OPTIMIZING DESCALING OPERATIONS - WATER EFFICIENCY WITHOUT COMPROMISING QUALITY[1]

Keith Knasiak[2]
Christy Hofherr[2]

Abstract

Mills are looking to reduce water consumption without compromising descaling effectiveness - this paper will discuss different ways mills can accomplish this goal by discussing the effects of header design, nozzle capacity, pressure, spray height, and lead angle on descaling efficiency.

Key words: Descaling; Optimization; Descale; Impact.

Resumo

Plantas Siderúrgicas estão, cada vez mais, procurando maneiras para reduzir o consumo da água, sem comprometer a eficácia da descarepação - este trabalho irá discutir formas diferentes de como as siderurgias podem alcançar este objetivo, discutindo os efeitos que: dimensionamento do header, capacidade de bico, pressão, altura de pulverização, e ângulo de ataque podem influenciar na eficiência do processo de descarepação.

Palavras-chave: Descarepação; Otimização; Impacto.

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[2] *Spraying Systems Co. Keith.Knasiak@spray.com; Christy.Hofherr@spray.com*

Introduction

Impact plays a crucial role in descaling operations and there are two main trends occurring in the industry. Mills with good descaling are looking to save money by reducing the amount of water used to get the same descaling effectiveness without losing quality or mills do not have good descaling and need help optimizing their system to get higher impact and better quality using the same amount of water as the current system. Both scenarios have a direct relation to impact provided by the descaling system, so it is important to know what parameters have the most effect and how to change them to get the right result. It is also important to know the trade-offs that come with this optimization to make an educated decision.

The descaling system has three main tasks to achieve proper descaling: 1. Shrink, crack and break up the scale layer on the steel surface, 2. Penetrate through to the base material and remove the scale from the steel surface, and 3. Move the scale completely off the strip to avoid re-attachment or the possibility of rolling in scale particles. There are many factors that affect efficient descaling including lead angle, spray height, pressure, and nozzle capacity. Other factors that indirectly affect the operations and are related to the above factors are turbulence and header design.

Each of the factors have a positive affect on impact performance but also has as negative affect on the total system. For every positive, there is a trade-off affect and to truly *optimize* a system, both aspects must be considered. The purpose of this paper is to briefly discuss and summarize the affects of each of the factors mentioned above as well as how to optimize a descaling operation through actual mill studies.

Pressure/Capacity

Spray nozzle capacity is important to descaling operations from a few different perspectives. First and foremost is probably the impact imparted by a given nozzle is definitely a function of its capacity. Look at the reaction force of a nozzle:

$I_T = .0527 * Q * \sqrt{P}$ for force in lbs or $I_T = .024 * Q * \sqrt{P}$ for force in Newtons

If nozzle capacity is doubled, the total force from the nozzle is also doubled. The capacity also will play a part in the overall cooling of the surface of the slab. The more liquid that is passing over the slab, the surface cooling rate will be higher. Needless to say, this needs to be controlled to ensure product quality. The amount of liquid passing over the surface also plays a role in the removal of the dislodged scale from the surface. If there is too much water such that it is remains static on the surface, this negatively affects impact performance because the impinging spray will have to pass through this standing water to get to the steel surface. The balance of getting the right flow to provide adequate cleaning impact, ideal surface cooling and effective scale removal can be a delicate balance. Every installation has its own idiosyncrasies that must be addressed when figuring this balance.

The operating pressure of the system is important for two primary reasons; firstly, pressure and capacity are two interrelated parameters and secondly, nozzle impact is a function of pressure. The higher the header pressure is, the greater the impact forces will be as quantified in the above impact equation. Also, with a higher pressure the header will also have a higher total flow rate. It is through this relationship that header flow rate and impact can be controlled along with the overall flow rate from the header. The detriment that increased pressure brings is turbulence. One of the primary obstacles to good impact is turbulence. Figure 1 shows images of nozzle performance with a low level of turbulence. While Figure 2 shows an image of the same nozzle with elevated turbulence levels.

