MEASUREMENT AND MATHEMATICAL APPROXIMATION OF THE IMPACT OF DESCALING NOZZLES

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1. Introduction

For precise manufacturing of descaling nozzles it is very important to measure the impact of nozzles at any condition.
The elimination of scale from hot metal surfaces has increased its priority and it is a considerable factor for good surface quality and less wear for example to the work rolls. The following picture shows a hydraulic descaling process with several descaling nozzles on top and below the hot metal plate. The plate is moved from the back to the front and you can see the plate before descaling in the rear part and after descaling in the front part.

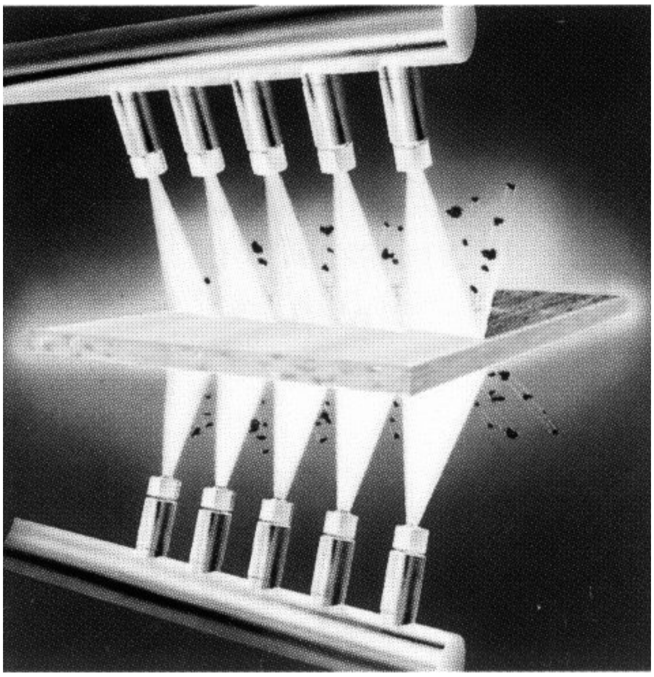


Fig.1: Typical descaling process that shows the descaled part in front and in the back the surface before descaling.

The development of descaling nozzles therefore focuses on maximizing the impact and homogeneity of impact distribution.

The following chapters shall give you an overview over our method to measure the impact distribution of descaling nozzles. Derived from these measurements a computer program was written that calculates the impact and other parameters of a spray.
The prediction of impact data with a computer program can be very helpful because there are many different conditions concerning pressure, distance from nozzle to surface, flowrate, spray angle, spray depth or turbulences in the nozzle that can influence the impact force results.

2. Measurement

Our method for measuring the impact force is based on a resistance strain gauge (force transducer) that can take force values from every position in the spray. To do this a small surface element of for example 3 x 3 mm or 1.5 x 1.5 mm is placed on the resistance strain gauge. The size of the used surface element is dependent on the flowrate, maximum impact and extent of the spray.

