Challenges in the Production of Thin Coatings at High Line Speed

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Cost reduction of products is and will always be a key objective of industrials. However, it is well identified that the wiping process reaches its limits at high line speed in general and especially thin coatings. If wiping models predict that it is possible to reach 32-37 g/m² of pure Zinc at 180 m/min provided the nozzle to strip distance can be reduced to 6mm, the possibility to reach that process window industrially with sufficient robustness is debated. 3 key problems are reviewed and analyzed: Zinc splashing and liquid drop emissions of various forms, the production of skimming and the noise generated by the nozzles. The available data and models are firstly used to predict phenomena. Secondly, videos and pictures from the lines showing what really happens on the edges especially in case of a strip width change are analyzed. Whereas the predicted level of skimming to remove from the pot is expected very high, it turns out that the target may be very close to the full splashing phenomena and that the most critical industrial situation is related to strip specification changes. It is then expected that the industrial feasibility of the 32-37 g/m² at 180 m/min will depend strongly on the amount of incoming strip with the same width that can be processed continuously.

Keywords *: coating, galvannealed coating, zinc, wiping, splashing, galvanizing*

1. The present practice

It is very well known that the gas wiping process has some limitations in the "coating thickness - line speed" map. In practice, the line speed is reduced for the thin coatings, which consequently lowers the line productivity and increases the operational costs. However, the present market trend is to consider thinner coating thickness, expecting a reduction in the cost of the purchased material as well as a better weldability.

The present industrial best practice for pure Zn (Gi) is estimated at 120-130 m/min for a 5 µm coating, 160-165 m/min for a 7.5 µm and 190-195 m/min for a 10 µm. No industrial results are reported for line speed over 200 m/min, even if some lines have been designed for. The performance for the Galvannealed coating are even a little lower due to the formation of a thicker intermetallic in the pot (between 0.5 and 1 µm) which increases the final total thickness consisting in intermetallic + the residual liquid.

The difficulty to reach thin coatings at high line speed is due to the increase of the entrained liquid by viscous forces and not by the residence time in the pot. Therefore, no benefit can be expected from mini-pots or similar which would keep the strip-liquid contact time to a minimum time since this does not modify the liquid entrainment

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2. The air knife capability and expected problems

Mathematical models, more or less complex, are available in literature. They allow to identify the wiping capability for a defined line speed when the nozzle to strip distance and the nozzle opening are set. However, on an industrial standpoint, limits exist mainly for 2 reasons. Firstly, the nozzle to strip distance cannot be kept safely below 7-8 mm since the risk for the strip touching the nozzle because of vibration and/or not perfectly flat sheet would become too high. Secondly, when the total gas flow going out of the opening is too high, the level of skimming becomes unacceptable, zinc droplets are removed from the bath surface according to the sketch of Fig. 1. Whereas the gas flow limit is not an absolute value, it is admitted that 1000 Nm^3/h per meter of nozzle on each side is a practical maximum. Finally, too small nozzle openings are very sensitive to dust and scratches, both of which leading to jet lines. In practice, an opening below 0.8 mm is very difficult to operate.

The last phenomena which must be included in the prediction of the coating weight is related to the fact that the reduction of the nozzle to strip distance (Z) becomes very inefficient below 7 times the nozzle opening (d) as shown on Fig. 2 which is a result from lab experiments with a water model.[1)]

When the industrial limitations here above described are introduced in the wiping models the expected minimal film thicknesses that can be obtained at 180 m/min are those of Table 1 for 3 different nozzle opening. The full details of the calculation will be available in the reference.[5)] The pressure indicated is the total Pressure just ahead of the opening, in the nozzle, not that measured in the feeding pipe due to the eventual pressure loss.

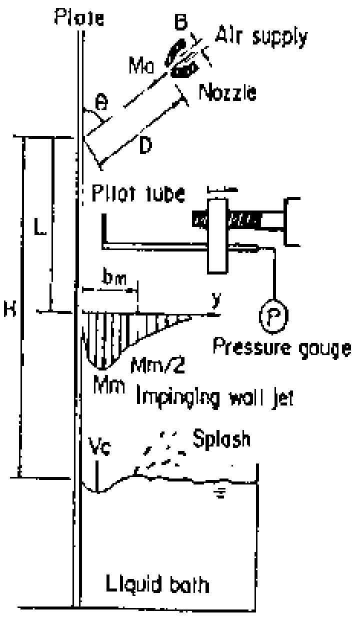


Fig. 1. Splashes due to high gas flow.