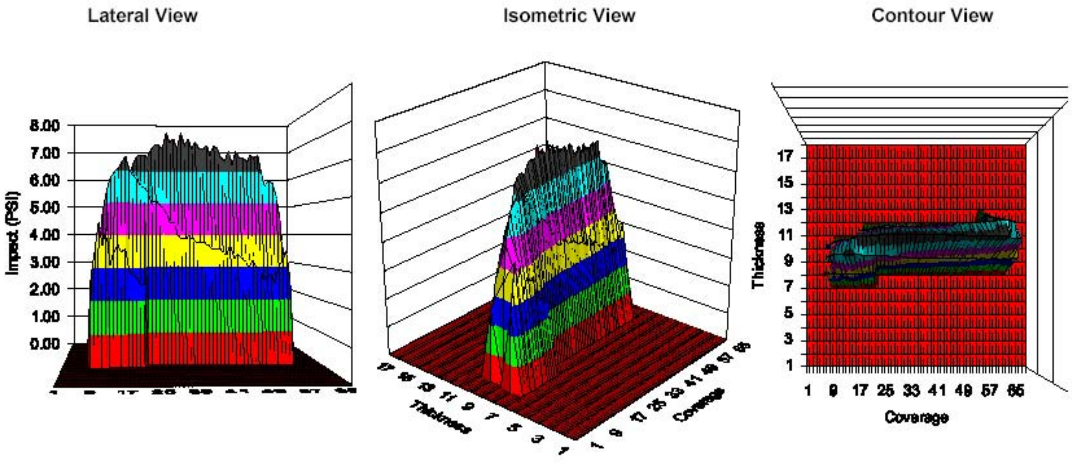

Figure 1.

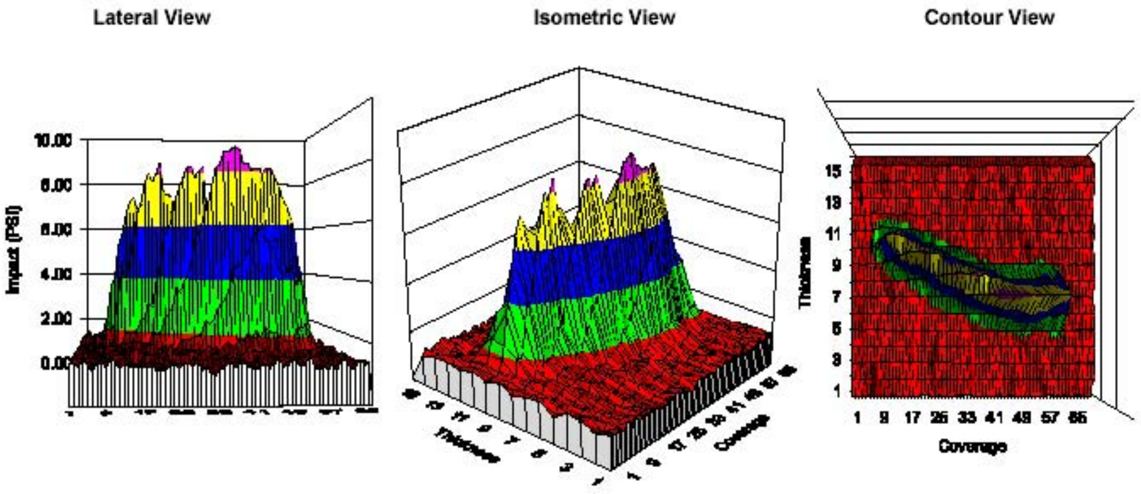

Figure 2.

Note that the impact distribution has been compromised giving uneven force distribution across the spray. Looking at the contour view, the shape of the spray has also deteriorated which will affect the overlap conditions across the header.

Turbulence or approach velocity of the nozzle is a relationship between total flow rate of the header, flow rate of the individual nozzle and the inside diameter of the pipe. It is advised to keep turbulence levels between 5-15 ft/s or 1.5-4.6 m/s and most properly designed descale nozzles will perform correctly.

