

# THE EFFICIENCY PROMOTION OF THE KEY TECHNIQUES IN HOT GALVANIZED STEEL ALLOYING PROCESS

Dan Mei<sup>a</sup>, Peng Lei<sup>b\*</sup>, Zhi Fang<sup>c</sup>, Meng Wen<sup>d,1</sup>

<sup>1</sup> Wuhan university of science and technology

<sup>a</sup>meidan@wust.edu.cn <sup>b</sup>leipeng200808@gmail.com <sup>c</sup>fz256@sina.cn <sup>d</sup>15671662701@163.com

**Keywords:** Hot dip galvanized steel; Alloying soaking pit; Flow filed optimization; Numerical simulation; Promotion of energy efficiency.

**Abstract:** Alloying soaking pit is one of the key equipments in hot galvanized steel alloying process. Alloying temperature indirectly effects the metallographic structure and product quality. To increase temperature in galvannealing furnace efficiently is very useful and energy-saving. Numerical simulation on 3D flow field and temperature field and analyzing the reason why the temperature in the furnace cannot meet the technical requirements were conducted using CFD, and then the optimum was proposed. Results indicate that if two baffles are added symmetrically in the top of soaking furnace, the furnace temperature will increase by 75% under the same resistance thermal power, then energy efficiency is enhanced.

## Introduction

Hot galvanized sheet steel is one of the effective corrosion-resistance steel materials, which is widely used because of its good paint adhesion and weldability.[1,2] Alloying is a process which makes pure zinc layer galvanized to sheet steel anneal at 450-550°C to make the layer and steel substrate diffuse and react in order to get zinc-iron alloy whose iron content is 7%-15%.[3] Alloying furnace heating mode, the spatial distribution of air flow, heat temperature and so on are all key factors effecting alloying layer structure.[4] CFD(Computational Fluid Dynamics) is playing a more and more important role in engineering design and optimization because of its high speed and low cost, especially in the problems of heat transfer and fluid flow simulation analysis.[5,6] Through the theoretical research and using CFD technology, calculating temperature filed and flow filed inside the furnace and analyzing the problem why temperature cannot meet the technical requirements, the flow filed optimization is proposed, which increases furnace temperature so as to prompt energy efficiency without thermal power promoting.

## Alloying Process and Summary of Soaking Pit Production

As Fig 1. shows, alloying furnace is directly above the zinc pot, it can be divided into galvannealing furnace and cooling tower. Before cleaned and dried the steel is fed through the pot of molten zinc. Alloying furnace heats the steel strip to a certain temperature to make galvanized layer and substrate steel react, and the resultant surface layer is a complex zinc-alloy, where more than one specific phase exists.<sup>[4]</sup> Then in cooling tower the formation of different crystal lattices complete and the crystal lattices are composed of different metallographic structures.[7]

The galvannealing furnace is divided into fixed segments and mobile segments, where the heating resistors are distributed. Heating resistors are the application of the principle of electromagnet heating: When a hunk of metal conductor move in a magnetic field or lies in a changeable magnetic field, eddy electric field inside the conductor occurs, producing eddy currents. Because of the small resistance of a large conductor, intense eddy currents produce a great deal of joule heat. Mode of heat transfer in the furnace include convective heat transfer between heat resistances and air and between the air and the sheet steel ,the thermal radiation between the sheet steel and heating resistor, and heat conduction inside sheet steel. From the viewpoint of flow, the motion include the spontaneous formation of natural convection caused by temperature rises , as well as the forced convection caused by the friction of the fluid due to movements of sheet steel.