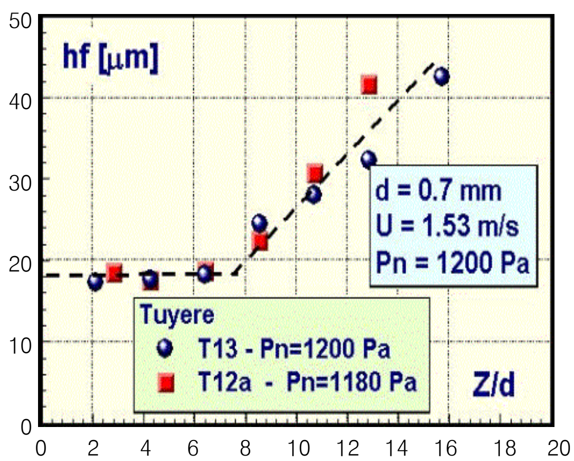


Fig. 2. Film thickness after wiping.

If the values obtained are quite promising on a productivity stand point, reaching them industrially on a regular base is very challenging. The main expected problems relate to splashing which have various forms, the most critical being that described in Fig. 3,[8)] noise level where the limitation to 85db in working areas trend to become a wish, the strip edge management and the skimming production.

Fig. 3. The full splashing phenomena.

Table 1. Minimum theoretical coating thickness and weight for various process conditions

(a) gap 0.8mm 180m/min Pressure~800mb

Distance	Mini Coat Th (μm/gm^2)
8mm	6.65 - 43
7mm	5.8 - 38
6mm	5.0 - 32
5mm	4.15 - 27

(b) gap 1mm 180m/min Pressure~550mb

Distance	Mini Coat Th (μm)
8mm	7.4 - 49
7mm	6.5 - 42
6mm	5.6 - 36
5mm	4.6

(c) gap 1.2mm 180m/min Pressure~400mb

Distance	Mini Coat Th (μm)
8mm	8.1 - 53
7mm	7.1 - 46
6mm	6.1
5mm	5.1

3. The splashing problems

The word "Splashing" is however used for different situations which have indeed different physical roots : the "Full splashing phenomena" reviewed and clearly described in[8] and the classical drop at the edges. The latter, very different from "Full Splashing" is the most usual situation which starts to occur at line speed over 120 m/min. The Zn drops are detached by the nozzle gas from the thick liquid back flow. Those splashes can however be limited or even suppressed when the edge baffle is correctly designed and adjusted as shown on fig. 4 a to c which refer to a line speed of 150 m/min (a & b) and 130 m/min (c). In practice, the difficulty when running thin coating at high line speed consists in the positioning of the baffle 2 mm maximum away from the edge while the gas flow is high and the fact that the Zn back flow makes easily a bridge between the strip and the baffle due to the high level of back flow. The problem is more related to mechanical and design problems then to physical limitations

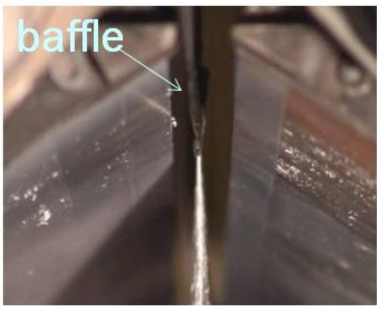
The "Full splashing phenomena" occurs over 160 m/min and is characterized by an Hysteresis phenomena meaning that the line speed at which it occurs is higher than that at which it disappears. The only way to proceed when the phenomena occurs on the line is to slow down. The phenomena is related to the fact that the liquid surface tension cannot avoid the back flow to explode under the shear stresses of the parietal gas flow and the dynamic forces. Previous work have shown that the splashing "disappearance" can be predicted by a formula linking the film Reynolds number (Re), the Weber number (We) related to the parietal gas flow and the nozzle wiping angle (fig. 5a, b and c):

$$We = e^{a\text{-}angle+b} * Re^{-n}$$

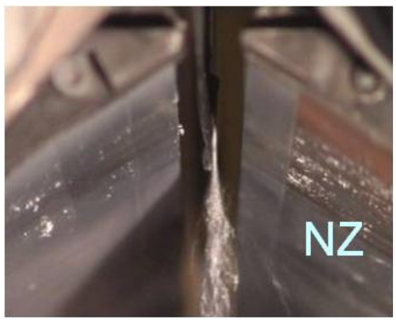
(a, b, n are constants fitted to experiment results, e is exponential function)