Another detriment that increased pressure has on descaling performance is wear life. Increased pressure could cause the nozzles to wear faster than systems with lower pressures, therefore the cost of changing nozzles more frequently needs to come into the decision as well.

The balance of the pressure and capacity is a delicate one and the negative affects of turbulence and improper header design must be considered when optimizing a system.

Offset Angle

The offset angle of a spray is defined as the angle that the spray is rotated from being orthogonal to the movement of the surface. This is best defined pictorially and is shown in Figure 3. Ensuring that the nozzles are rotated enough so that there is minimal interference is critical. This rotation can also affect the ideal nozzle spacing so this must be taken in to account as well. Finally, this rotation can facilitate the removal of the loose scale from the surface if done correctly.

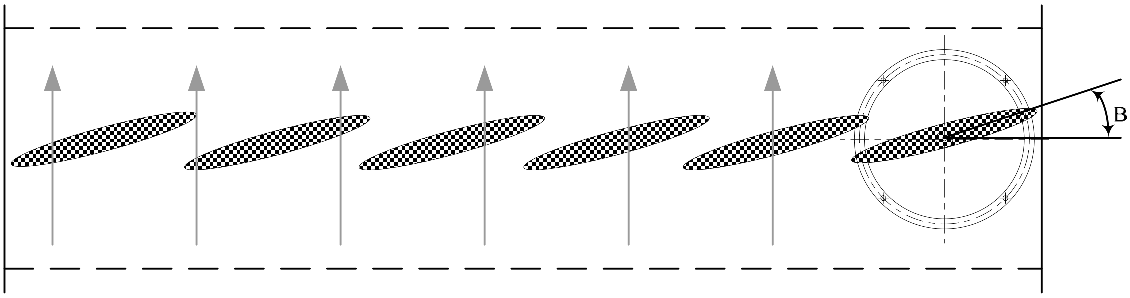

Figure 3.

Small offset angles will increase the overlap between adjacent nozzles which will reduce the total number of nozzles needed, however it may not be enough to drive the water and scale debris off the strip. Large offset angles will drive the water off the edge, but the trade-off is less overlap thus more nozzles for proper coverage. More nozzles mean more maintenance and replacement costs. This must be considered and again, each installation needs be analyzed for its own merits.

Lead Angle

Many installations are set such that the spray is not set orthogonal to the surface. Typically they are angled counter to the surface movement direction. This is commonly referred to as lead angle. Figure 4 shows a typical setup and graphically defines the lead angle (α).

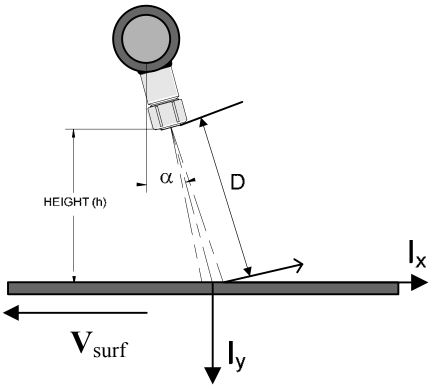

Figure 4.

The lead angle has two major effects regarding the impact of the nozzle. First, and probably most obvious, it has the effect of causing the nozzle to appear further from the substrate than the measured nozzle height (h). This effective distance (D) is calculated by D= h/cos(α). The second effect is that there are now two components of the impact force imparted to the substrate surface, these being the normal force (I_y) and the tangential force (I_x). Having a measurement of either I_x or I_y, we can calculate the total impact force I_T through the relationships: $I_T = I_x / \sin(\alpha)$ and $I_T = I_y / \cos(\alpha)$.

I_x will I_y will both have an effect on cleaning the surface. This paper is not investigating the cause lead angle will have on performance. It is however important enough that the authors felt that it should be mentioned. Any installation that has their header set with a lead angle needs to be aware that there are effects caused by this and if not investigate the effects that lead angle may be having on system performance.

