Fluid dynamics analysis of a zinc pot in a continuous galvanising line

A fluid dynamics analysis method for a zinc pot has been developed. Simulation results show that the places where it is likely for dross to adhere to the strip are located between the running strip and rotating rolls, especially between the inlet strip and the sink roll. Following many simulations and production experience, some methods to decrease the probability of dross adhering to the strip have been established.

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In the automotive industry high quality galvanised sheet is widely used to make car body panels to prevent steel corrosion Because of the high cost of the electroplating process, galvanised sheet is generally made by hot dip galvanising, however, surface quality can be affected by dross adhering to the strip in the zinc pot. Various methods have been tried to solve this dross adherence problem, but until now, no efficient method has been developed.

According to research, dross is formed by chemical reaction and exists mainly in the form of Zn-Fe and Fe-Al intermetallic compounds. The Al content of the zinc pot determines the type of the dross and, on the basis of the equilibrium phase diagram of the Zn-Al-Fe ternary system, when the Al concentration is low, the dross is $FeZn_7$ type, and when the Al concentration is high, the dross is Fe_2Al_5 type. The density of the compound $FeZn_7$ is higher and the density of compound Fe_2Al_5 is lower than that of Zn. Therefore, $FeZn_7$ usually sinks to the bottom of the pot as bottom dross, while Fe_2Al_5 rises to the top of the pot as top dross.

During the galvanising process, the dross will move with the fluid zinc in the form of floating dross, which could then adhere to the strip surface. Since the fluid flow in the zinc pot has an overwhelming impact on the dross adherence, to understand the nature of the processes and predict it quantitatively is very important so that the optimum pot design can be obtained. Here the numerical simulation of a zinc pot is performed using FIDAP software.

BUILDING OF THE SIMULATION MODEL

Governing differential equations The laws governing fluid dynamics problems can be expressed in mathematical form, generally in terms of differential equations. The two principal governing equations in the simulation model are as follows:

1) Continuity equation

$$\frac{\partial \rho}{\partial t} + \operatorname{div}(\rho \vec{u}) = 0$$

2) Conservation of Momentum (Navier-Stokes equation)

$$\rho\left(\frac{\partial u}{\partial t} + u \cdot \operatorname{grad} \vec{u}\right) = -\operatorname{grad} p + \operatorname{div} \vec{\tau} + \rho F_b$$

where, p: density; $\vec{u}$: velocity vector; p: pressure; $\vec{\tau}$: stress tensor; F_b: body force .

Simulation condition *Figure1* shows the schematic drawing of the zinc pot. Strip passes through a snout at a fixed angle and enters the zinc pot, which is filled with molten zinc. With the aid of sink roll 3#, the direction of the running strip is changed to be vertically upward. On the upward running strip, there is a stabilising roll 1# and a correcting roll 2# to stabilise and control the position of the running strip.

Because of the larger dimension along the length direction of each roll, two-dimensional fluid dynamics analysis can reflect the real flow pattern in the zinc pot ▷