However, if the present model has the merit to predict the limit, it is too simple. For example, the model is not able to predict the following observations:

- full splashing is not reported on thin coatings (10 µm



(a)



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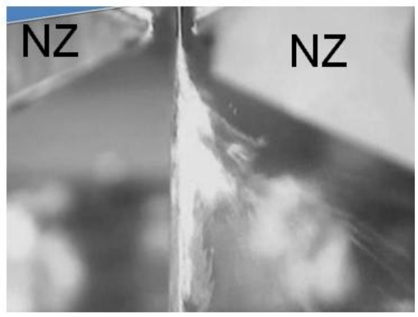
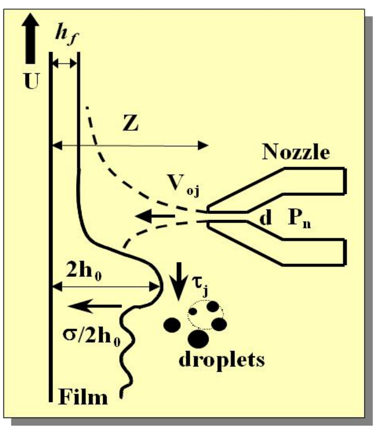
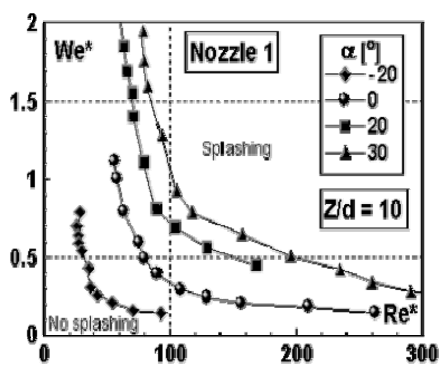


(c)

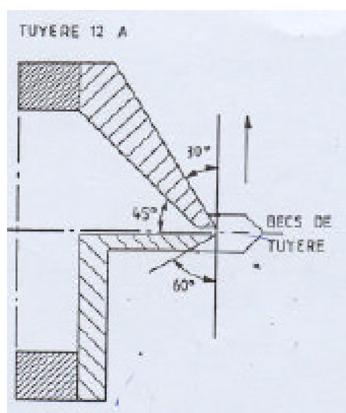
Fig. 4. (a) Excellent edge control, (b) critical edge control, (c) dramatic edge control.



(a) Phenomenological approach



(b) Splashing Limit for one type of Nozzle



(c) Nozzle 1 tested

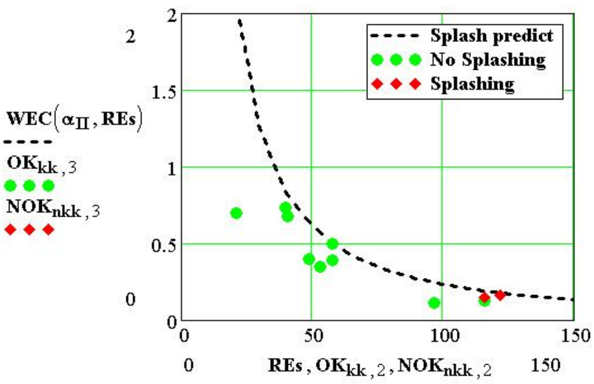
Fig. 5. Description of full splashing phenomena and process window where it is observed from[8].

and lower) up to 165 m/min
- Full splashing occurs very frequently on 20 µm over 150 m/min in specific process conditions
- the external nozzle design can move the location of the limit in the We-Re map.[8)]