Spray Height

The distance that a descale nozzle is located from the material surface is a very critical parameter in ensuring sufficient impact force with an even impact force distribution across the entire header. To accomplish this, an understanding of how a given type of nozzle's coverage changes with respect to spray distance must be understood. Measurement and empirical data is probably the best method of accurately determining any given nozzle's spray performance characteristics. This is not always practical so the assumption can be made that each given nozzle type has roughly equivalent behavior for a given flow rate and spray angle. An example of a nozzle's change in total coverage as a function of spray distance is provided below in Figure 5. For given nozzle types these curve fits can be empirically generated and used for future header layout.

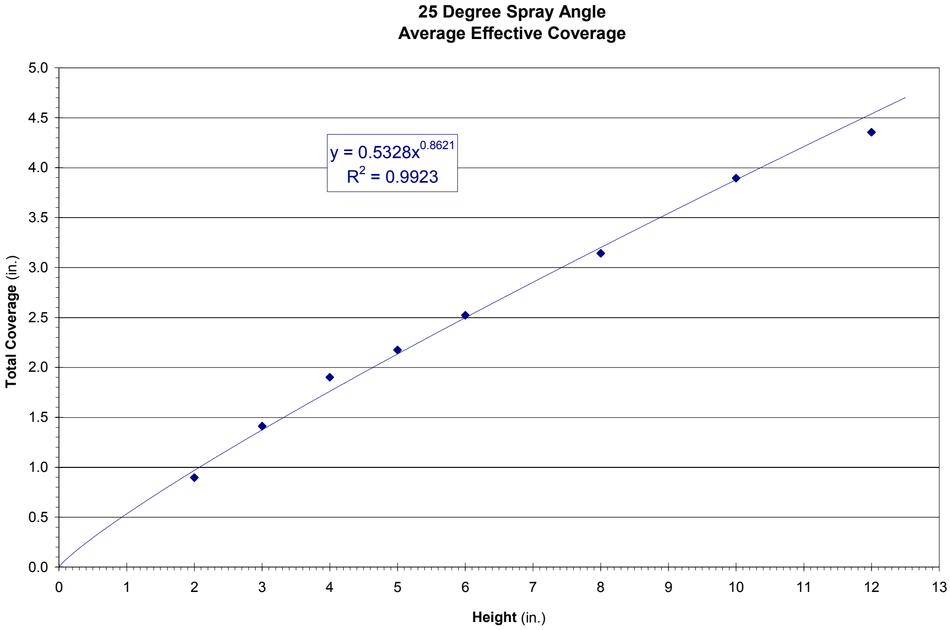

Figure 5.

In the area near the nozzle the spray angle can accurately predict the coverage that a nozzle will provide. However, as distance is increased this becomes less and less the case. Due to air entrainment caused by spraying the nozzle, a low pressure zone is created in the area of the spray. This has the effect of the spray pulling in towards the center of itself thereby decreasing the effective spray angle of the nozzle. A graphical representation of this is provided below in Figure 6. It is this effect that causes the coverage to be a non-linear function of spray height.

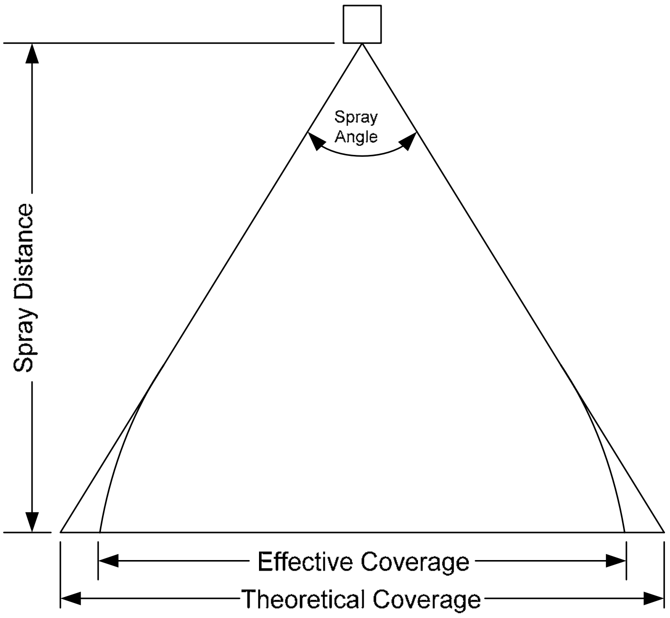

Figure 6.

