Effect of Spray Height, Lead Angle and Offset Angle on Impact

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Abstract

Hot strip mills can benefit from optimizing their descaling systems. One aspect of optimizing the system is examining the effectiveness of the orientation of the descale header. Experimental results were examined and compared against theoretical calculations to determine how impact is affected by varying different aspects of header orientation. Variables examined were spray height, lead angle and offset angle.
Introduction

Hot strip mills use hydraulic descaling to remove primary and secondary scale from steel formed after the re-heat furnace. It is important to remove the scale to prevent defects in the material and to also increase the life of the rolls. Traditionally high pressure flat spray nozzles are used in this application in slab, billet or bloom operations. The force of the spray impinges the steel surface breaking up the scale and moving it away. Optimizing header design can help improve product quality and reduce energy costs for the mill. Spray height, lead angle and offset angle are three variables in descale header design that can affect the efficiency of the descaling process.

Previous studies [1-5] have been done to determine the mechanisms of scale removal. Sheppard and Steen [3] examined the effects of lead angle, scale thickness, spray velocity, steel temperature and time of exposure to spray pattern. In their studies on lead angle the scouring action of the nozzle was found to have a bigger affect on the descaling operation than the force into the steel surface.

The purpose of this study is to determine what the effects on impact are by changing the spray angle, lead angle and offset angle of the spray. Flat spray nozzles used for descaling have been designed to reduce losses as the flow approaches the orifice. As these losses are reduced the efficiency of the flow exiting the orifice approaches the theoretical impact value.

EQUIPMENT & METHODS

Theory

No nozzle can exceed the theoretical total force and it is the same for all nozzles of the same flow rate and pressure.

\[ I_T = \rho QV \]  
\[ I_T = \text{Total Impact Force} \]
\[ \rho = \text{Density} \]
\[ Q = \text{Flow Rate} \]
\[ V = \text{Velocity} \]

All of the above variables affect both the flow rate and velocity of the spray, which in turn affects impact. Spray impact is controlled by mass per unit time, spray angle, concentration of the spray, operating pressure, drop size and air friction. Mass per unit time is the product of the density and flow rate. Velocity is affected by drop size in that smaller drops lose velocity faster due to air friction. Larger drops will maintain velocity further from the orifice.

The final force equation reduces to equation 2 for English units, with impact in pounds, flow rate in GPM and pressure in PSI and equation 3 for metric units, with impact in Newtons, flow rate in l/min and pressure in bar.

\[ I_T = 0.0527 * Q * \sqrt{P} \]  
(2)

\[ I_T = 0.235 * Q * \sqrt{P} \]  
(3)

The theoretical total force the nozzle can produce is a valuable number but in order to compare this number to the actual measured values, more mathematics need to be applied and here we define the term theoretical maximum impact. This is the theoretical force the nozzle will produce along the centerline of the spray pattern provided there are no losses in the nozzle. To determine the theoretical maximum, the specific impact is multiplied by the area of the measurement pin. Specific impact (I_m) is defined as impact per unit area where X*Y is the impingement area of the entire spray pattern.

\[ I_m = \frac{I_T}{X*Y} \]  
(4)

Spray angle and spray concentration are important variables in determining specific impact. Smaller spray angles will have a smaller impingement area with more drops per unit area. The smaller the impingement area of the spray, the higher the specific impact is of the spray pattern produced. Impingement area calculations can be estimated based on the spray height and spray angle of the nozzle.
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Trigonometry can estimate the impingement area but as the spray height increases the error percentage of equation 5 increases. The lateral spray angle, $\Theta$, and transverse angle, $\alpha$, are only accurate close to the orifice. Depending on pressure and capacity the spray tends to start to pull in as it leaves the orifice. For purposes of this study all impact calculations are based on actual pattern measurements for each nozzle.

Experimental Set-up

Impact testing was done using a patent pending process to measure the load throughout the entire spray pattern. A small pin is attached to a load cell which moves through the spray in an X-Y grid pattern and is controlled by two servo motors. The force of the spray pushes down on the pin and the data is collected by a data acquisition system.

