Scale formation and its removal in Hot rolling Process
Santosh Chacko, Suresh Vasani, A.K.Ray
Lechler (India) Pvt. Ltd., Thane, India
E-mail: lechler@lechlerindia.com

During hot rolling of steel, its surface is exposed to air which leads to oxidation, resulting in scale formation. The scale formation is affected by the temperature, steel grade, surrounding atmosphere and the exposure time. There are two kinds of scales relevant in rolling mills – sticky and dry scales. Sticky scales can be removed most effectively by use of high pressure water jets upto 450 bar. Dry scales can be removed from the surface by application of descaling systems with low distances of the descaling nozzle to the material.

Nozzle characteristics and spray header design play a major role in the performance of descaling system. The paper focuses on the recent innovations of descaling nozzles.

INTRODUCTION

Besides the customers in the automotive industry, manufacturers of construction and agricultural machinery using hot rolled steel for outer body parts demand defect free surfaces. The production of oil and gas pipe lines also has set very stringent surface quality standards to the plate mills rolling of API grades of steels. Especially existing rolling mills entering into these lucrative markets for high quality steel often struggle to fulfill those quality requirements because of limitations of the descaling systems installed in terms of pressure and flow rate. In view of the above, nozzle manufacturers must have detailed knowledge of the performance of the nozzles under operating conditions and system design. Of particular concern are:

• Nozzle spray characteristics
• Variables of impact
• Design parameters of an optimal nozzle arrangement on a descaling header

SCALE FORMATION AND SCALE TYPES DURING ROLLING

During hot rolling of strip, its surface is exposed to air which leads to its oxidation. Structure and growth of scales so formed depends on the chemical composition of the steel material, temperature, surrounding atmosphere, exposure time as the chemical composition of the steel material, temperature, surrounding atmosphere, exposure time as well as surface condition before starting the reheating. Scales are composed of Wustite (FeO), Magnetite (Fe₃O₄) and Hematite (Fe₂O₃). Below 570°C, FeO is not stable, only Fe₃O₄ and Fe₂O₃ are present while above this temperature, these two oxides are accompanied by inner layer of FeO. It is generally considered that their growth in pure iron is controlled by diffusion of iron vacancies in FeO and Fe₃O₄ and by oxygen diffusion in Fe₂O₃.
In course of oxidation, certain elements contained in steel become concentrated at metal/scale interface. This local enrichment can be compensated by inward diffusion into metals. However, under practical conditions, their accumulation due to oxidation is much more rapid than their inward diffusion so that interface becomes enriched in alloy additions and residuals. For a few alloying elements, morphology of scale can broadly described as below.

Manganese forms oxides MnO, Mn₃O₄ and Mn₂O₃ which are isomorphous to the corresponding iron oxides with which they form solid solutions. Manganese is thus oxidized along with iron and is present in considerable quantity in the scale.

Chromium and Aluminum have identical behaviors during oxidation. When present in large amounts, they can form external oxides (Cr₂O₃, Al₂O₃) at metal/scale interface which can protect the steel from further oxidation. However, in carbon steel, their concentrations are too low for this.

Nickel is rejected at the scale/metal interface in form of metallic filaments which promote pegging between the scale and the substrate. Sulphur bearing steels contain oxides (Fe, Mn)O and sulphides (Fe, Mn)S inclusions and can form liquid oxysulphides. Minimum temperature at which this can happen depends upon the amount of Manganese in solid solution. It is 900°C for 10 ppm Mn and can rise to 1200°C if steel contains 1% Mn. With formation of low melting point phase at temperature above 960°C, it can lead to preferential attack of metal grain boundaries.

The effect of Silicon depends upon temperature range. Below 1177°C, FeO reacts with silica (SiO₂) to form fayalite (Fe₂SiO₄) at metal/scale interface. In contrast, a eutectic reaction occurs between FeO and FeSiO₄ at 1170°C leading to formation of liquid phase. Liquid phase preferentially attacks the grain boundaries of metal making the scale highly adherent.