Another effect of spray height is the major effect it has on the impact from a nozzle. Reducing the spray height of a nozzle by half can increase its impact by up to four times. This, at first glance seems like an easy solution to a low impact problem. However, effects of coverage must also be considered. By moving the nozzles closer to the surface, they will also need to be moved closer together to maintain good coverage. This means more nozzles on each spray header which in turn can cost more to maintain. Lower spray heights also put the nozzles at risk of damage from bounce-back spray and/or cobbles occurring in the mill. A happy medium must be found by the mill that maintains maintenance cost and time while preserving the integrity of the product.

Spray Angle

The effect of spray angle on impact is directly related to impact pressure which is defined as the total force divided by spray area. It goes to reason that narrower spray angles give smaller total spray areas and thus gives higher impact pressure values. Smaller spray heights essentially have the same affect. But as mentioned above, smaller angles will require more nozzles, overlap becomes critical, and maintenance costs increase. But there is no question that simple changes to a system by reducing spray angles slightly can significantly improve impact performance.

Experimental Methods

Measurement methodologies and control of experimental parameters can have a significant effect on the results obtained. Historically, impact tests were performed by spraying on a substrate of some homogenous material such as lead. As time passed the forces from the nozzle would erode the surface of the material. Comparing timed nozzle test results would provide a qualitative measure of the nozzle geometrical parameters and impact forces. Some of the issues with this method are material inhomogeneity and actual quantification of localized impact forces.

A more modern approach to impact testing is to use some type of force sensor that can be recorded. Typically, pressure forces are measured through the spray using some surface connected to a pressure/force measurement device such as a load cell. The shape and makeup of this surface can have an effect on the measurements made. In all cases, this measurement method is *in situ* and can have an effect on the measured values. It is for this reason that careful design followed by thorough validation must be performed on these instruments to ensure their accuracy.

In the recent past measurements were conducted using a small, floating bar that sat atop a load cell. This bar could then be moved through the spray, laterally or transversely, to measure the impact forces. This methodology is typically referred to as a one-dimensional impact test. This method provides a quantifiable measurement of the impact forces. Localized values could be observed as well. An image showing this type of impact measurement instrument is shown below in Figure 7.

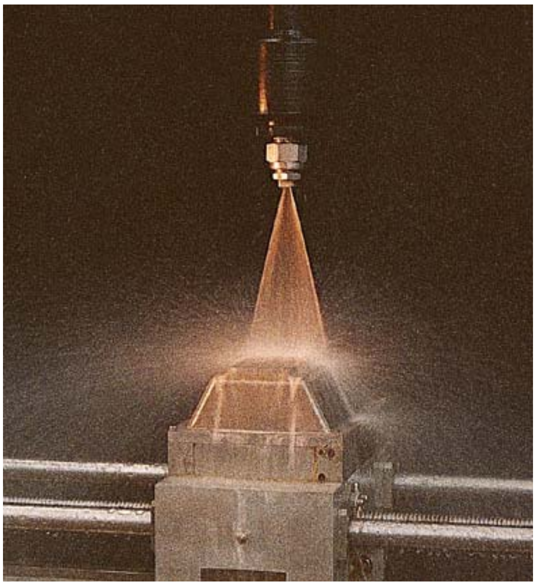

Figure 7.

A small disadvantage to this method is that spatial averaging occurs. This is because typically this small bar will pass through the entire spray meaning that the full width of the spray is being summed into each measurement point. Figure 8 shows a typical plot done using the tester shown above in Figure 7.