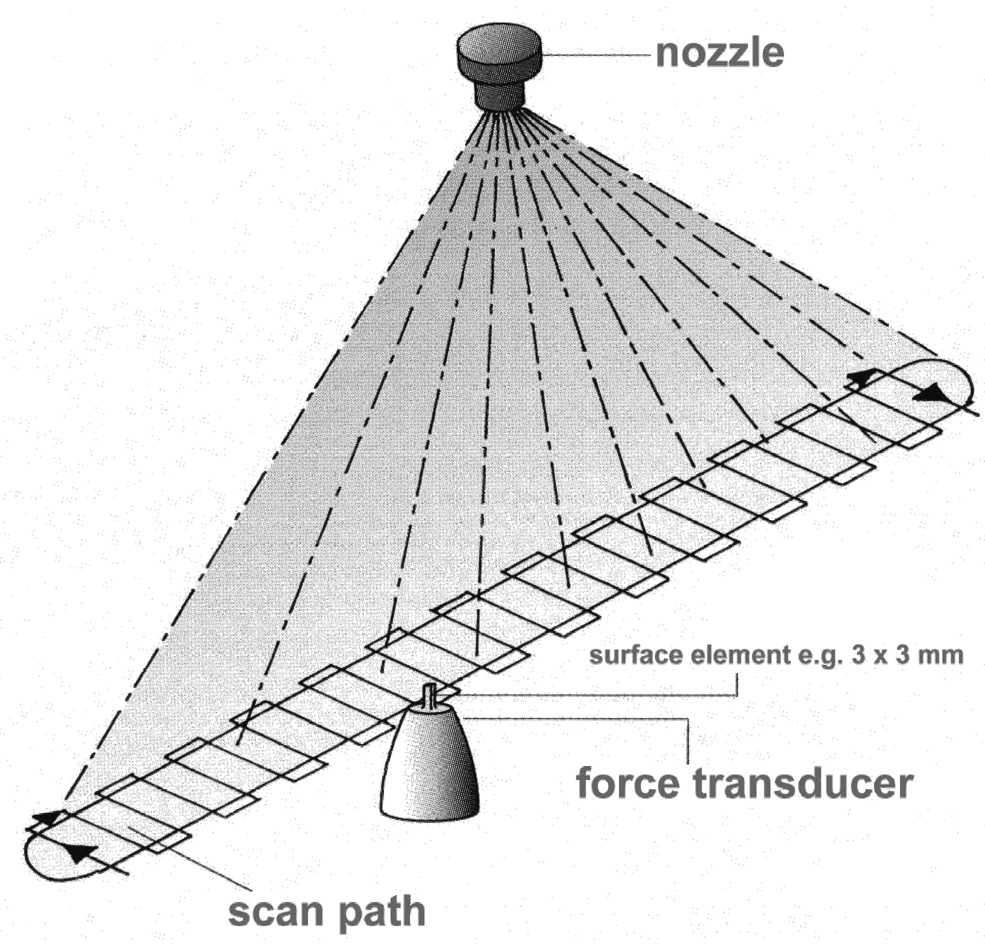


Figure 2: Principle set-up for impact measurement

When performing a measurment the surface element is moved with the force transducer under the spray. The distance between nozzle and surface element is variable but fixed during the measurement. The spray is scanned as shown in figure 2 along the scan path. When starting on the forward left side of the spray the transducer moves along the depth of the spray (Y-axis). At the back side of the spray the transducer stops and moves one surface element width along the width of the spray in X-axis (for example 3 mm for a 3 x 3 mm surface element or 1.5 mm for a 1.5 x 1.5 mm surface element). The transducer now moves back again through the spray to the forward side. Arriving there this movement of the transducer is repeated until the transducer reaches the end of the spray at the right side.
During the movements along the depth of the spray in Y-axis the impact force on the surface element is measured continuously and transmitted to the computer. At this point it is very important to know the correct size of the surface element because the force on a 3 x 3 mm element is larger than the force on a 1.5 x 1.5 mm element.
The following figure 3 shows the whole basic scheme of the test bench.

