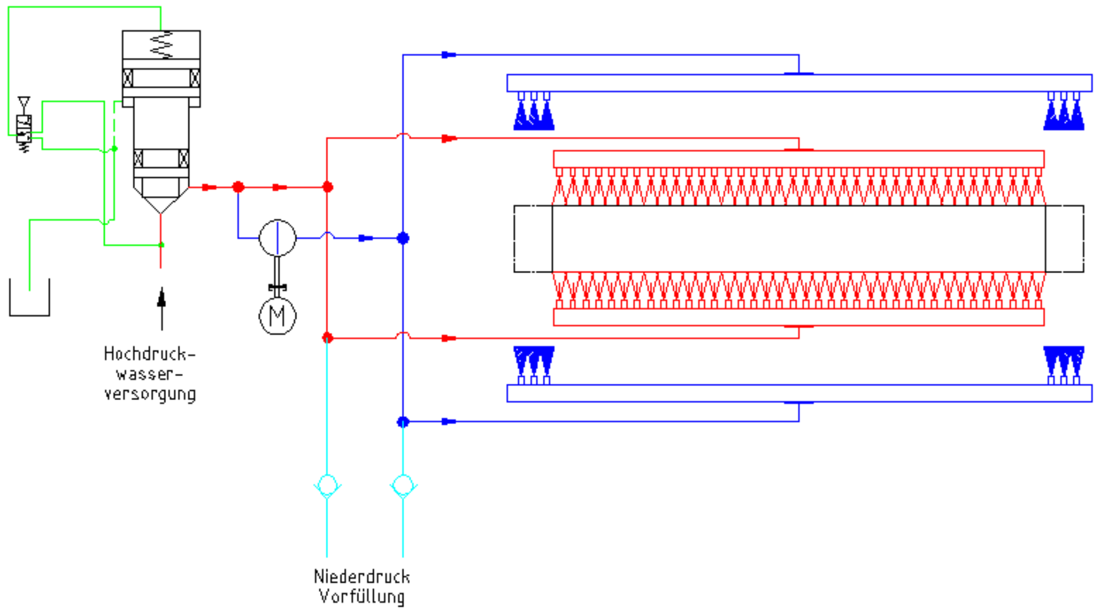


Figure 10: Width dependent descaling by two separated water cycle systems (Hochdruckwasserversorgung: high pressure water supply; Niederdruckvorfüllung: low pressure water supply)

The low pressure water supply is essential for air removal from the water cycle system before starting high pressure descaling.

Figure 11 gives a view of the descaler at the entry of the finishing train of the Huyndai hot strip mill in South Corea. One can recogize the water conduits of the descaler in the front part. The time for changing one spray header is roughly 30 minutes. This can be achieved by use of a quick locking coupler and hydraulically acting hoods of the descaling box.

Questions regarding descaler design. To guarantee impermeability of the valves and to prevent tracking water after descaling nonrigid seals are used. Solid contents in the descaling water can be minimised by use of automatic filters or the application of precision filters with a maximum size of 50 microns.

Nozzle wear with the consequence of pressure and impact drop and the wear of valves as well as the water filtering can be achieved by application of precision filters or sand-filters.