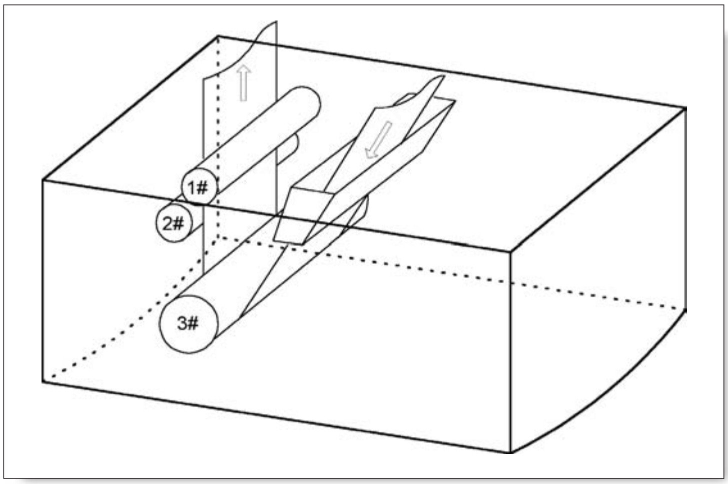

Fig.1 Schematic drawing of the zinc pot

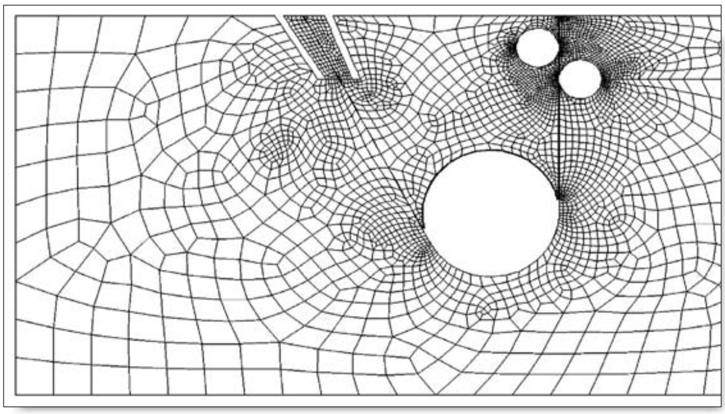

Fig.2 FEM mesh generation for the zinc pot

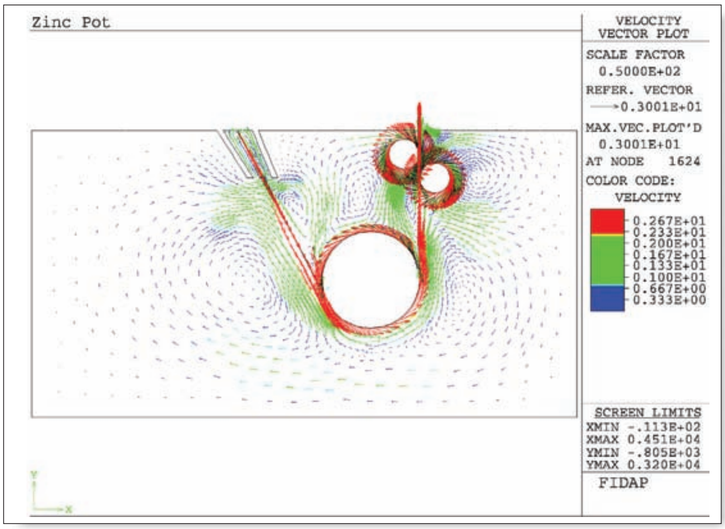

Fig.3 Vector plot of the computed velocity field for the zinc pot *Strip running speed: 3.00m/s*

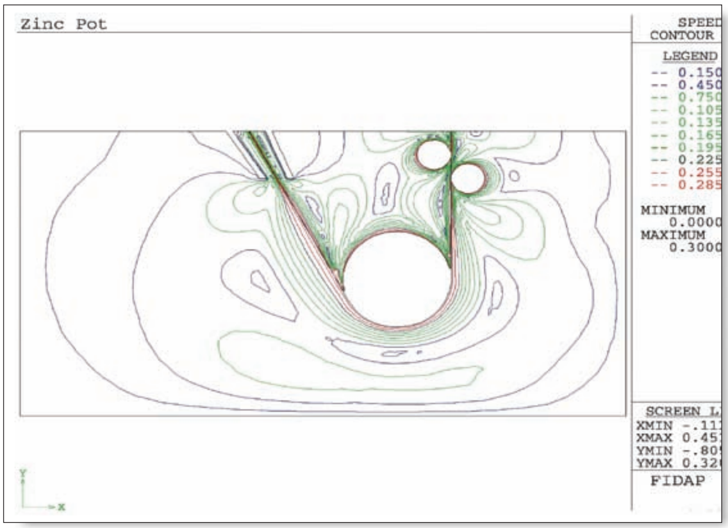

Fig.4 Speed contour plot for the zinc pot *Strip running speed: 3.00m/s*

very well. However, if the flow status in the area between the roll end and side wall of the zinc pot is also required to be known, three-dimensional fluid dynamics analysis is necessary. As more time is necessary for three-dimensional analysis, and the program is so large that it takes a large amount of memory of the computer, it is beneficial to develop a two-dimensional fluid dynamic model to analyse the flow pattern in the zinc pot.

The zinc pot for simulation was selected from a steel plant and is 4.5x2.4m. The other simulation conditions are as follows:

Fluid media: molten zinc
Zinc pot temperature: 733K (460℃), isothermal
Zinc density: 6500kg/m^3
Viscosity: 0.0037Pa.s
Strip running speed: 1.67, 2.33, 3.00m/s (100, 140, 180m/min)
Element type: 4 node quadrilateral
Mesh type: paved

Mesh generation In order to use FEM for simulation of a flow problem in a zinc pot, it is necessary to divide the flow domain into the finite element mesh. The accuracy of the results is often highly dependent on the quality of the finite element mesh. Because many oblique lines and circles exist within the zinc pot area, and form the irregular region, the paved mesh technique has been used. Because high velocity gradients occur in the area near to the running strip and rotating rolls, smaller elements have been set there, while in the area near to the zinc pot wall where small velocity gradients exist, larger elements are set. *Figure 2* shows FEM mesh generation for the zinc pot. It is 4-node type, and includes about 5000 elements.