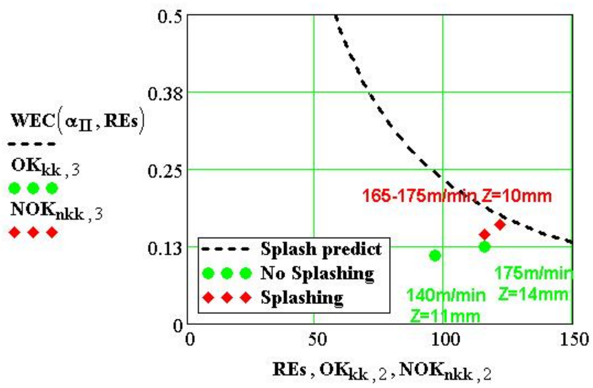
On Fig. 6a and b are plotted in the We-Re map the process conditions where, for a defined nozzle, full splashing industrially occurs (right diamond) and does not (green points). It is observed that the concept previously defined is quite valid but lack of some accuracy. For example, the high sensitivity of 20 µm coating over 160 m/min when wiped close to the strip do not clearly appears (Fig. 6b) as well as the effect of the nozzle shape.[8)]

The reason why the thin coatings are not expected to suffer too much from full splashing is because their Reynolds number is small and then would require a much higher Weber value to generate the phenomena. The concept has however been used to predict the full splashing limit for some thin coatings, purpose of the present work. The results are shown on Fig. 7 and correspond to a 1 mm nozzle opening. It turns out that the risk of splashing is not too high for line speed up to 180 m/min but exist. Line speed over 200 m/min appears as much more critical.

In order to better understand the impact of the nozzle



(a) Observed NON splashing (green dots) and splashing (red diamonds) with theoretical limit



(b) Observed NON splashing (green dots) and splashing (red diamonds) for 20 µm coating only

Fig. 6. Industrial results where Full splashing is observed or not.

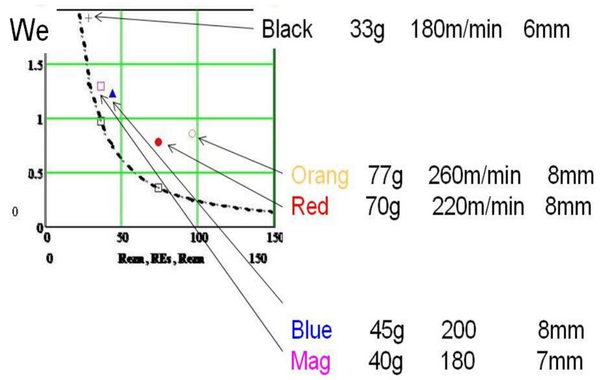
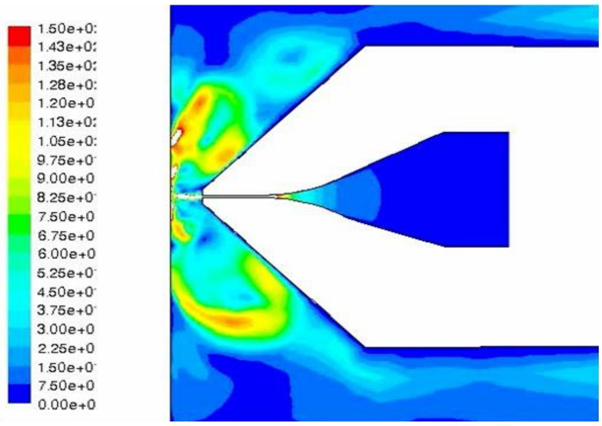
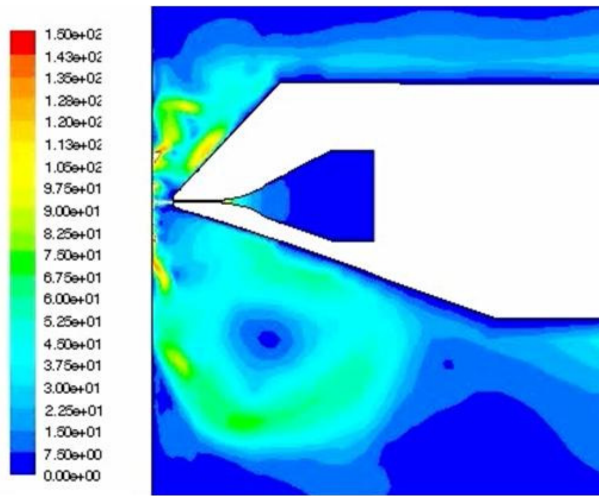


Fig. 7. Prediction of full splashing for thin coatings.