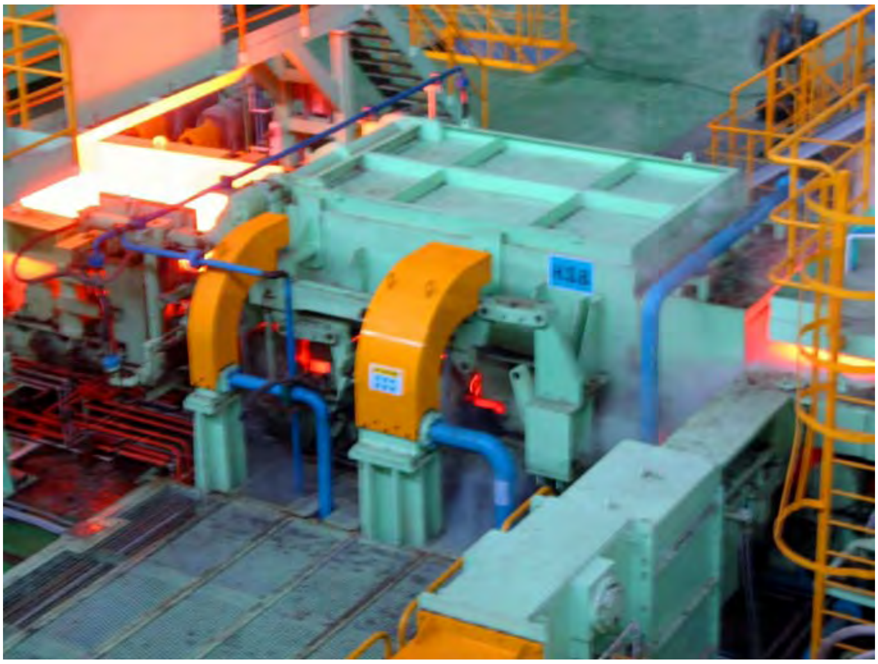


Figure 11: View of the descaler at the entry of the finishing mill of the Hyundai Steel hot strip mill

Wear of the descaling box can be reduced by means of usage of ceramic protection elements and by strengthening the box with high-strength steel material.

Water and scale removal into the sinter channel is enabled by multiple and movable water curtains or by integaration of angled water catchers into the descaling box.

Silencing of descaling noises is achieved by the low water pressure supply of the header before descaling and by application of direct driven pumps.

Descaling projects

In the following three descaling projects – carried out by the system supplier Schäfer & Urbach – are presented:

- Descaling of slabs in the slab casting plant of HKM in Duisburg,
- Primary descaling of reheated slabs in the 4,5 m heavy plate mill of Severstal in St. Petersburg,
- Primary and secondary descaling in the hot strip mill of Hyundai Steel in South-Corea.

Slab descaling at HKM. The slab descaling system at HKM was commissioned in 2005, **figure 12**. The descaling system consists of three parts: (1) All components which are located nearby the casting strands, (2) All components located nearby the high-pressure water pumps and (3) filtering station on the low pressure side of the system.

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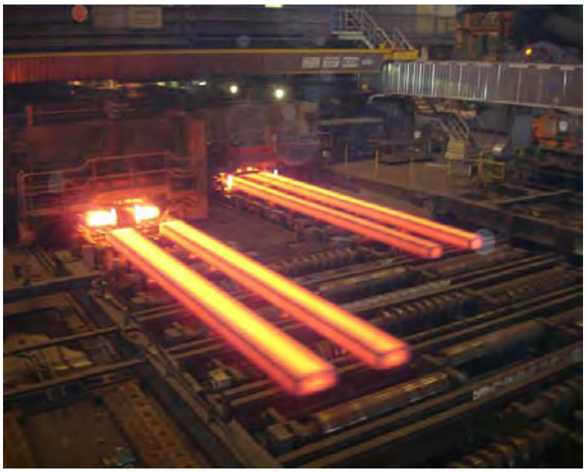


Figure 12: Descaling system for the slab casting plant with four individual strands at HKM

The descaling system for the two casters consists of four plunger pumps, each pair of them for one strip caster. One pump of the pair is stand-by with the possibility to carry out maintanance work while operating with the other pump. For adjustment of the descaling pressure the motors of the plunger pumps are frequency-controlled driven. This gives the ability of adaption of the jet force to the cast steel grade.

The spray height of the descaler is 120 mm and the descaling pressure 210 bar.

Slab descaling gives the following advantages to the customers in the hot strip mills in Bochum and Hohenlimburg:

- The descaled slabs are free from so called "Kelvin-Holes" with measured temperature differences in the order of magnitude of 100 K.
- The scale free surface enables crane slab transport with magnets.
- Due to the scale free surface improved slab inspection is possible in the slab yard.
- Slab descaling causes the omission of the isolating scale layer, which impedes the energy input during slab reheating in the furnaces of the rolling mill.
- Principally the slabs can be further processed in the mill in one heat (direct charging).