SIMULATION RESULTS

Three strip running speeds of 1.67, 2.33 and 3.00m/s were selected for simulation. According to the simulation results, the flow patterns for the three different strip speeds are almost the same, so only the velocity field for strip running speed at 3m/s is shown in *figure 3*. The speed contour plot is also shown in *figure 4*. From these figures, we can find that the velocity at the surface of the sink roll, stabilising roll, correcting roll and on the strip surface are all equal to the strip running speed. The fluid velocity decreases quickly with increasing distance away from the strip. In the snout area, fluid is brought into the snout and out along the strip surface. Here there are some vortices formed because of the running strip and the rotating rolls.

Figure 5 gives the X-direction fluid speed distribution along line A-A under different strip running speeds. Line

A-A is a horizontal line in the middle of the distance between the circumferential surface of the sink roll and the correcting roll. As the figure shows, with the strip running speed increasing, the absolute value of X-direction fluid speed increases. At the intersection of line A-A with the inlet strip, the X-direction fluid speed reaches its positive peak value, then decreases quickly and then changes its direction several times. At the intersection line A-A with the exit strip, the X-direction fluid speed will be zero then it increases to another positive peak value.

Figure 6 gives the Y-direction fluid speed distribution along line A-A under different strip running speeds. As the strip running speed increases, the absolute value of Y-direction fluid

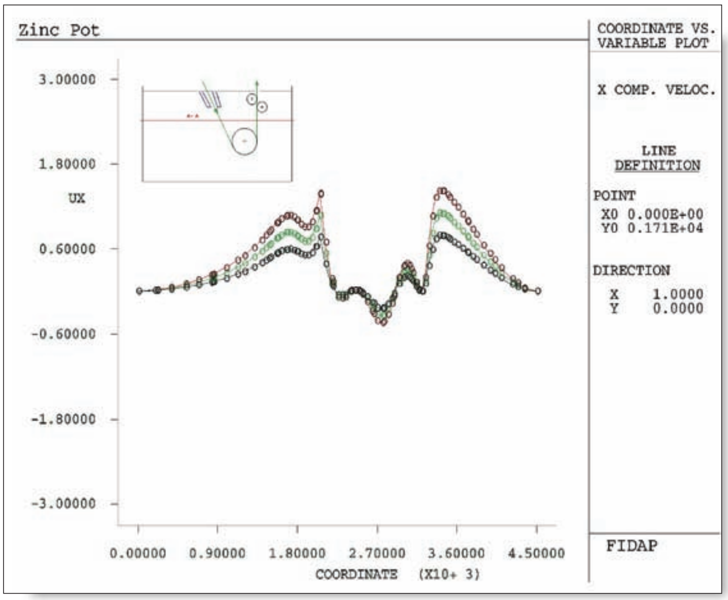

Fig.5 X-direction fluid speed distribution along line A-A under different strip running speeds *Strip running speed: 1.67m/s (black line), 2.33m/s (green line), 3.00m/s (red line*