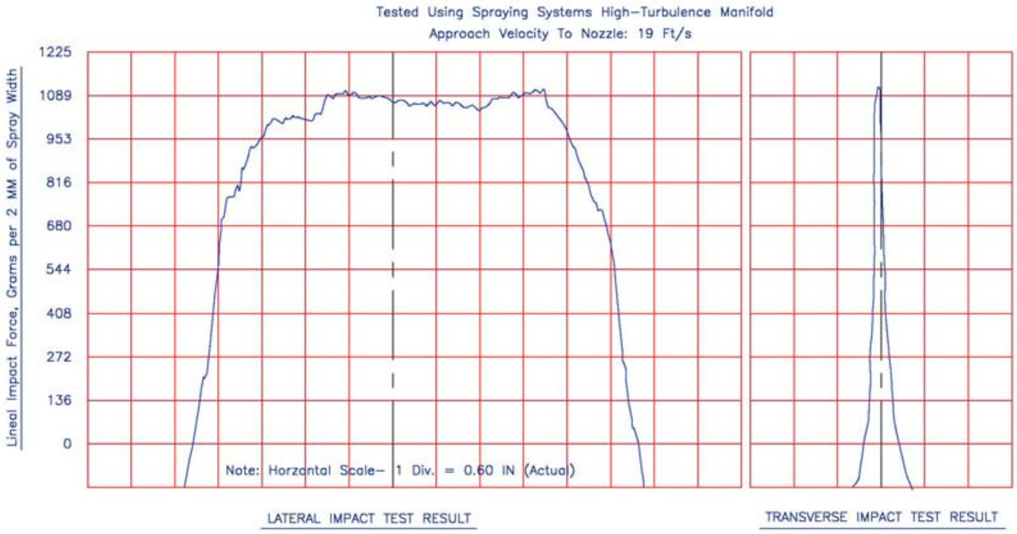

Figure 8.

Present day technology allows the use of a two-dimensional impact tester. This device, instead of using a small bar uses a small pin. This allows for a significant reduction of the spatially averaged component of the data. An image of this instrument is shown in Figure 9.

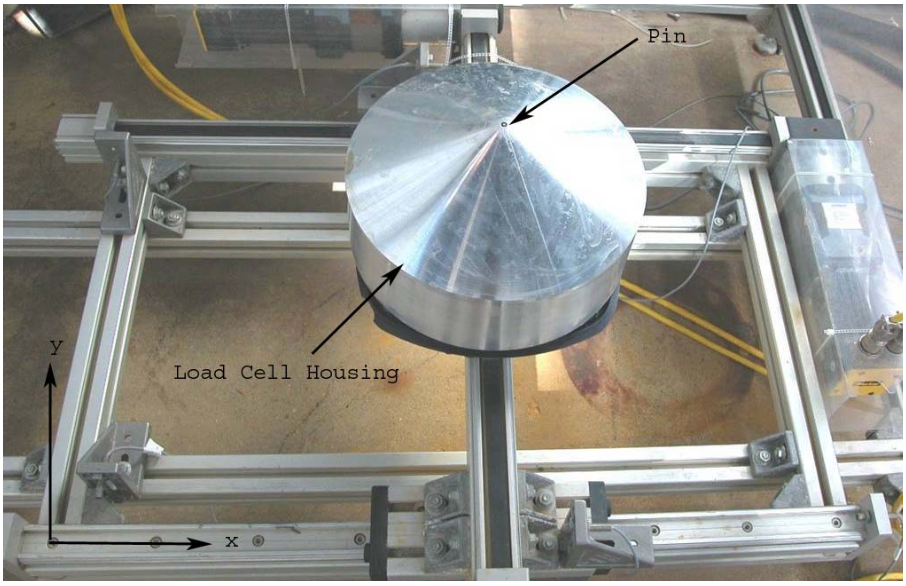

Figure 9.