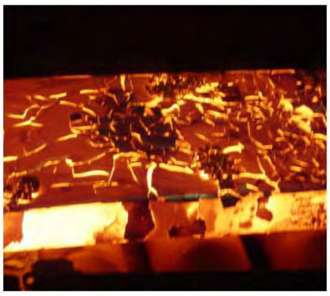
Primary descaling at the heavy plate mill of Severstal. The task when commissioning the primary descaling system at the heavy plate mill of Severstal in St. Petersburg can be summarized as follows:

The special steel grades with sticky scale effort a high descaling impact. The impact value of $2,67\frac{N}{mm^2}$ is achieved by application of a plunger pump with an operating pressure of 320 bar. The slab thickness is in between 150 mm and 900 mm. For guaranteeing constant spray height the top header is hydraulically adjustable.

Figure 13 gives the applied high pressure plunger pump, the nozzle header and the surface condition of the slab before and after descaling.

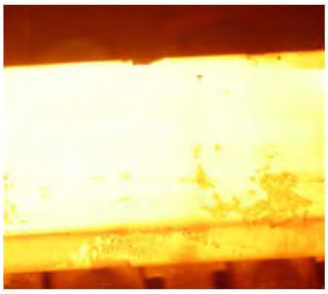
High pressure plunger pump PPW 220

Nozzle header



Slab before descaling

Descaler



Slab after descaling

Bild 13: Primary descaling system at the heavy plate mill St. Petersburg at Severstal

Primary and secondary descaling at Hyundai Steel hot strip mill. In November 2006 complete systems for primary and secondary descaling had been put into operation at the Huyndai Steel hot strip mill in South Corea. The ½ - continuously operating mill is equipped with a coilbox and 6 finishing stands. The rolled steel grades are further processed in the cold mill. The final customer is the automotive industry with high quality demands regarding the strip surface.

The descaling systems in the hot strip mill are equipped with hydraulically adjustable top spray headers due to varying slab and transfer bar thickness. The spray height for the primary descaler is 110 mm and 98 mm for the descaler at the entry of the finishing mill. Strip width dependent descaling is possible. The descaling pressure is 450 bar.

Outlook

Further developments in the field of application of high pressure pumps and descaling technology are planned:

- Roll surface cleaning with high pressure pumps. This technology has been implemented successfully in aluminium hot rolling mills and can be transferred to steel rolling mills. In aluminium hot rolling mills the roll surface is cleaned by applying high pressure water of about 700 bar via an oscillating nozzle header. The driven brushing system with a high failure rate is not essential anymore for the roll cleaning process. In some heavy plate mills high pressure pumps for roll surface cleaning had been already tested.
- Strip cleaning with high pressure. Steel strip material will be protected against corrosion by applying metallic or non metallic coatings onto its surface in processing lines of a cold rolling plant. The coating process assumes a dirt and particle free strip surface. The surface is cleaned by applying brushes and acid fluids in the cleaning section of the processing lines. First tests with high pressure water cleaning devices with 450 up to 900 bar have prooven econimical benefits and increased process safety in strip processing lines.
- due to prevention of particle transfer from the rolls to the strip. Formerly the aluminium rolls had been cleaned by a brushing system. The installation of a high pressure cleaning system provides continuous production without interruptions due to changes of the brushing system. For the steel sector such a roll cleaning facility is not available so far. Especially when rolling strip with critical surfaces for the automotive and packaging industry the roll and strip surface and therefore the yield can be improved in the hot strip mill by the new system.
- Descaling nozzle control by comparison of measured and calculated flow rate at the spray header.
- Erection of systems for predictive maintenance by condition monitoring of the descalers.
- Erection of service points for spare part delivery just in time.

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