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# PROCESS OPTIMIZATION FOR CONTINUOUS HOT-DIP GALVANIZING OF LOW-CARBON STEEL: THE ROLE OF FURNACE ATMOSPHERE

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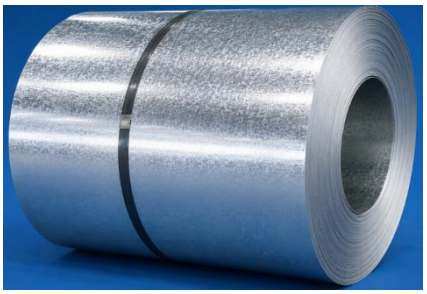
This study focuses on the importance of controlling the dew point within the furnace atmosphere during the continuous hot-dip galvanizing process to achieve a high-quality zinc coating on steel sheets. The dew point is crucial because inappropriate values, particularly an excessively high dew point, can increase the oxidizing potential of the furnace atmosphere and promote high-temperature oxide formation on the steel surface. These oxide patches act as barriers to liquid zinc wetting and may result in uncoated areas on the galvanized steel sheet, which are more susceptible to corrosion during service. The results showed that altering the dew point values influenced the quality of the galvanized steel sheet surface. Higher dew point values were associated with increased water vapor content in the furnace atmosphere, leading to potential coating defects. The study concluded that achieving lower and well-controlled dew point values resulted in a galvanized surface with fewer coating defects.



## INTRODUCTION

For successful realization hot-dip galvanizing surface of low carbon steel (Table 1), several criteria must be met, among which the two most important are:

– cleaning the steel surface before galvanizing
–creating suitable conditions for zinc adhesion

*Table 1*

Chemical composition of steel

| C (%) | Mn (%) | Si (%) | P (%) | S (%) |
|---|---|---|---|---|
| *0.12* | *0.60* | *0.5* | *0.10* | *0.045* |

During the surface preparation for galvanizing, the steel sheet undergoes thermal treatment (recrystallization). During this stage, a protective atmosphere must be created in the furnace to prevent oxidation of the steel sheet, therefore dissociated ammonia is used as the furnace atmosphere for thermal processing. Dissociation is performed in a dissociator at a temperature of 980 ºC according to the reaction:

$$2NH_3 \rightarrow 3H_2 + N_2$$

Before being supplied to the furnace, the dissociated ammonia must be dried in a dryer. The dried dissociated ammonia is then used in the furnace to reduce iron oxides on the steel sheet

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surface according to the following reaction:

$$FeO + H_2 \rightarrow Fe + H_2O$$

Dissociated ammonia was supplied to the furnace at a flow rate of 100 $Nm^3/h$, maintaining an internal pressure of 100 mbar above atmospheric pressure. This positive pressure prevents oxygen ingress from external air into the furnace, because oxygen entering the hydrogen-containing furnace atmosphere would create a severe risk of hydrogen combustion and explosion. The oxide-free steel sheet is placed in a bath of molten zinc at 455 °C. During the process of preparing the surface of steel sheet[1–3] one of the most critical aspects for creating the conditions for the best adhesion of zinc is to control the dew point and maintain its values at appropriate intervals for the best quality adhesion of the zinc layer on the steel surface.

## EXPERIMENTAL

The determination of the dew point is done through the data which are obtained by Alnor Dewpointer 7000-U device[4] Fig. 1.

Fig. 1 – Alnor Dewpointer 7000-U device.

The device works based on adiabatic expansion. The gas sample is withdrawn from the furnace, compressed to a given pressure, and then expanded. During the expansion, the pressure is recorded at the point when the first signs of fog appear. The dew point was determined using Eq. (1):

$$T_2 = T_1 \cdot \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\gamma = \frac{Specific\ Heat\ at\ Constant\ Pressure}{Specific\ Heat\ at\ Constant\ Volume} = \frac{C_p}{C_v}$$

$$Q = \frac{\gamma - 1}{\gamma}$$

$$T_2 = T_1 \cdot \left(\frac{P_2}{P_1}\right)^{Q} \qquad (1)$$

where:

$T_2$ – final temperature

$T_1$ – initial temperature

$P_2$ – final pressure

$P_1$ – initial pressure

For Alnor Dewpointer[4] the final temperature is the dew point temperature, while Q is the gas constant being tested. The values of thermodynamic constants[5] used in the above relation are taken from Table. 2.

*Table 2*

Thermodynamic constants of some gases for Dewpointer[5]

| Compound | Formula | Cp (kcal) | Cv (kcal) | ɣ (kcal) | Q (kcal) |
|---|---|---|---|---|---|
| Ammonia | $NH_3$ | 0.5232 | 0.3995 | 1.3096 | 0.2364 |
| Hydrogen | $H_2$ | 3.39 | 2.40 | 1.41 | 0.292 |
| Nitrogen | $N_2$ | 0.2477 | 0.1765 | 1.4034 | 0.2874 |

## RESULTS AND DISCUSSION

Dew point values are related to the water vapor content in the furnace atmosphere and have a direct influence on the oxidizing potential of the atmosphere. Higher dew point values may promote high-temperature oxide formation on the steel surface. These oxide patches act as a barrier to

liquid zinc wetting and can result in poor zinc adhesion, uncoated areas, and reduced corrosion resistance during service.[6]

Depending on the different values of the dew point (Table 3), surfaces with different qualities can be achieved.