The load cell is housed in a water proof enclosure below the pin. The pin is then moved to a reference point within the spray. Once the traverse reference location (≈ center of the spray) is known the testing can begin. A graphical representation of the test matrix is shown below in Figure 10. The load cell first moves to outside of spray pattern. It then starts traversing through the spray, taking measurements at intervals along the way with a predetermined step size. When the test is complete we have a matrix of data. Each node shown below (Figure 10, a-c) is a point where data was recorded.

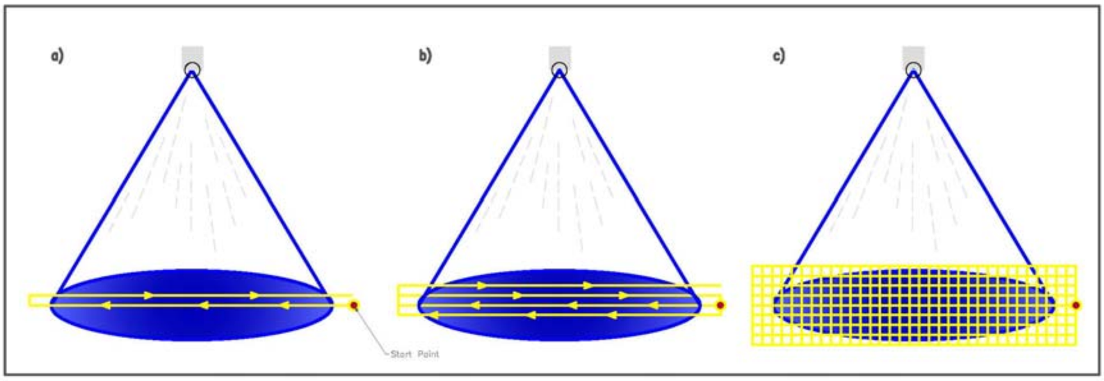

Figure 10.

The step size is the distance between each node and is set by the user. The typical pin size used is 2mm (0.077in.). To fully cover the spray a step size of 2mm (0.077in.) is ordinarily used.

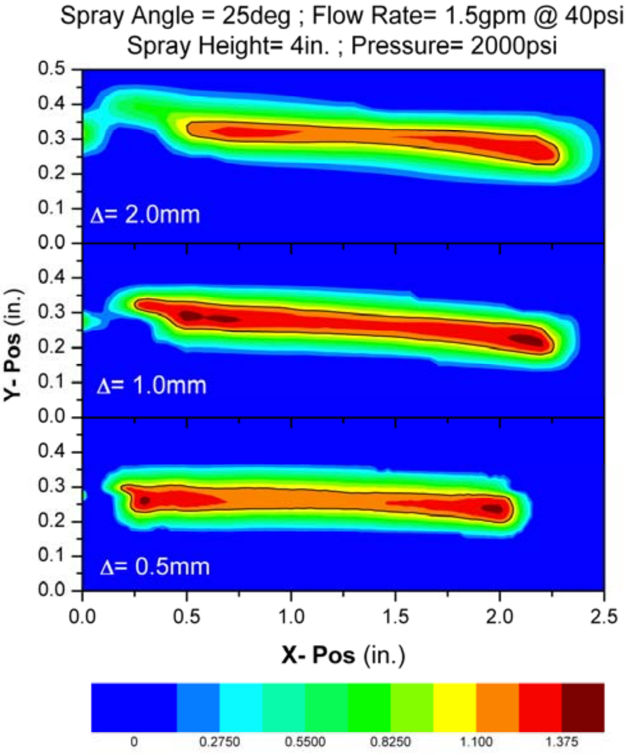

Figure 11.