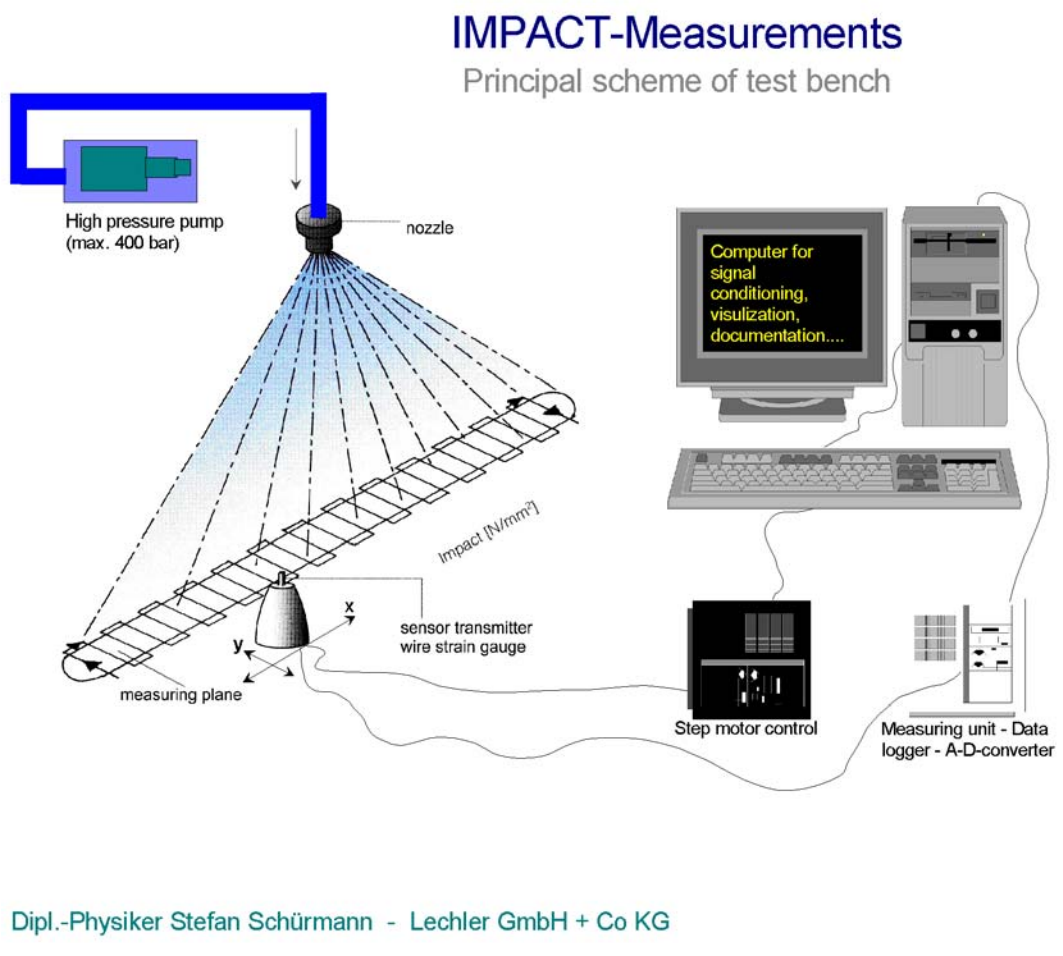


Figure 3: Basic scheme of impact test bench

The high pressure pumps provide the necessary pressure (max. 400 bar for this test bench) and flowrate (max. 300 l/min). During the measurement these 2 parameters must be constant of course. A step motor unit controls the movement of the transducer with the surface element. A measuring unit with an analog-digital converter records the incoming impact force data. The computer synchronizes both the step motor unit and the measuring unit. After each step in Y-axis the data is transmitted to the computer for further calculations.

The following figure 4 shows a descaling nozzle spraying at 200 bar. The force transducer is moving from the left side of the spray to the right side scanning the spray in x- and y- direction.