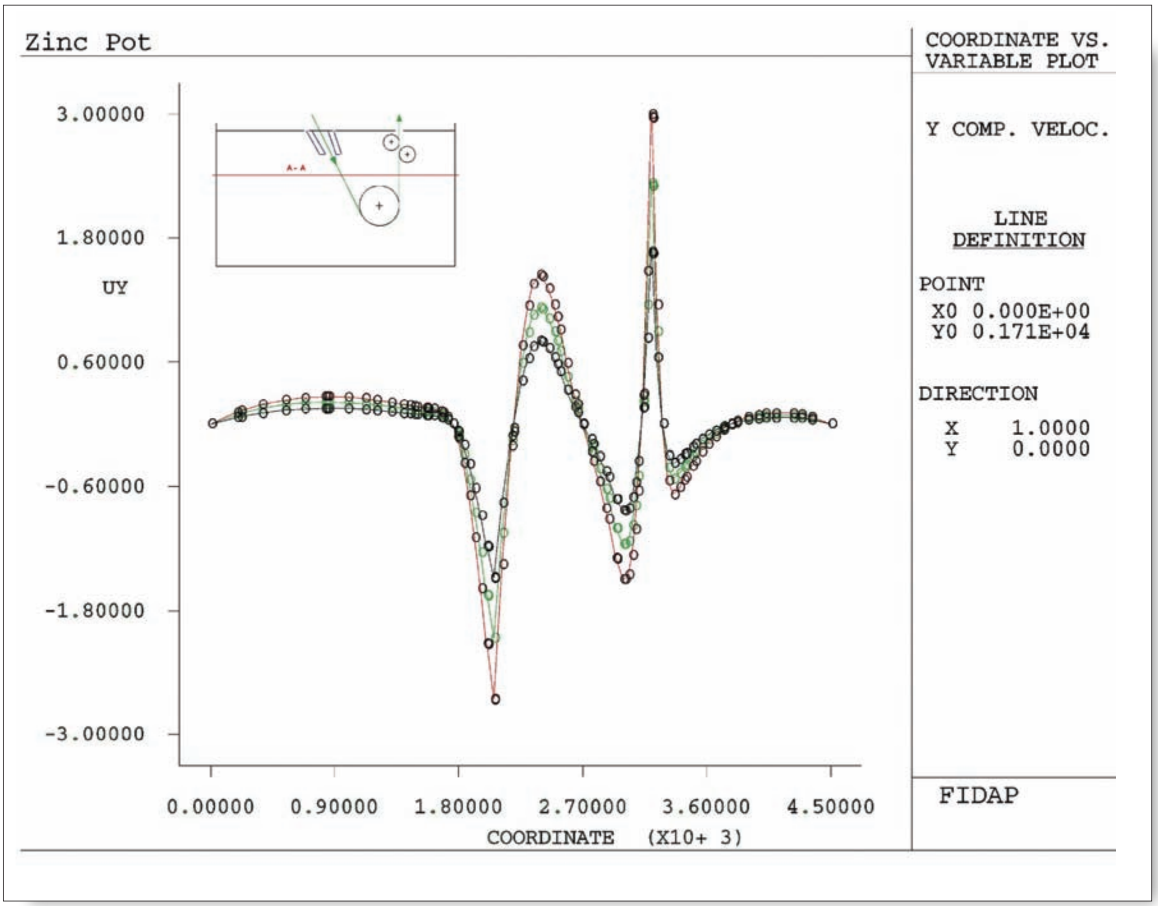

Fig.6 Y-direction fluid speed distribution along line A-A under different strip running speeds *Strip running speed: 1.67m/s (black line), 2.33m/s (green line), 3.00m/s (red line)*

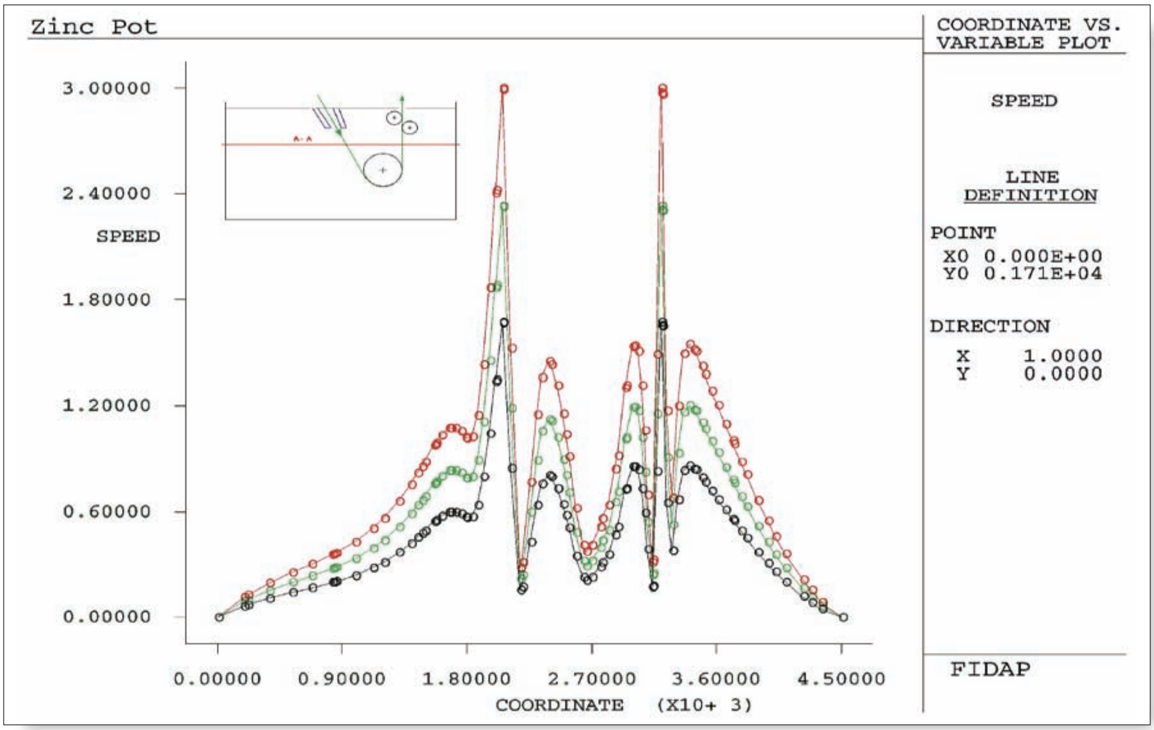

Fig.7 Fluid speed distribution along line A-A under different strip running speeds *Strip running speed: 1.67m/s (black line), 2.33m/s (green line), 3.00m/s (red line)*