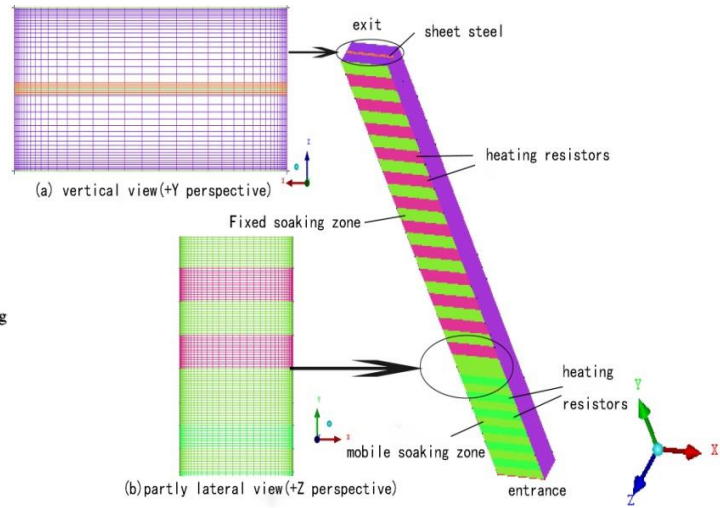
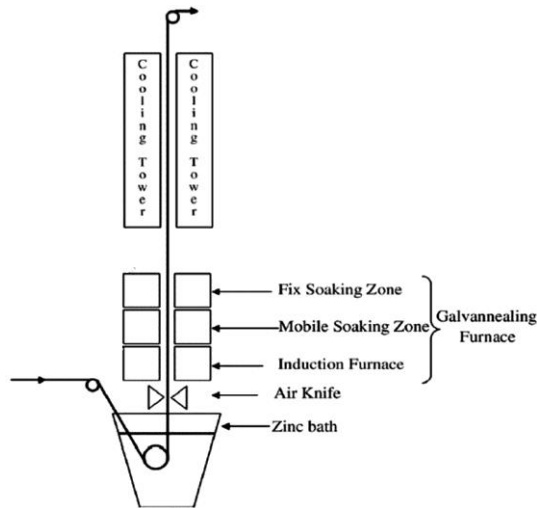


Fig. 1 Geometry model of alloying soaking pit Fig. 2 Alloying soaking pit (soaking zone)

## The Simulation of Flow Field in Furnace Based on CFD

**The Establishment of Grid.** ICEM CFD is used to establish alloying furnace's three dimensional model and the model was then divided into structural grids. [8] Due to the differences in the medium and heat transfer, calculation models are segmented into solid domain and fluid domain. [9] Solid domain model is a total of 94109 grids, and the fluid domain model is in total of 1914452 grids.

**Mathematical model.** The flowing air in the alloying furnace can be seen as three dimensional, steady state flow. k-ε model was selected as turbulence model. Flow and heat transfer control equations are:

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0 \quad (i=1,2,3) \quad (1)$$

$$\frac{\partial(\rho u_i T)}{\partial x_i} = -\frac{\partial \rho}{\partial x_i} + \frac{\partial}{\partial x_i} \left[ (\mu + \mu_t) \left( \frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} \right) \right] \quad (2)$$

$$\frac{\partial(\rho u_i T)}{\partial x_i} = \frac{\partial}{\partial x_i} \left[ \left( \frac{\mu}{\rho_r} + \frac{\mu_t}{\sigma_t} \right) \frac{\partial T}{\partial x_i} \right] [10] \quad (3)$$

$$\frac{\partial(\rho u_i k)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k - \rho \varepsilon \quad (4)$$

$$\frac{\partial(\rho u_i \varepsilon)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + \frac{G_{1\varepsilon}}{k} G_k - \rho \frac{\varepsilon^2}{k} \quad (5)$$

$$\text{Where } G_k = \mu_t \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \frac{\partial u_i}{\partial x_j} \quad \mu_t = c_\mu \rho k^2 / \varepsilon$$

$\rho$  is density;  $u_i$  is component product in X direction of velocity vector  $\mathbf{u}$ ;  $\mu$  is dynamic viscosity.[11]  
 $C_{1\varepsilon}$ 、 $C_{2\varepsilon}$ 、 $C_\mu$ 、 $\sigma_k$ 、 $\sigma_\varepsilon$  are constant in model, where  $C_{1\varepsilon}=1.44$ ;  $C_{2\varepsilon}=1.92$ ;  $C_\mu=0.09$ ,  $\sigma_k=1.0$ ,  $\sigma_\varepsilon=1.3$  .[12]

Fluid-structure coupled equation: in the interface of fluid and solid ,the stress between fluid and solid ( $\tau$ )、 heat flow ( $q$ )、 temperature ( $T$ ) should meet Equation (6):

$$\begin{cases} \tau_f * n_f = \tau_s * n_s \\ q_f = q_s \\ T_f = T_s \end{cases} \quad (6)$$