*Table 3*

The value of the dew point, the volume of water in% and the mass of water per $m^3$

| DewPoint (°C) | Vol.% | Humidity mass g/$Nm^3$ |
|---|---|---|
| –18 | 0.123 | 0.989 |
| –17 | 0.135 | 1.09 |
| –16 | 0.148 | 1.19 |
| –15 | 0.163 | 1.31 |
| –14 | 0.179 | 1.43 |
| –13 | 0.196 | 1.57 |
| –12 | 0.214 | 1.72 |
| –11 | 0.234 | 1.88 |
| –10 | 0.256 | 2.06 |
| –9 | 0.280 | 2.25 |
| –8 | 0.305 | 2.45 |
| –7 | 0.333 | 2.68 |
| –6 | 0.363 | 2.92 |
| –5 | 0.396 | 3.18 |
| –4 | 0.431 | 3.46 |
| –3 | 0.469 | 3.77 |
| –2 | 0.510 | 4.10 |
| –1 | 0.555 | 4.46 |
| 0 | 0.602 | 4.84 |
| 1 | 0.649 | 5.21 |
| 2 | 0.696 | 5.59 |
| 3 | 0.750 | 6.02 |
| 4 | 0.803 | 6.45 |
| 5 | 0.861 | 6.91 |
| 6 | 0.922 | 7.41 |
| 7 | 1.06 | 7.94 |

Example: For a good galvanizing the dew point would be –20ºC Fig. 2 while the water vapor volume in % would be 0.1, for the –15ºC dew point the water vapor volume would be 0.163, and so on.

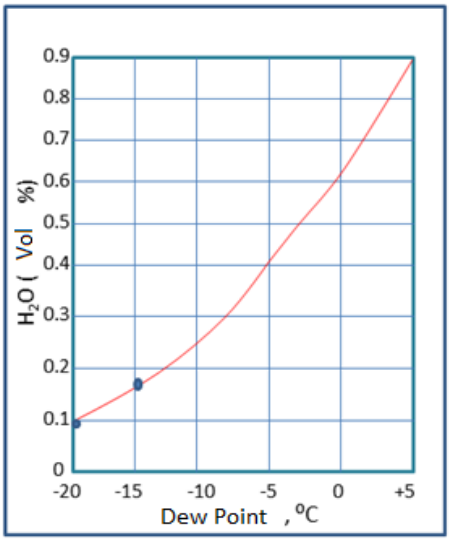


Fig. 2 – Relationship between dew point and water vapor volume.

Dew point values in the table below the red line are not suitable for continuous hot-dip galvanizing,[7,8] and these values would cause damage to the galvanized surface. The dew point is typically measured approximately three times during a 24 hours production period. From the data obtained with the

Alnor Dewpointer 7000-U, results for the dew point have been achieved in different cases presented in Table 4. Based on the obtained results, it can be observed that higher dew point values lead to larger areas without zinc adhesion is as shown in Fig. 3. These areas are most likely related to high-temperature oxide formation on the steel surface due to the increased oxidizing potential of the furnace atmosphere.

*Table 4*

Dew point in different cases

| Dew Point (ºC) | $T_1$ (K) | $P_2$ (bar) | $P_1$ (bar) | Q (kcal) |
|---|---|---|---|---|
| 10.1 | 273+ 25 | 0.839 | 1 | 0.292 |
| 5.17 | 273 + 25 | 0.79 | 1 | 0.292 |
| –0.08 | 273 + 25 | 0.74 | 1 | 0.292 |
| –10.34 | 273 + 25 | 0.649 | 1 | 0.292 |

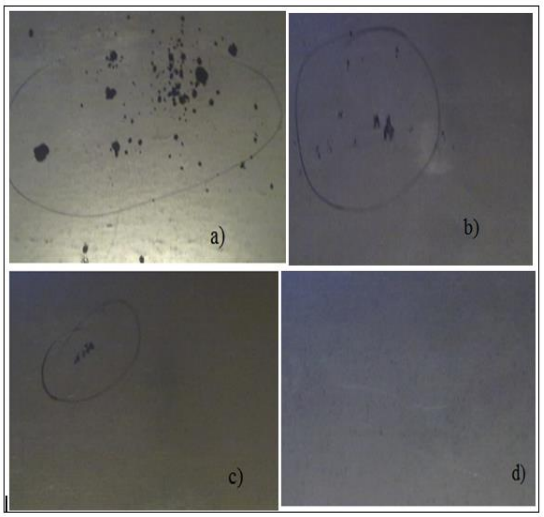


Fig. 3 – a) Dew Point 10.1ºC; b) Dew Point 5.17ºC; c) Dew Point –0.08ºC; d) Dew Point –10.34ºC.

## CONCLUSIONS

For a successful hot-dip galvanizing process, maintaining the dew point below 0°C is very important. During galvanizing, it is critical to ensure a protective, reducing atmosphere in the furnace. This is because even slight positive dew point values may result in incomplete zinc adhesion, leading to uncoated, corrosion prone areas on the steel surface.

The furnace atmosphere must therefore be monitored regularly to maintain reducing conditions, and the dew point is typically measured approximately three times during a 24 hours production cycle. Positive dew point values are often associated with excessive moisture or malfunctioning dryers, and they may indicate increased oxidizing potential of the furnace atmosphere, which may promote high-temperature oxide formation on the steel surface. When the dew point is found to be positive, it is imperative to inspect and service the drying systems promptly to restore optimal conditions for zinc adhesion.

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