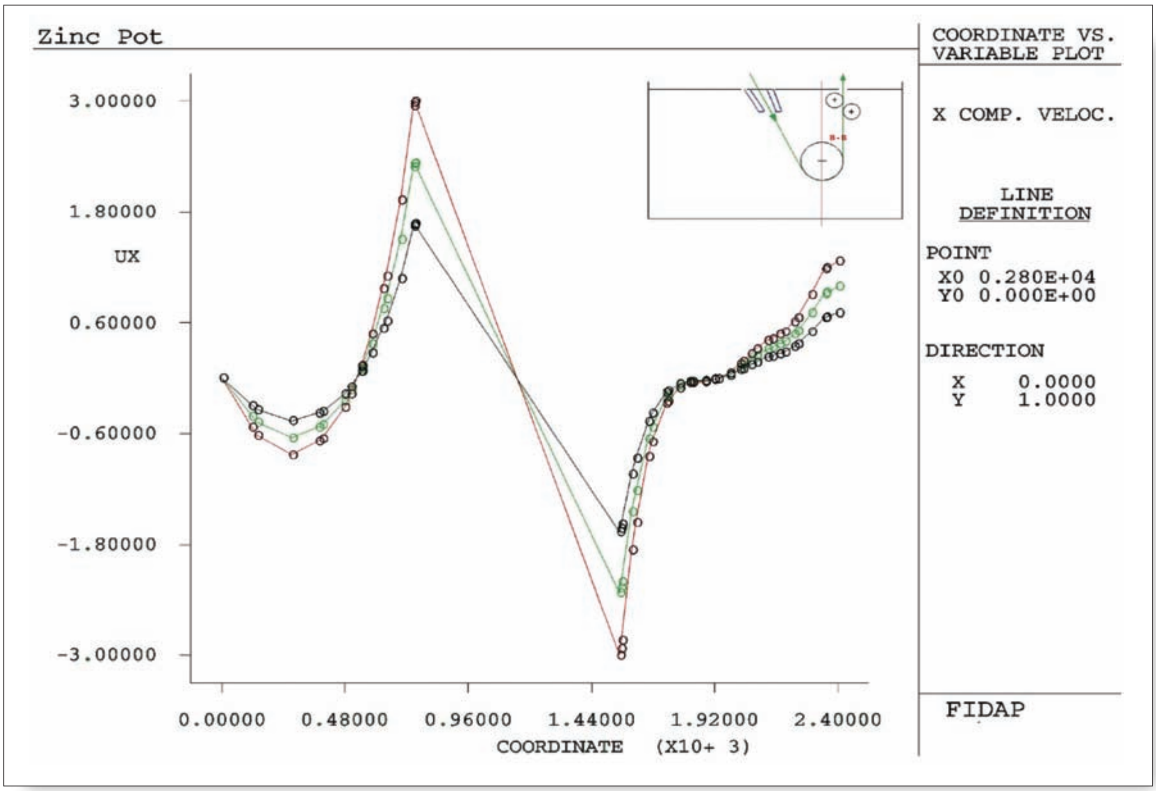

Fig.8 X-direction fluid speed distribution along line B-B under different strip running speeds *Strip running speed: 1.67m/s (black line), 2.33m/s (green line), 3.00m/s (red line)*