(a)

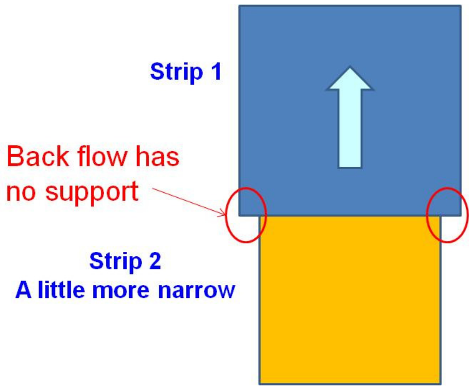


(b)

Fig. 8. (a) Velocity maps unsteady condition, (b) velocity maps unsteady condition.

shape on the Full splashing limit, 2D CFD modeling has been done with 2 different nozzle shapes. The feeding pressure in the chamber is set to 500 mb and the nozzle to strip distance to 10 mm. The Low eddy Simulation approach is used and the time step adjusted to 1E-5sec. The velocity maps of the 2 designs are shown on Fig. 8 (scale 0 -150 m/sec). It turns out that circulation loops develop over and under the nozzle. Those circulation loops can change the local Weber number. The circulation loops are indeed very different for the 2 designs. This could explain the effect of the external design of the nozzle on the full splashing limit. As it has been observed in experiments, nozzle 8b has a higher splashing limit. From modeling, the velocities in the circulation loop are lower in that case, especially where the back flow detachment is suspected to occur. More work should however be needed to validate that assumption

Another big problem expected industrially deals with the strip width change during which, as shown on the sketch fig. 9, the back flow is strongly disturbed. It must be understood that in case of a strip reduction, the back flow coming from Strip one has no more support to flow



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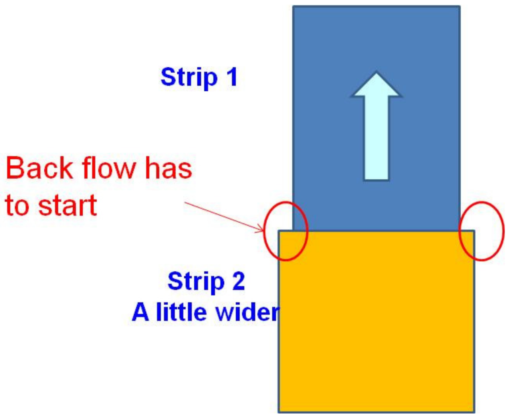
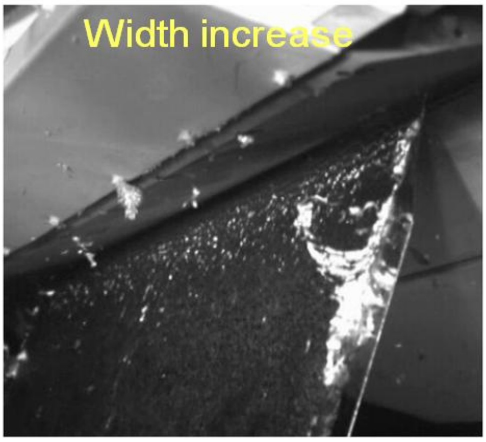
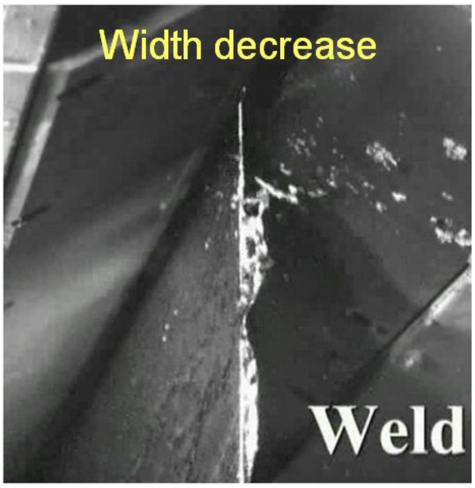


(b)

Fig. 9. (a) Strip width decrease situation, (b) strip width increase situation.



(a)



(b)

Fig. 10. (a) Splashes at the weld for a strip width increase, (b) splashes at the weld for a strip width decrease.

on and therefore will detach from the strip. Such a situation generates a lot of big drops and splashes, a situation which is even more critical because the edge baffles are open at that moment. The case of an increase of strip width is not better. In that situation, the back flow on the edge corresponding to the strip increase has to start (red balloon on Fig. 9b). This also induce a lot of splashes. The phenomena described has been observed industrially has shown on the pictures of Fig. 10 both of which corresponding only to 90 m/min for a 7 µm coating. It is expected that that film explosion will generate much more splashes and drops when the line speed and the wiping gas flow are increased due to the kinetic energy of the total zinc layer moving up. Such strong instabilities justify the reason why the "Full splashing phenomena" is mainly observed when the weld pass the nozzles and why it is the disappearance curve that must be considered as industrial limit.