During hot rolling, three kinds of scales are possible: primary scale, secondary scale and tertiary scale. Primary scale is formed during 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 coiling train.

**SCALE REMOVAL FROM STRIP SURFACE BY HIGH PRESSURE WATER JET**

High pressure water jet is normally used to remove the scale from hot strip surface. Primary scale is removed by making the scale more breakable by controlling furnace atmosphere, giving suitable reduction at vertical edger and finally using high pressure (160 -240 bar) water jet through specially designed descaling nozzles. The secondary scale which normally forms on
strip surfaces while it travels from roughing stand to first finishing stands, is removed by controlling strip temperature and applying high pressure water jets. Suitable roll cooling system which washes scales from rolling surface is helpful in minimizing Secondary scale pickup from work rolls to rolled strip. Mechanism of scale removal from hot surface by high pressure water jet is quite complex. However, it is at present, believed that the following factors are responsible for creating necessary stress for breaking / flushing the scale from steel surface.

- Steel – scale temperature difference
- Thermal gradient within scale
- Mechanical pressure by water jet
- Shear at interface
- Explosive creation of steam with cracks

Normally, the following impact pressure is required to remove the scale.

<table>
<thead>
<tr>
<th>Type of scale</th>
<th>Desired Impact Pressure, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary Scale</td>
<td>0.5</td>
</tr>
<tr>
<td>Dry Furnace Scale</td>
<td>1.0</td>
</tr>
<tr>
<td>Scales which adheres due to mode of furnace operation / nickel alloy steel</td>
<td>5.0</td>
</tr>
</tbody>
</table>

DESIGN ASPECTS OF DESCALING NOZZLES

Hydraulic descaling nozzles are normally flat (jet) spray nozzles. Typical nozzle arrangement and important nozzle parameters are shown in Fig.1.

![Fig.1 Typical descaling nozzle arrangement](image)

The exact definition of the spray characteristics such as spray angle, spray thickness and impact distribution together with the specification of the operating parameters are the first two steps when a spray nozzle is designed. The standardization of descaling nozzles based on the nominal spray angle was introduced many years ago and has proved to be advantageous with regard to header design flexibility and product availability. Four spray angles describing the width of the
spray are now very common. These are 22°, 26°, 30° and 40° nozzle tips each available with 13 standard flow sizes varying from 12 to 134 lpm, 16.97 to 189.5 lpm and 24 to 268 lpm at pressure of 100, 200 and 400 bar respectively.

The area of impact is a result of the spray width and spray thickness at a given spray height. The spray thickness (also often called spray depth) describes the width in the minor axis of the spray. The spray thickness as well as spray width vary with the spray height.

Having selected one particular nozzle type, spray width at a given spray height is fixed by standardized spray angle. The spray thickness, however, depends predominantly on the internal nozzle design.

The impact distribution over the width and thickness of spray can be measured and documented precisely as shown in Fig.2. This tool is essential for design not only of the nozzles but also for nozzle arrangement on a header. New generation sensors (force transducers) are presently used for better accuracy of measurement. A new measurement software has been developed for data integration.

The key components of descaling unit are

- Nozzle filter stabilizer unit
- Nozzle tip

**Design features of Conventional descaling nozzle (SCALEMASTER HP)**

The nozzle filter stabilizer unit of conventional descaling nozzle (SCALEMASTER HP) is shown in Fig.3.
The water from the header passes through longitudinal filter slots of brass which are machined by sawing blades leaving a sharp edge behind. It is then passed through the stabilizer which is a star-shaped component machined from stainless steel. The stabilizer has a solid core either with flat surface or spikes on each end. The primary function of the stabilizer is to reduce turbulence and form a laminar water flow before it enters the nozzle tip.