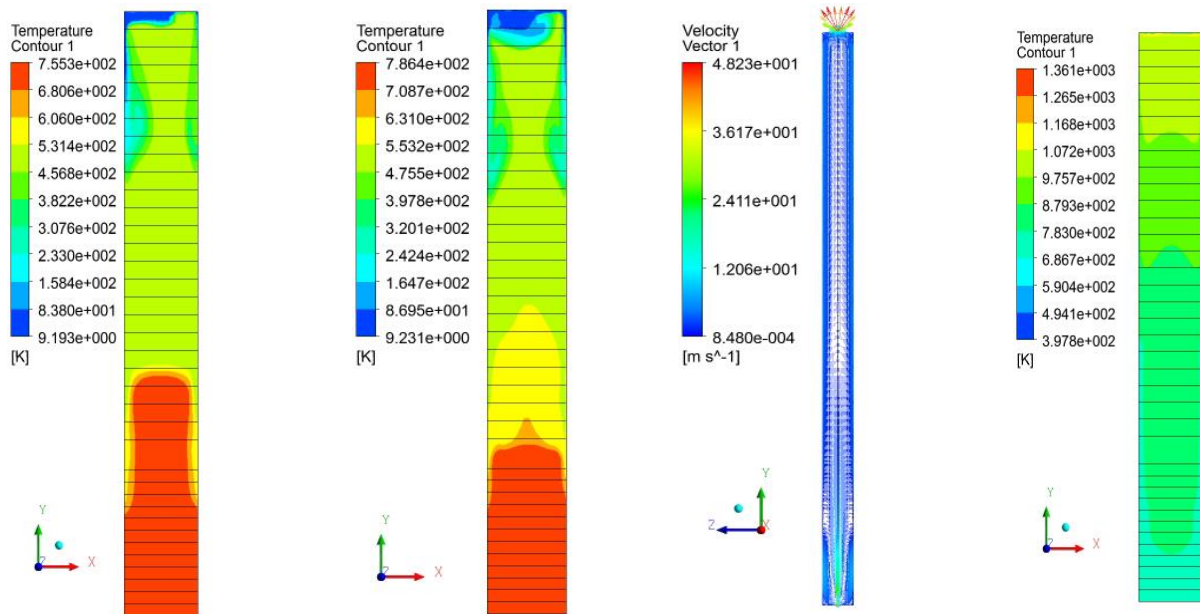
Where  $q_f$  refers to heat variation of fluid;  $q_s$  refers to heat variation of solid. Heat variation  $q$  is proportion to the difference in temperature( $\Delta t$ ) between two surfaces and the area perpendicular to

heat flow direction, inversely proportion to the thickness, namely  $q = \lambda A \frac{\Delta t}{\delta}$ , where  $\lambda$  is the

coefficient of thermal conductivity.[13]

**Boundary conditions.** According to alloy furnace operating parameters boundary conditions are set as follows: 2m/s sheet steel moving speed; temperature 750K; typical heating power 29240W/m<sup>2</sup>; environmental temperature 300K; heat transfer of sheet steel coefficient: 60.5W/(m\*K); solid domain-free wall-slip; ideal gases in the furnace.

**Numerical Simulation Results and Analysis.** Through the simulation of soaking pit, air movement and temperature distribution in furnace was mastered and then followed by the effects analysis on the flow filed and the temperature of the sheet steel. Surface temperature distributions with the heat flow of the 29240W/m<sup>2</sup> and 58480W/m<sup>2</sup> were shown in Fig.3:



(a)Heat flow of 29240w/m<sup>2</sup> (b)heat flow of 58480w/m<sup>2</sup> (c)velocity vector (d)map of temperature

Fig. 3 Temperature distribution of air (a, b) Fig 4. Contour maps of air with baffles(c, d)

By comparing contour in two different conditions, it is apparent to see that the higher power heating resistances have, the greater heat flow is, the faster fluid flows, the higher furnace gas temperature is. Specific comparisons are shown in Table 1:

Table 1 the temperature and velocity contrast

Heat flow( $\text{w}/\text{m}^2$ )	29240	43860	58480
Outlet temperature (K)	486	498	521
Outlet air flow ( $\text{m}^3/\text{s}$ )	6.58	7.02	7.36

As showed in the Table 1: if the thermal power increase by 100%, outlet gas temperature only increases by 4%, indicating increased power will not solve the problem of low temperature. Because with the increase of thermal power, the buoyancy of the gas also increases, gas temperature increase as well as speed increases, causing bigger amount of hot air overflow which leads to unnecessary heat loss. So only by confining the high-temperature air from spilling out can the furnace temperature increase.