4. Looking at skimming

The Skimming production is also a big concern for thin coatings at high line speed. As it has been demonstrate by DUBOIS[6] the top dross are more dependent on the galvanized surface than on the total loaded Zn in the pot. In addition, it is observed that the amount of dross per surface unit increases when wiping increases. The most critical situation is indeed in the case of thin coatings at high line speed. Physical models to predict the skimming formation are not yet available but some figures can be obtained based on the values observed in lines (Table 2)

Therefore, a production of 22 to 30 g/m² of skimming per m² of galvanized sheet seems a reasonable estimation for the case of 5 µm Zn at 150 and 180 m/min respectively. Those values are used to compute the top dross weight to remove per shift (fig. 11). This amount corresponds to a loss of 24 and 27% of the loaded Zinc in the pot respectively for the line speed of 150 and 180 m/min. On a practical standpoint, removing 3 to 4T of skimming requires investigation on the method in addition to the fact that dross removal is known to increase the surface defects on exposed sheets

Table 2. Skimming production industrially observed for average coating of 10 µm[6]

	Pot T ℃	Skimming g/m² 2sides	Speed m/min
Galfan	440	7 to 10	130
Gi 0.25%	460	15 to 18	130
Gi 0.25%	460	18 to 22	160
Gi 0.25%	480	25 to 30	130
Gi 0.25%	460	12 to 15	80
Gi 0.17%	460	18-22	130

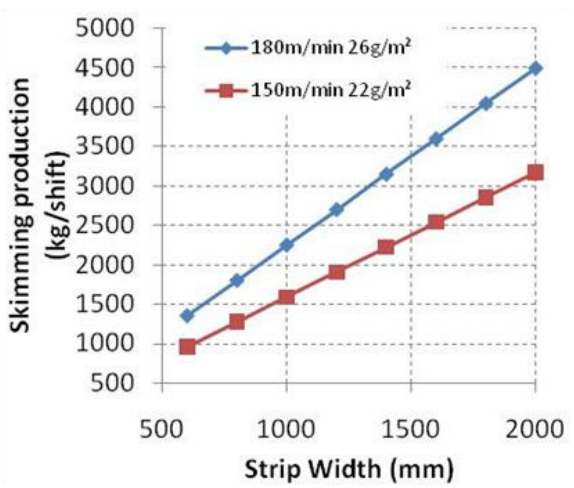


Fig. 11. Expected top dross production.

5. The problem of noise

The noise generated by the nozzle has been studies by some researchers.[7),4)] The sound pressure as well as the tones obtained are due to the flipping of gas jet going out of the facing nozzles. Therefore, the total sound pressure can be drastically reduced when the baffle plates are located in such a way that both nozzles become independent as the experiments have shown (Fig. 12). This implies one more time that the positioning of the edge baffles are a key issue for noise reduction. However, since the wiping pressure must be high, the 85db will never be reached when producing thin coatings at high line speed.

In line measurements have shown that the noise level around the pot is highly dependent on the wiping pressure as shown on fig. 13. When baffle plates and nozzles are not perfectly set, the noise spectra show frequency peaks over 500 hz (Fig. 14). However, after having analyzed many in line situation, it has appeared that the noise level on a CGL line is also highly dependent on the general line design. Many equipment generate noise like hydraulic groups, gear boxed, dryers, any type of blowers, high

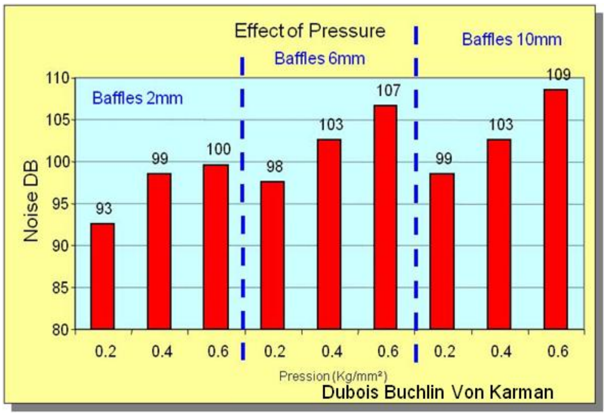


Fig. 12. Noise generated by 2 facing nozzle for different baffle to strip distance.[4)]