The nozzle tip (Fig.4) consists of outer body containing tungsten carbide (TC) insert and in most cases a press fit bushing which keeps the TC insert in place. A gasket in between is also required in this case. Consequently the tip alone can consist of up to four components.

The TC insert which shapes the spray pattern is manufactured traditionally by pressing and machining the “Green Part” which is sintered afterwards before the final orifice is obtained by grinding with diamond grinding wheel. Grinding is an additional process which leaves a very sharp and sensitive orifice edge and also changes the homogeneity of the total surface structure. In most cases, Cobalt is used as the TC binder.

The main drawbacks of the conventional descaling nozzle unit are
• High pressure drop in the filter stabilizer unit due to sharp edge of the brass filter slots
• Sharp and sensitive edge of nozzle tip
• Difficulty in fabricating nozzle tip

Innovations in descaling nozzle design

All the above drawbacks of the conventional nozzles have been addressed in the design of the new generation of descaling nozzle, SCALEMASTER HPS.

In the new design, the filter stabilizer (Fig.5) which are no longer machined traditionally but completely metal injection molded (MIM). Shapes and forms can now be produced economically with these new production technologies which have never been possible with traditional machining by metal cutting. As a result the entire filter stabilizer unit which is now a single piece component entirely made from stainless steel giving it a much higher mechanical strength against water hammers. Contact corrosion in case of low pH descaling water no longer take place at the interface between tip and filter because brass has been completely removed from the nozzle.

![Fig.5 Filter stabilizer unit of new generation descaling nozzles (SCALEMASTER HPS)](image)

Since the filter slots are no longer cut, their lower ends could now be internally shaped with a smooth radius in the water flow direction eliminating most of the turbulences the sharp edges of the old design caused at this point. With additional slots at the filter cap a more homogeneous water flow into the filter is obtained.

The core of the stabilizer which is no longer a separate component has now been removed providing the water a free and nearly undisturbed passage resulting in a stabilized water flow.

The nozzle tip (Fig.6) also has been completely redesigned. The body material has been changed to pre-tempered high temperature resistant stainless steel giving a much higher strength against
water hammers. The slot at the tip front also has been replaced by an oval opening for the water jet.

Fig. 6 Nozzle tip of new generation decaling nozzles (SCALEMASTER HPS)

The tungsten carbide insert is also being produced by applying metal injection molding (MIM). After sintering no more grinding is necessary because of the highest precision which can be guaranteed in mass production. A new internal shape and orifice geometry has been developed for a maximum impact of the spray. The use of nickel as binder for tungsten carbide gives a higher chemical resistance against low pH descaling water. The new orifice geometry also reduces nozzle wear and extends the service life.

ANALYSIS OF NEW GENERATION NOZZLE VIS-À-VIS CONVENTIONAL NOZZLE

Computational Fluid Dynamics (CFD) technique has been used to analyze the flow characteristics of conventional (SCALEMASTER HP) and new generation (SCALEMASTER HPS) nozzle.

Fig.7 shows the pressure profile inside a conventional SCALEMASTER HP nozzle. The coloured areas are representing the water at different pressures. In the red area the water is at maximum pressure which extends all the way through the filter slots until shortly in front of the stabilizer. The maximum pressure loss occurs in the slots (light blue colour) of the stabilizer because of very high water velocity. After the stabilizer in the center where the velocity is higher, the area with the significantly reduced pressure continues until the nozzle tip orifice. It may be noted that the pressure drop inside the nozzle is around 7 bar. This has to be compensated by a larger tip orifice so that the specified nominal nozzle water flow can be reached.
The water pressure profile inside new generation descaling nozzle (SCALEMASTER HPS) is shown in Fig. 8. It is seen that the red zone of higher pressure extends into the center of the nozzle tip. The overall pressure drop in this case is around 2 bar. Consequently, the tip orifice has become smaller compared to conventional nozzle resulting in higher exit velocity of water thereby providing higher force on the target surface. This was possible due to the optimized internal geometries ranging from filter to TC insert, the elimination of the stabilizer core and a new orifice tip.