Testing was performed on AA218 DescaleJet® nozzles with spray angles of $18$, $25$ and $32$ degrees and capacities of $4.0$, $5.0$ and $6.0$ gallons per minute at $40$ PSI. Spray heights ranged from $6$ to $10$ inches, lead angles ranged from $0$ to $30$ degrees and offset angles ranged from $0$ to $30$ degrees. Pressures for this study remained constant at $2000$ PSI.

To determine the effect of spray height the lead angle and offset angle were set to zero, see figure 2. Spray height was measured from the orifice of the nozzle to the tip of the pin of the load cell.

Figure 2. Side view and top view for nozzle orientation with zero degree lead angle and zero degree offset angle.

Figure 3 shows the set-ups for both lead angle and offset angle testing and all spray heights were measured from the orifice to the tip of the pin. For all lead angle and offset angle testing spray height were kept constant at $6$ inches. The lead angle was determined by measuring the angle the spray was from perpendicular. The offset angle was determined by the angle of the spray to the X-axis of the test grid.

Figure 3. Side view of nozzle orientation for lead angles other than zero. Top view of nozzle orientation for offset angles other than zero.
Results

The first phase of testing looked at the effect of spray height on impact and nozzle efficiency. By determining the optimum spray height for a nozzle, losses due to air friction can be minimized. In order to put together a complete picture of the spray height effect, nozzles of different spray angles and capacities were examined. Nozzles of different spray angles were examined first. The capacity was kept constant in this case at 4.0 GPM at 40 PSI. Table 1 shows the results for the different nozzles at the different heights.

<table>
<thead>
<tr>
<th>Nozzle</th>
<th>Spray Height (in)</th>
<th>Average Peak Impact (lb)</th>
<th>Theoretical Peak Impact (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA218+TC1840E</td>
<td>6</td>
<td>1.659</td>
<td>1.851</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1.155</td>
<td>2.110</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.795</td>
<td>1.815</td>
</tr>
<tr>
<td>AA218+TC2540E</td>
<td>8</td>
<td>0.707</td>
<td>1.768</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.533</td>
<td>1.477</td>
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<tr>
<td>AA218+TC3240E</td>
<td>6</td>
<td>0.834</td>
<td>1.591</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.490</td>
<td>1.400</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.375</td>
<td>1.154</td>
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</table>

Table 1. Impact values for nozzles of different spray angles.

In comparing impact results it is best to compare the average peak impact across the spray with the theoretical peak impact. The theoretical peak impact is the impact value of the spray if the impingement force is concentrated at the center of the spray. Ideally, nozzles for descale operations are designed to concentrate the impingement force in the center of the spray. Nozzle efficiency can then be found by comparing the actual and theoretical peak impact values. Figure 4 is an example of measured data for an AA218+TC2550E at 6 inches. Average peak impact is found by averaging all values above the minimum peak value across the center of the spray.

The peak impact decreases as the spray height increases and for all nozzles the rate of decrease is the same, between 45 to 48 percent. However, the range of peak impacts for the nozzles is different. For the 18 degree nozzle the peak impact at 6 inches is 1.659 lb and decreases to .795 lb at 10 inches. The 32 degree nozzle has a peak impact of .834 lb at 6 inches and decreases to a peak impact of .375 lb at 10 inches. This difference in peak impact values is because the nozzles have different areas of impingement. Nozzles with smaller spray angles will have more concentrated spray patterns and produce higher specific impact values.

Comparing the theoretical peak impact to the measured value it can be noted the efficiency for each nozzle decreases as the spray height increases. Nozzle efficiency is defined as measured peak impact/theoretical peak impact. Figure 5 shows the relationship between spray height and nozzle efficiency for each of the three spray angles.

Figure 4.

Figure 5.
RESULTS & DISCUSSION

At each of the three spray heights the nozzle with the smallest spray angle has the highest efficiency at all spray heights. However, after about 6 inches, the efficiency of all nozzles drops off drastically. This is due to drops losing velocity to air friction and a larger impingement area see figure 6. As the impingement area increases the spray concentration decreases and therefore the specific impact decreases. In comparing the average peak impact for the different capacities the decrease in impact was relatively the same. As the spray height was raised from 6 inches to 10 inches the decrease in impact was approximately 40 to 44 percent.

The relationship between nozzle efficiency and spray height for nozzles of different capacities is shown in figure 7. For all three capacities the nozzle efficiency decreases as the height is increased from 6 to 10 inches. The sharpest drop is between 6 and 8 inches. After 8 inches the decrease in impact seems to even out.