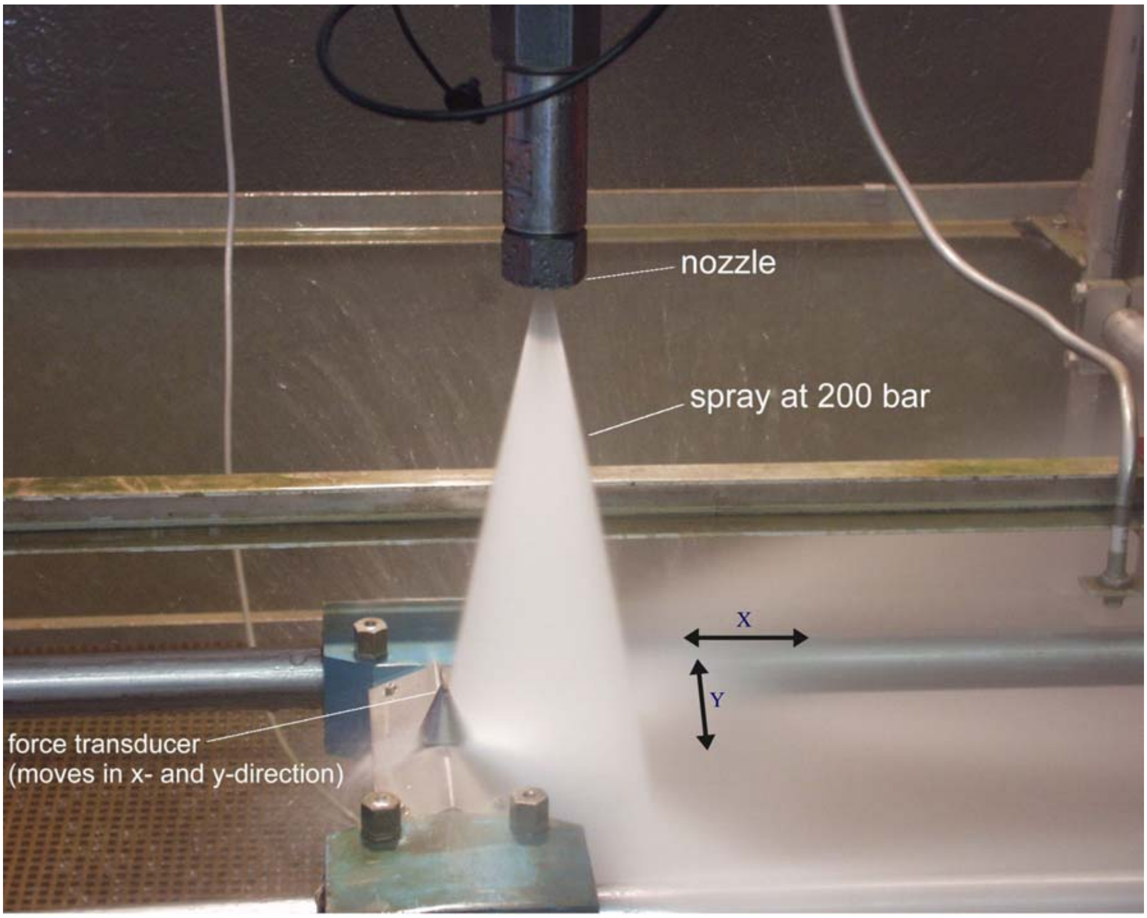


Figure 4: Set-up of descaling nozzle in test bench for impact measurement.

The result of a measurement is shown on the computer by diagrams that show the impact-distribution over the entire spray area (see figure 5).

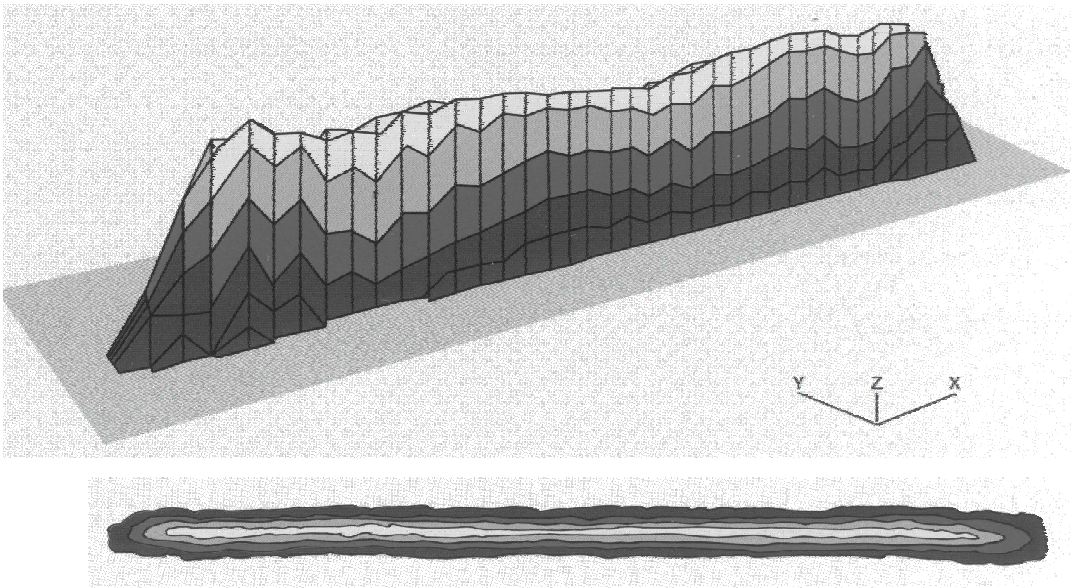


Figure 5: Impact distribution of descaling nozzle

3. Mathematical approximation and computer program

When analyzing the impact measurements illustrated above one can find that it is necessary to create functions that describe dependencies of spray angle, spray form and spray depth on pressure, flowrate, nozzle type and some other parameters. These dependencies influence significantly the impact distribution. The construction of such functions makes it possible to calculate impact and spray form at any other pressure, flowrate or height.

When making a measurement the following parameters have to be considered:

- **<u>Constant parameters</u>**
  - Pressure [bar]
  - Flowrate [l/min]
  - Height [mm] - (distance from nozzle to measuring area)
  - Density of liquid [kg/m³]

  - Mouthpiece outlet diameter [mm]
  - Nozzle type and stabilizer

- **<u>Measured and calculated parameters</u>**
  - spray width [mm]
  - spray depth [mm]
  - spray angle [mm]
  - impact [N/mm²]

The impact is the most important parameter. It depends on the spray width and the spray depth. Its dimension is N/mm². So the impact increases when spray width or spray depth decrease. The impact also increases when pressure or flowrate increase because the impulse raises – but the increasing pressure also influences the spray width and spray depth that influences the impact again.