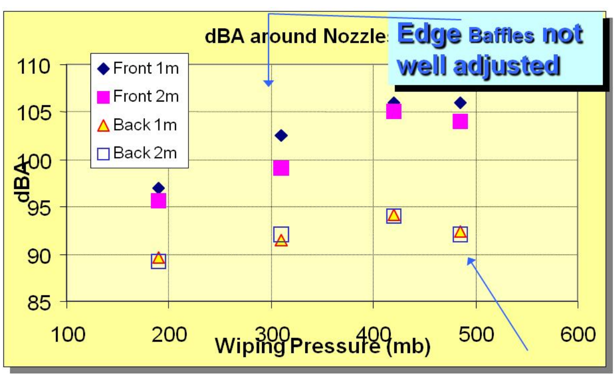


Fig. 13. In line noise measurement around the pot Opening.

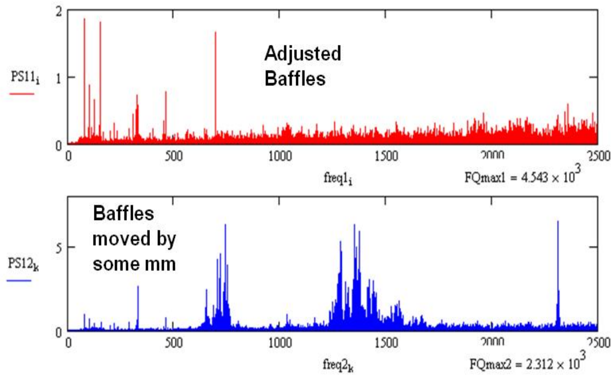


Fig. 14. Effect of baffles on noise spectra. Inline measurement 150 m/min, Wiping P 300 mb 11 µm gap 1.2 mm.

speed edge nozzles which are sometimes used to remove water from edges. In practice the noise level around the pot is often over 95 db, even when the line is stopped but all other equipment running. The real impact of the air knives on noise is the generation of specific tones with peaks depending on the wiping pressure: the higher the pressure and the shorter the nozzle to strip distance, the higher the frequency.

On a more general stand point, no practical and industrial solution seems possible to reduce the noise level around the pot down to 85 dB. The high noise level is indeed inherent to the wiping process. Solutions like "opposite noise generation" or "full encapsulation of the nozzles" cannot be used due to the complexity the operations to fulfill around the pot (nozzle cleaning, dross removal, pot management···) and the wide process widow of a classical galvanizing line.

6. Conclusions

If the wiping model predicts that a coating weight of 32-37 g/m² of pure zinc can be reached at 180 m/min provided wiping is conducted as close as 6 mm away from the strip, the industrial feasibility is analyzed and lead to the following conclusions:

- Thin nozzle opening are better due to the lower gas flow used and the possibility to wipe closer to the strip
- Full splashing is not expected be the highest problem based on the available models which have however their limitations. However, the process window is predicted very close to the splashing limit.
- CFD modeling of 2 different nozzles have shown that the gas flow between the nozzle and the strip is strongly dependent on the external shape. This could explain the reported effect of the nozzle design on the splashing limit
- Strip width transitions generate strong wiping instabilities in the back flow. Short customer orders with frequent width changes are expected to be a big limitation in the industrial feasibility of thin coatings at 180 m/min.
- Edge baffles are a key equipment due to the impact they have on the control of the back flow on the edges. Locating them very close to the edge at high line speed and under a high gas flow is really challenging.
- The skimming production will be high with 2.5 to 3.5T to remove from the pot per shift. This corresponds to a Zn loss higher than 20% of the loaded Zn
- Noise cannot be kept at 85 dB due to the high wiping pressure used, even with edge baffle perfectly located. It must however be kept in mind that a big part of the total noise is generated by other equipment than wipers like any blower, dryer, pump and gear boxes

Based on the present analysis, it turns out that if 32-37 g/m² of pure Zinc is feasible, reaching the target with sufficient robustness would require a absolute accurate adjustment of the wiping system and a quite big amount of the same specification to avoid the adjustment changes and strip width variations.

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