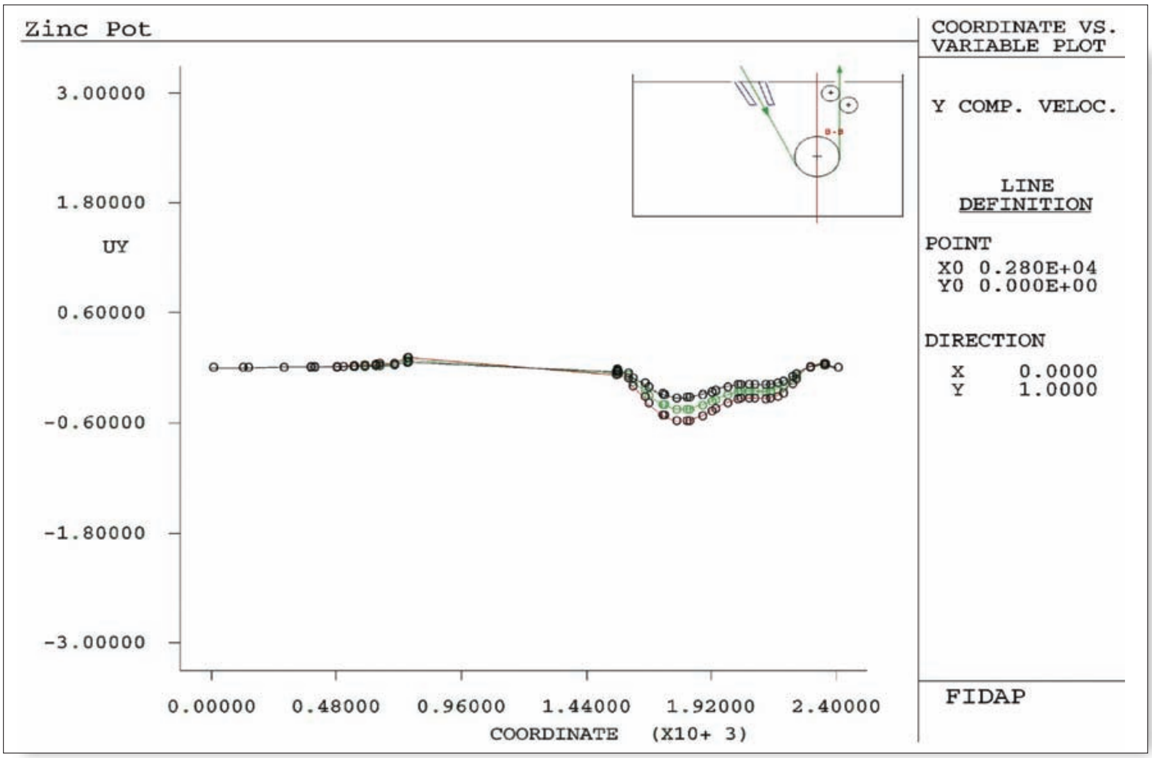

Fig.9 Y-direction fluid speed distribution along line B-B under different strip running speeds *Strip running speed: 1.67m/s (black line), 2.33m/s (green line), 3.00m/s (red line)*

speed increases. At the intersection of line A-A with inlet strip, the Y-direction fluid speed reaches its negative peak value, after which the absolute value decreases quickly, and then changes direction several times. At the intersection line A-A with exit strip, the Y-direction fluid speed reaches its positive peak value, ie strip running speed, then quickly decreases.

By combination of the above two vectors, the total fluid speed distribution along line A-A under different strip running speeds is obtained as shown in *figure 7*. Fluid speed increases with increasing strip running speed. At the intersection of line A-A with both inlet and exit strip parts, the fluid speed reaches its highest value, ie strip running speed, but decreases quickly on both sides of the strip.

Figure 8 gives the X-direction fluid speed distribution along line B-B under different strip running speeds. Line B-B is a vertical line through the center of the sink roll. With the strip running speed increasing, the absolute value of X-direction fluid speed increases. At the intersection of line B-B with the sink roll, the absolute value of X-direction fluid speed reaches its peak value - the surface speed of the sink roll, but decreases quickly on both sides of the sink roll.

Figure 9 gives the Y-direction fluid speed distribution along line B-B under different strip running speeds. Y-direction fluid speed increases with increasing strip running speed. Compared to the value of X-direction fluid speed, the value of Y-direction fluid speed is relatively small, and almost equals zero except in the area between inlet strip and exit strip.

By combination of the above two vectors, the total fluid speed distribution along line B-B under different strip running speeds is obtained, as shown in *figure 10*. Fluid speed increases with increasing strip running speed. At the intersection of line B-B with the sink roll, the fluid speed reaches its highest value, the surface speed of the sink roll, but decreases quickly on both sides of sink roll.

According to the above simulation results, inferences can be drawn that it is highly possible for dross to adhere to the strip between the running strip and the rotating rolls, especially between the inlet strip and the sink roll. As *figure 3* shows, the direction of the fluid flow near the inlet strip surface is towards the intersection of the inlet strip and the sink roll, the direction of fluid flow near the sink roll is also to the same point, and there exist counter-clockwise vortices in that area. Therefore, if there is some dross there, it can be easily drawn in and adhere to the strip surface.