To get detailed information about the dependencies there must at least one parameter be kept constant. The following figure 6 shows a diagram with constant pressure and flowrate for one nozzle type. The variable parameter was the height.

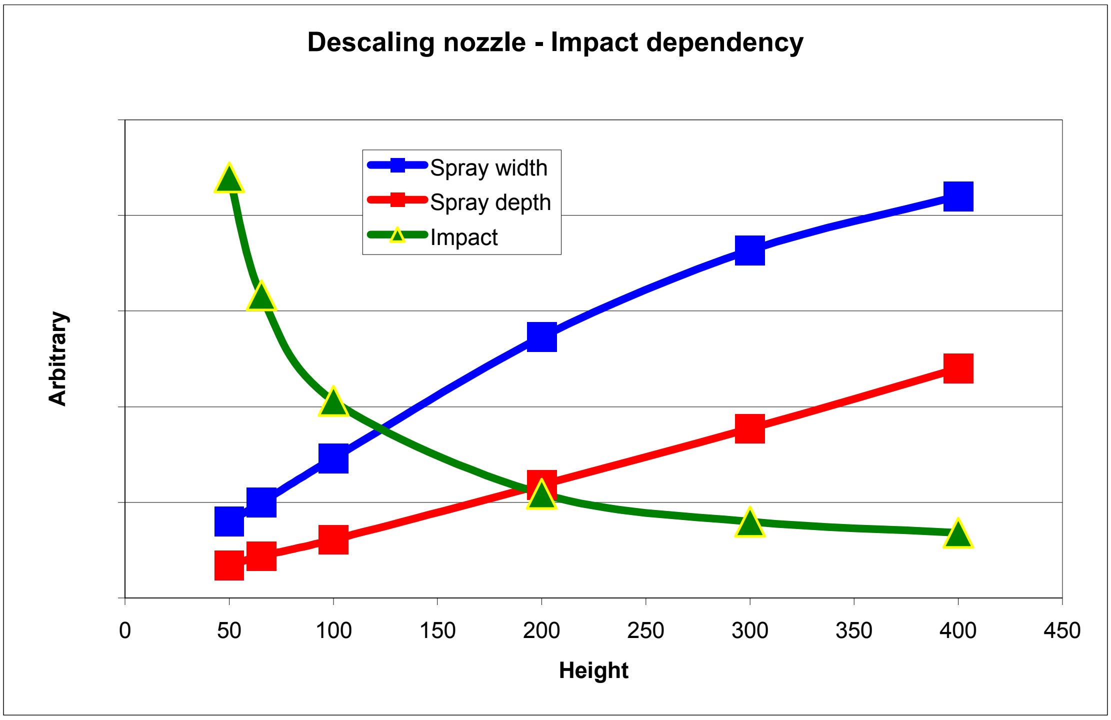


Figure 6: Impact, spray width and depth over height for a high impact descaling nozzle with constant pressure and flowrate

The next diagram in figure 7 shows the Impact, spray width and spray depth for different flowrates. The height was kept constant.