Recent work has suggested that the step size selection is more a function of spray height and nozzle footprint more than pin size, nozzle flow rate, spray angle and/or pressure. This was determined through an investigation into the total and effective coverage of high impact nozzles as a function of pressure and spray height. It was seen that there was a noticeable variability in the measured coverage between different nozzles with the same spray angle and equivalent and varying capacities. In reasoning through what may be the cause of this, measurement resolution became the suspected issue. Further work was performed with the same nozzles while varying the measurement resolution at equivalent test conditions. A definite improvement in the measurement consistency was seen. Figure 11, shows the difference in the same spray measured at the same test conditions but with progressively finer measurement resolution.

Optimization Studies

Case 1: Increasing Impact while holding total capacity relatively constant
A mill wanted to improve impact performance of their current system while holding their overall water capacity somewhat constant. Their current system was as shown in Table 1.

Table 1.

Current System		
Pressure	1950 psi	137 bar
Flow Rate	34.6 GPM	131 lpm
Spray Angle	47°	47°
Spray Width	6.94 inch	176 mm
Lead Angle	20°	20°
Offset Angle	15°	15°
Spray Height	7.5 inches	191 mm
Nozzle Spacing	6 inches	152 mm
Nozzle Coverage	6.704 inches	170 mm
Overlap	.704 inch	18 mm
Number of Nozzles	21	21
Total Coverage	126.704 Inches	3.22 m
Total Flow Rate	726.6 GPM	2750 lpm
Impact Force	91.4 psi	~.63 N/mm^2

The goal was to maximize impact using 750 gpm or less. The proposed and installed system was as shown in Table 2

Table 2.

Proposed System		
Pressure	1950 psi	137 bar
Flow Rate	31.4 GPM	119 lpm
Spray Angle	32°	32°
Spray Width	5.57in	141 mm
Lead Angle	15°	15°
Offset Angle	15°	15°
Spray Height	7 inches	178 mm
Nozzle Spacing	5.10 inches	130 mm
Nozzle Coverage	5.57 inches	141 mm
Overlap	.5 inch	13 mm
Number of Nozzles	24	21
Total Coverage	122 Inches	3.10 m
Total Flow Rate	754 GPM	2854 lpm
Impact Force	151 psi	1.04 N/mm^2

Case 2: Improve Impact performance while reducing total water capacity
For this same mill, another proposal was made where impact pressure was increased from the current proposal but this proposal shows a reduction in total flow rate. This proposal is shown in Table 3.

Table 3.

Alternate Proposed System		
Pressure	1950 psi	137 bar
Flow Rate	27.9 GPM	106 lpm
Spray Angle	32°	32°
Spray Width	5.57in	141 mm
Lead Angle	15°	15°
Offset Angle	15°	15°
Spray Height	7 inches	178 mm
Nozzle Spacing	5.10 inches	130 mm
Nozzle Coverage	5.57 inches	141 mm
Overlap	.5 inch	13 mm
Number of Nozzles	24	21
Total Coverage	122 Inches	3.10 m
Total Flow Rate	670 GPM	2536 lpm
Impact Force	131 psi	0.9 N/mm^2

In both proposed systems, there is an improved level of impact and descaling. Ultimately it is up to the mill which system they prefer.

Another quick comparison came from a mill that just wanted to know the differences in impact between two capacities and spray angles. The mill wanted to know what would be the affect on impact and total flow rate along with the number of nozzles. A quick comparison is shown in Table 4.

Table 4.

AA218 Nozzle Size	Spray Angle	Impact Force (N/mm^2)	Flow Rate @ 2200 psi (gpm)	# of nozzles	Total Flow Rate (gpm)
3260	32°	1.34	44.5	14	623
3250	32°	1.12	37.1	14	519
2560	25°	1.79	44.5	16	712
2550	25°	1.49	37.1	16	594

Each condition provides a good amount of impact performance, what the mill needs to decide is how much water they want to use and the associated maintenance costs for the number of nozzles used in the system.

Conclusion

Many factors affect descale performance. Each of these factors has positive affects and negative affects and for true optimization, all need to be taken into consideration. The balance between improved performance and maintenance costs is an ultimate decision that has to be made by the mill.

The goal of any optimized system is to provide the most impact with the least amount of water and the lowest possible maintenance costs.

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