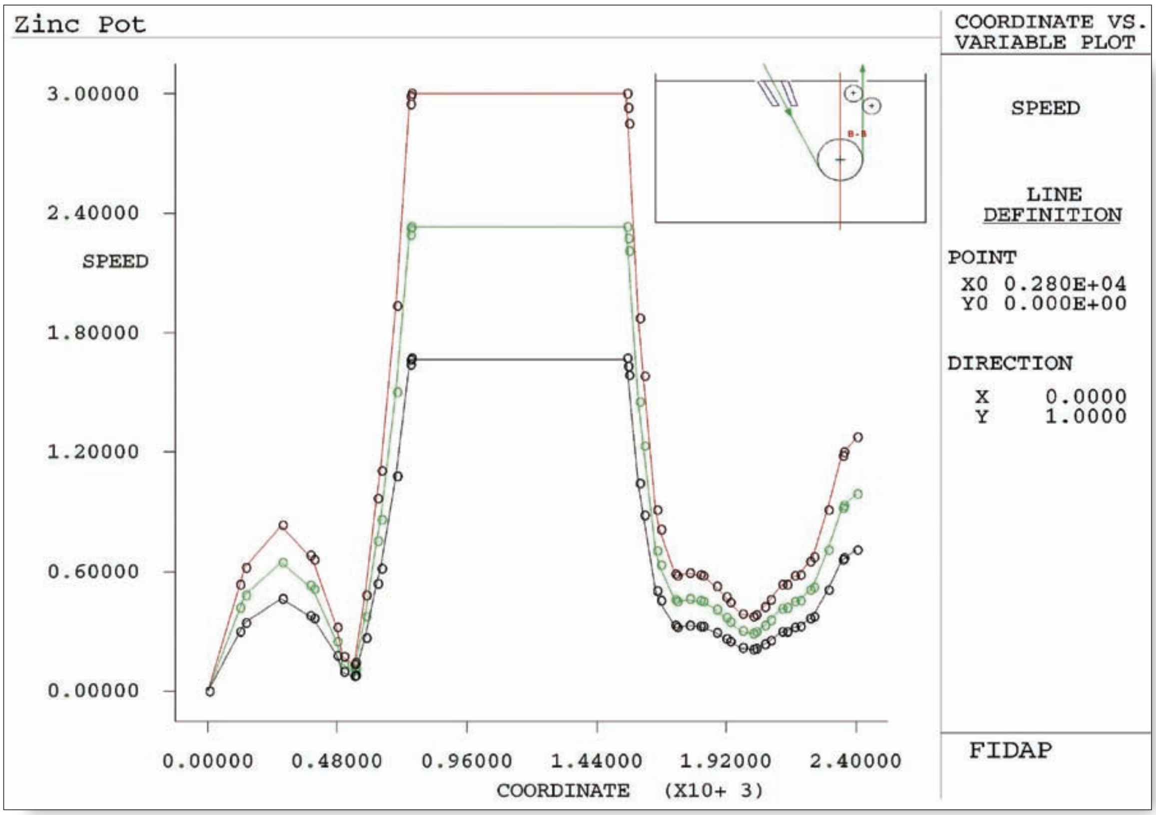

Fig10 Fluid speed distribution along line B-B under different strip running speeds *Strip running speed: 1.67m/s (black line), 2.33m/s (green line), 3.00m/s (red line)*

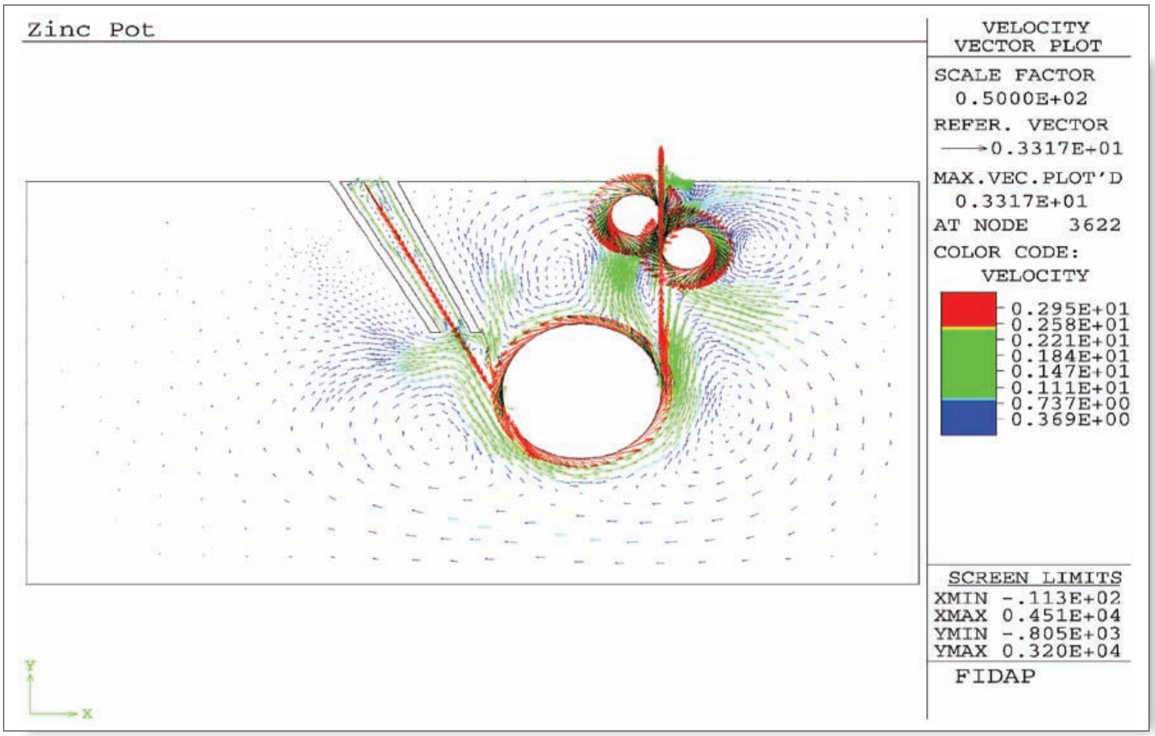

Fig.11 Vector plot of the computed velocity field for the zinc pot with a long snout *Strip running speed: 3.00m/s*