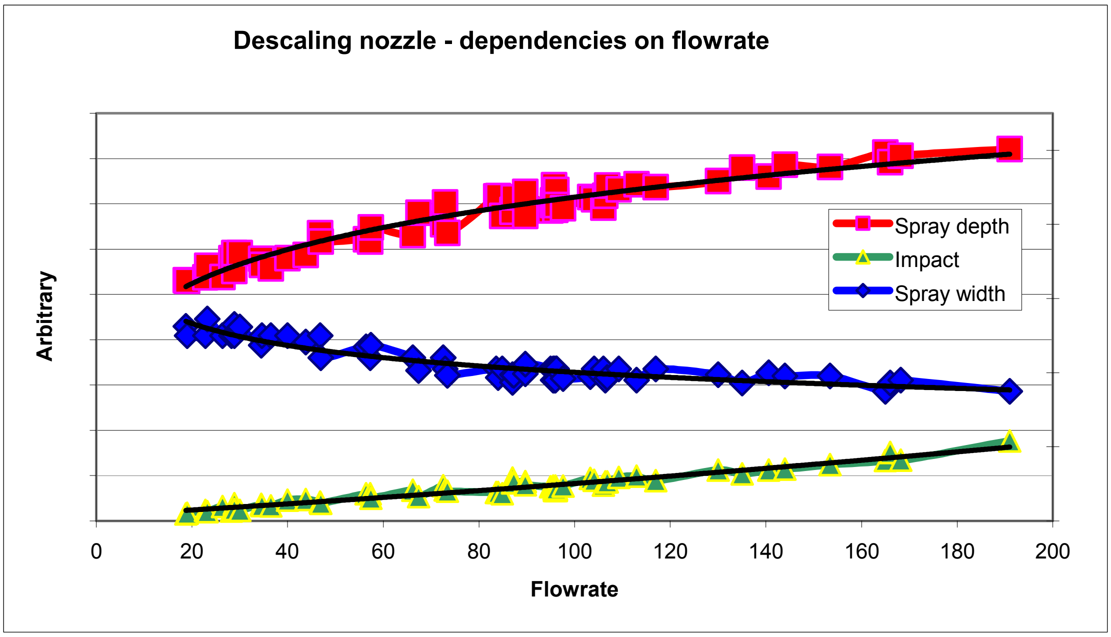


Figure 7: Dependencies of Impact, spray width and depth on flowrate with constant height.

Diagrams like those shown in figures 6 and 7 have been produced for all Lechler descaling nozzle types and designs as a basis for the simulation program.

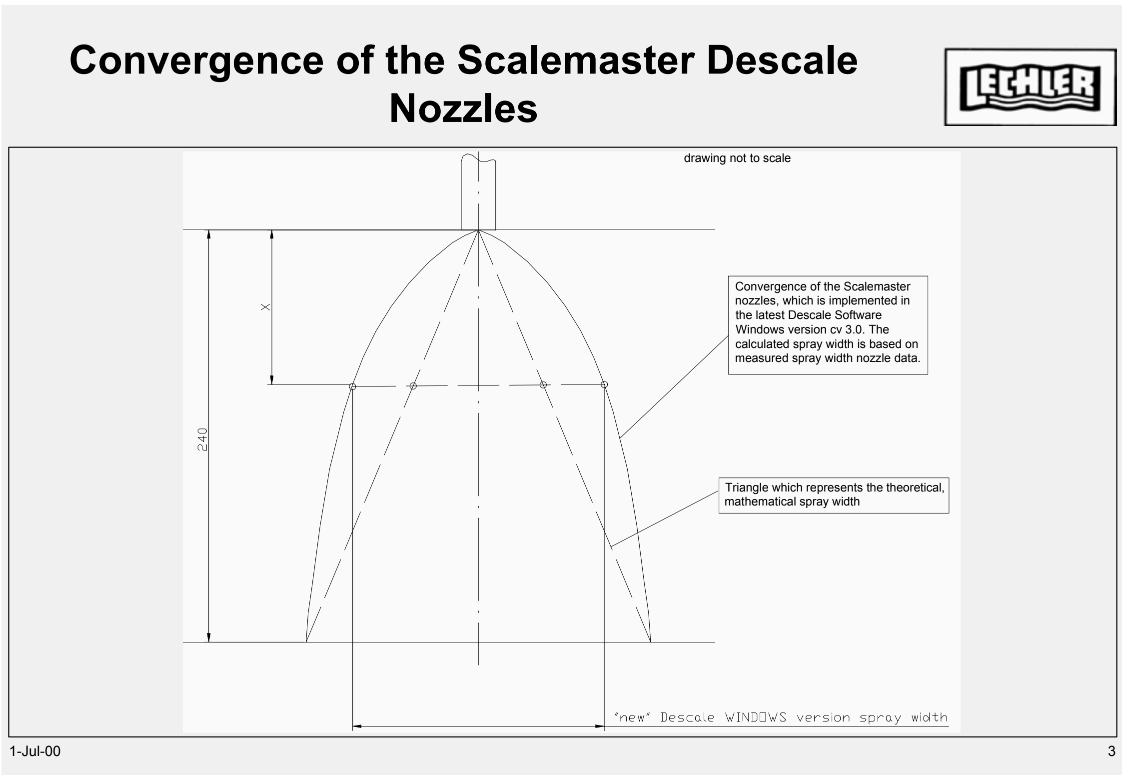


Figure 8: Convergence of descaling nozzle

As mentioned above the spray width is an important parameter for the calculation of the impact. Also it is very important to know the spray width very exactly especially for the design of a multi-nozzle arrangement.

The figure 8 describes that problem. Descaling nozzles typically have a spray width convergence that cannot be neglected. The convergence depends mainly on pressure whereas the degree of convergence also changes from one nominal spray angle to another (26°, 30° and 40°).
For every nozzle type individual functions had to be developed from that information in order to describe the convergence behaviour accurately at all conditions.