The turbulence profile inside a conventional descaling nozzle (SCALEMASTER HP) is shown in Fig.9.

The coloured areas are representing the water at different degrees of turbulences. The dark blue areas the water is very calm like in front of the filter and in the welding nipple around the filter. As soon as water enters the filter slot, especially where there is a sharp edge left by the sawing blade extremely violent turbulences are being introduced (red and yellow colour). These turbulences are being maximized further downstream by the core of the stabilizer and are extending into the stabilizer slots where they are not being reduced. After the stabilizer directly
behind its lower core end in a “Dead Zone” again reach high values. Turbulences remain at critical values throughout until the water reaches the orifice tip.

![Image](image1.png)

**Fig.9 Turbulence profile inside conventional descaling nozzle (SCALEMASTER HP)**

In case of new generation nozzle (SCALEMASTER HPS), the internal turbulences of the entire nozzle unit have almost been completely eliminated (Fig. 10).

![Image](image2.png)

**Fig.10 Turbulence profile inside new generation descaling nozzle (SCALEMASTER HPS)**

The effect of these turbulences on spray jet can effectively be demonstrated with a stroboscope, where the highly turbulent movements of the jet in thickness direction is seen. For conventional descaling nozzle, this increase in spray thickness caused by a “Dancing jet” also increases the area of impact which subsequently reduces the impact. In case of new generation nozzle (SCALEMASTER HPS) the “Dancing jet” effect has disappeared due to elimination of internal turbulence. This has helped to reduce the spray thickness and hence the area of impact (Fig. 11).
For new generation decaling nozzle (SCALEMASTER HPS), high water impact velocity and reduction of spray thickness result in higher impact of water spray on the surface of the steel strip facilitating better decaling.

![Turbulence and Spray Depth](image)

**Fig. 11** Comparison of Spray depth for new generation nozzle vis-a-vis conventional nozzle

The impact of water spray is measured in a specially designed nozzle test stand (Fig. 12) for nozzle development, quality control and comparisons between individual nozzles.

![Spray Impact Diagram](image)

**Fig. 12** Water jet Impact Measurement system

A measurement protocol is formulated indicating all important details of pre set measurement conditions and test results in exact figures in 3D format. Only figures and numbers obtained through measurements on the same test stand can really be compared.

In absence of sophisticated 3D measurement technique, a simple method was introduced in Japan which is erosion test on aluminum plates. This method does not represent the true operating conditions in rolling mill since the test spray time needs to be between 2 and 10 minutes whereas in hot rolling the surface remains under the spray for only fractions of second.

Nevertheless, the erosion test method does also visualize the difference in spray performance as shown in Fig. 13. This figure shows the imprint of a SCALEMASTER HPS (top) and
SCALEMASTER HP (bottom) on aluminum plate. The water flow pressure was 150 bar and the vertical height was 150 mm. As described above, the SCALEMASTER HPS concentrates the water on a much sharper spray resulting in a reduced spray thickness a deeper and more uniform groove.

Fig. 13 Comparison of imprint of SCALEMASTER HPS and SCALEMASTER HP Nozzle on aluminum plate

CONCLUSION

Scales formed during hot rolling of steel mainly consists of wustite (FeO), magnetite (Fe₃O₄) and hematite (Fe₂O₃). Wustite having high plasticity is desirable phase during rolling. The characteristics of scale as well as their stickiness to the metal substrate depend on the type of steels rolled and the operating conditions during rolling. With increasing demand of defect free surface of rolled products, it is necessary to have efficient descaling system. New generation descaling nozzle (SCALEMASTER HPS) developed by Lechler are designed to give higher and uniform impact pressure across the spray width facilitating removal of sticky scales. It has more operational reliability due to use of superior material and reduction in number of components and also gives longer service life.

REFERENCES