Nozzles of different capacities at different spray heights were examined next to determine the effect on impact. In this case the angle was kept constant and AA218+TC25__E nozzles were used for all tests. Table 2 shows the results for the different nozzles at the different heights.

<table>
<thead>
<tr>
<th>Nozzle</th>
<th>Spray Height (in)</th>
<th>Average Peak Impact (lb)</th>
<th>Theoretical Peak Impact (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA218+TC2540E</td>
<td>6</td>
<td>1.204</td>
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<td>10</td>
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<tr>
<td>AA218+TC2550E</td>
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<td>1.765</td>
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<td>1.627</td>
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<td></td>
<td>8</td>
<td>1.037</td>
<td>1.611</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.742</td>
<td>1.346</td>
</tr>
</tbody>
</table>

Table 2. Impact values for nozzles of different capacities.

Figure 6. Impingement area of the AA218+TC2540E nozzle at 6, 8 & 10 inches.

Figure 7. The second phase of the study looked at what happens to impact when the lead angle of the header is changed. The goal of the spray is to not only break the scale from the steel but to also pick it up and move it away. In order to do so the header needs to be set at an angle. The question is what does this actually do to impact? Previous studies have suggested the higher the lead angle the more effective the header is at descaling steel [1]. However this study looked at amount of water collected in the direction of the spray and not the effect on impact. To study the effect of lead angle on impact one nozzle was tested at lead angles of 0, 15 and 30 degrees. Higher lead angles were not able to be measured due to limitations of the equipment but the trends can be seen in the lead angles that were tested. The value measured in these tests is the vertical force of impact. When the angle of the header is moved from perpendicular the impact takes on both a horizontal and vertical component.
**RESULTS & DISCUSSION**

Figure 8 shows the results for the vertical component of impact for the AA218+TC2550E at different lead angles. The vertical component of impact decreases as the lead angle is increased. Also as the lead angle increases the width over which the impact of the spray is effective increases. The combined effect of both the vertical and horizontal component of impact can be determined by $I_y / \cos(a)$. Using this relationship the total average peak impact decreases as the lead angle increases. If there were no losses present when increasing the lead angle this value should equal the average peak impact at zero degrees. However, because the impingement area increases with increasing lead angle the specific impact decreases. At a 30 degree lead angle the impact force is 90% the impact force at 0 degrees. The relationship between lead angle and total average peak impact is shown in figure 9.
The third phase of the study was to determine the effect of offset angle on impact. In using the same comparisons as for spray height and lead angle to compare impact, the changes in impact due to offset angle are negligible. The only effect offset angle has on the impact of the spray is the direction of the impact. Offset angle has two functions in header design. The first function is to prevent interference from adjacent sprays. Headers are typically designed with minimal overlap to ensure impact across the entire width. If the spray is allowed to interfere the impact of the edges of the spray will become ineffective and could cause striping problems.

The second function of the offset angle is to provide channels for the water to leave the steel surface. Not providing a channel for water to leave allows water to build up on the steel surface and decreases the effect of the spray impact. The smaller the layer of water on the surface the more effective the descale sprays.

**Conclusion**

Spray height, lead angle and offset angle all play important roles in header design. Optimizing these three variables will help the mill increase the effectiveness of their descaling system and reduce energy costs. Testing was conducted to determine what effects these variables have on impact. Spray height and lead angle were found to have a significant effect on impact. As spray height is increased, impact decreases. Lead angle splits the overall impact into two forces, a horizontal and vertical component. As the lead angle is increased the horizontal component of impact increases and the vertical component decreases. The effect on the combined impact, though, is a decrease based on the impact at a lead angle of zero degrees. Offset angle, however, did not have any effect on the value of the impact force. Offset angle’s only effect on impact is to determine the direction of the force.

In general, these three factors of header orientation can be examined to determine the effectiveness of the descale system. By examining these variables the factors that affect impact, mass per unit time, spray angle, concentration of the spray, operating pressure, drop size and air friction can be optimized to give the best results for the desired impact.
References


3. Sheppard T and Steen WM, Hydraulic Descaling of Steel a Preliminary Experimental Study, JISI September 1970