**Efficiency promotion scheme based on flow filed optimization.** According to the flow filed analysis above, adding baffles in the exit to curb high -temperature air spillover was considered. After adding the two baffles, the map of furnace temperature filed and velocity filed are shown in Fig.4.

Under the same power of resistor, sheet steel surface temperature comparison is shown in Fig.5:

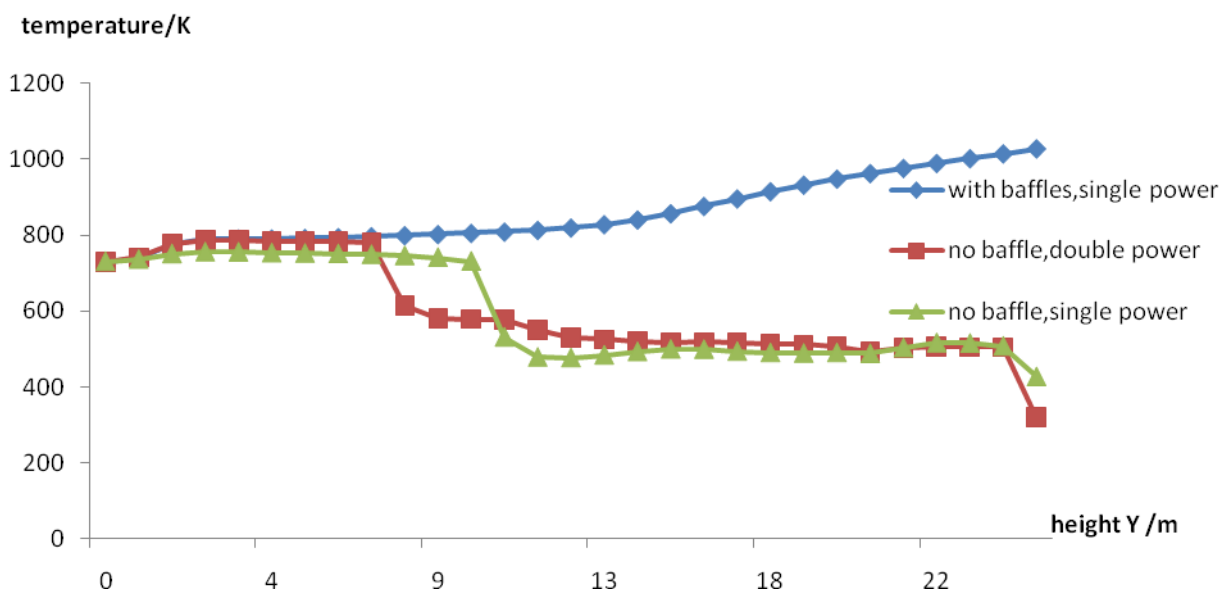


Fig. 5 Comparison of surface temperature of steel under the same power

After adding two symmetrical baffles in the exit, the temperature in the furnace is intensely promoted. Sheet Steel surface temperature can reach up to 1000K, compared with no baffle, the temperature increases by 75% and energy efficiency is enhanced.

## Conclusions

(1) Numerical simulation based CFD on the process of hot dip galvanized sheet steel sheds some light on the link between the resistor power and the flow field and the relationship between the resistor power and temperature field, so it is feasible to optimize the whole procedure using CFD.

(2) Adding two symmetrical baffles in the exit of the furnace to curb high-temperature air outflow, compared with no baffle, the average temperature is 75% higher, which can be used to improve energy efficiency and save energy and reduce productive cost.

## Acknowledgements

This programme is financially supported by science and technology innovation foundation for students of Wuhan University of Science and Technology (2013-2014) and by foundation of innovation training projects in Hubei province.

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