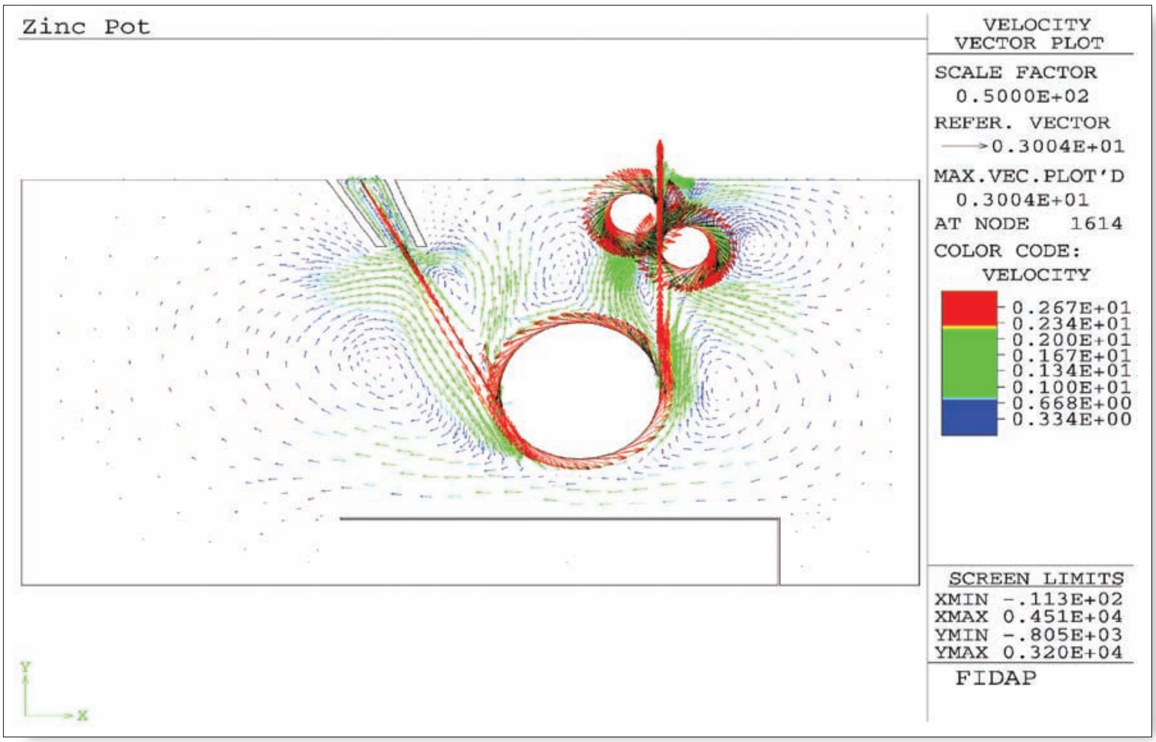

Fig.12 **Vector plot of the computed velocity field for the zinc pot with a baffle plate** *Strip running speed: 3.00m/s*

EFFECT OF ZINC POT MODIFICATIONS

Following many simulations and production experience, some methods to decrease the chance for dross adhering to the strip have been verified.

Figure 11 shows the velocity field for a strip running speed of 3m/s when using a long snout. From the figure, we can see that there are no vortices in the area between the inlet strip and the sink roll, and the flow pattern there becomes smoother, which will decrease the chance for dross adhering to the strip.

Figure 12 shows the velocity field for a strip running speed of 3m/s with the use of a baffle plate. It can be seen that there is almost no fluid flow under the baffle plate, which will greatly decrease the chance for bottom dross to be stirred by the movement of fluid. Another advantage is that bottom dross can sink behind the baffle plate, which will prevent the dross adhering to the strip.

CONCLUSIONS

A fluid dynamics analysis method for a zinc pot has been developed and has been shown to be a powerful tool for simulating the flow pattern in the zinc pot that cannot be seen in the actual production line.

The simulation results show that the places where it is highly possible for dross to adhere to the strip are located between the running strip and rotating rolls, especially between the inlet strip and the sink roll. The use of a long snout and baffle plate are efficient methods to decrease the probability of dross adhering to the strip.

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