The functions determined for a 30°-nozzle are of the following form:

$$\gamma_1 = \left(f_1^{'} \cdot \Delta p + f_1^{''}\right)$$
$$\gamma_2 = \left(f_2^{'} \cdot \Delta p + f_2^{''}\right)$$
$$\gamma_3 = \left(f_3^{'} \cdot \Delta p + f_3^{''}\right)$$
$$\gamma_4 = \left(f_4^{'} \cdot \Delta p + f_4^{''}\right)$$

$$\alpha = \alpha_{nom} + \left[\gamma_1 \cdot h^3 + \gamma_2 \cdot h^2 + \gamma_3 \cdot h + \gamma_4\right]$$

$$D = E + \left(N_2 + \frac{\dot{V}}{10000}\right) \cdot \left[1 - \left(\frac{\Delta p - 250}{1000}\right) + \left(\frac{\alpha - 30}{150}\right)\right] \cdot h + N_3 \cdot h^2$$

$$F_{tot} = 2 \cdot \frac{\dot{V}}{1000 \cdot 60} \cdot \sqrt{2 \cdot \Delta p \cdot 100000 \cdot density \cdot 1000} \cdot \frac{\sin\left(\frac{\alpha}{2}\right)}{\alpha}$$

$$\text{Impact} = \frac{N_1 \cdot F_{tot}}{2 \cdot D \cdot (h + 25) \cdot \tan\left(\frac{\alpha}{2}\right) \cdot 0{,}6127}$$

where:

$\gamma_i =$ variables

$f_i =$ coefficients for nozzle type concerning spray angle

h =height

$\alpha_{nom} =$ nominal spray angle (e.g. 30° for a 30°-nozzle)

$\alpha =$ calculated spray angle

D = spray depth

N_i = coefficients for nozzle type concerning impact and spray depth

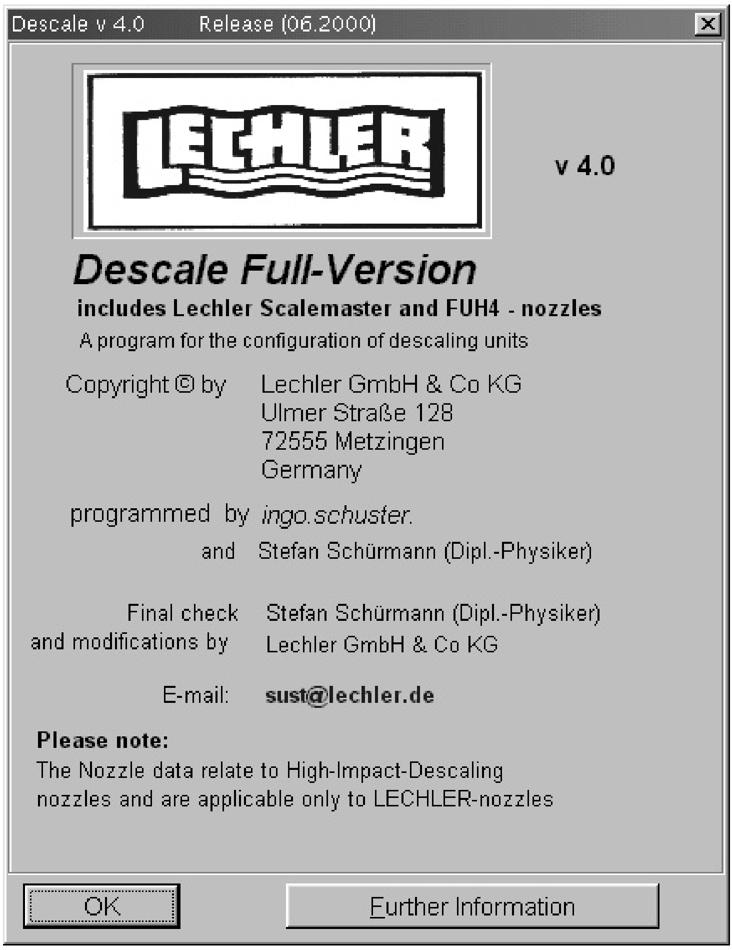
E = Extent of mouthpiece outlet diameter

F_{tot} = total force of spray

$\dot{V}$ = flowrate

Δp = pressure

These formulas are the basis of the simulation program called Descale. This software is an important tool for us which allows us to work out quickly detailed proposals for a nozzle arrangement. Often alternative proposals are produced before a final decision is taken.



It is possible to calculate the impact and spray extent for any pressure, flowrate or height within reasonable limits. The optimal nozzles arrangement for any descaling application can be done that way. The nozzles can be arranged side by side using overlapping criteria to get the most homogeneous impact distribution over the entire plate or strip width.

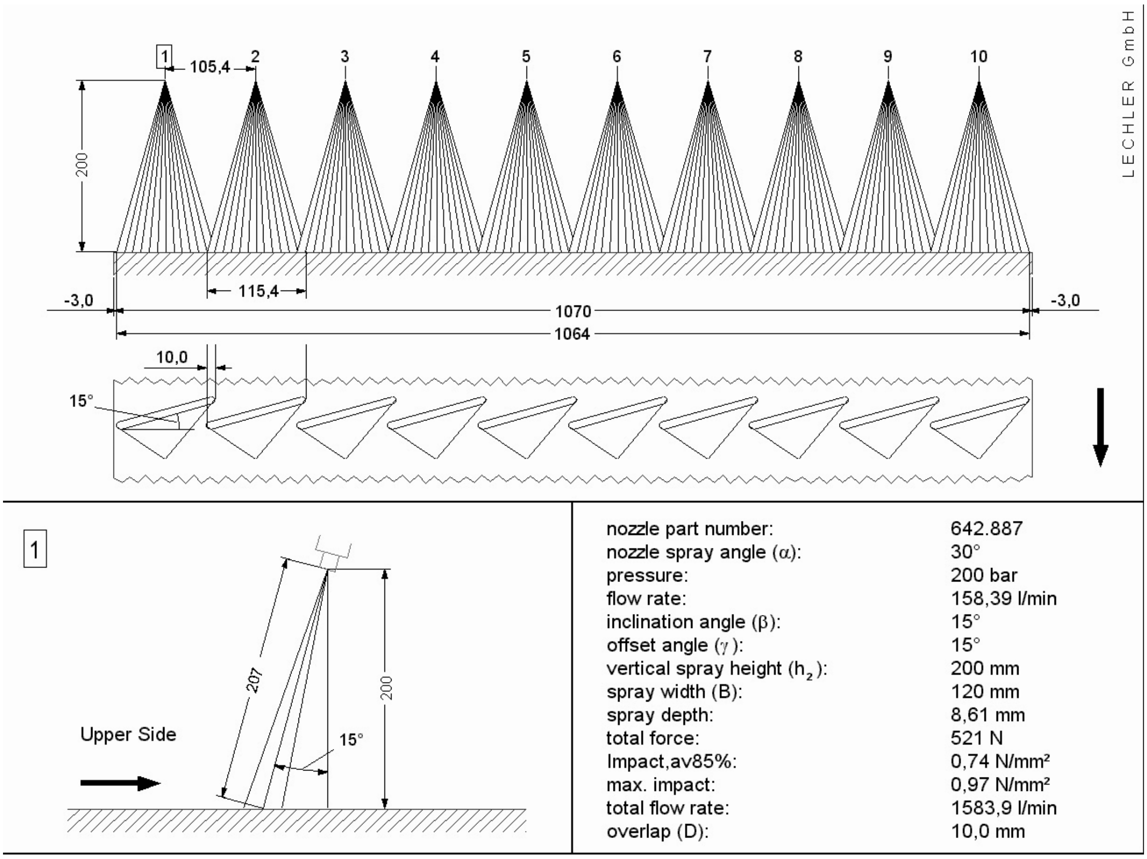


Figure 9: Print of a typical installation proposal carried out with the Lechler 'Descale' program.

4. Conclusion

The measuring of high water impact distribution is very important to know the characteristics of descaling nozzles. Therefore we measure the impact on an impact test bench at typical descaling conditions.
Many of those impact measurements were done to develop mathematical formulas that describe the spray behaviour concerning impact and extent for different types of descaling nozzles.
As there are a number of variables influencing the design of a descaling nozzle arrangement on a header such as

- Water pressure
- Total water flow
- Spray height
- Material width and thickness

we have developed a computer program based on existing measurement data which enables us to accurately and quickly predict the impact under the given conditions. No time consuming and expensive high impact measurements have to be carried out in order to obtain the impact values.
That software goes for both – the investigation of an existing nozzle arrangement on it's potential for improvement as well as for brand new installations.