

# Development of i Box Pickling Tank for Hot Rolled Strip Enabling Energy-Saving, High-Speed Pickling



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Recently the production volumes of high tensile strength steel strip has increased. This type of steel requires longer pickling times compared to normal low carbon steel. This prolonged pickling time becomes the bottle-neck in the steel production process. At the same time, a decrease in energy consumption and production costs is desired, calling for greater importance of high-speed pickling.

To solve this problem, conventional electric-pumped forced pickling systems, called circulation type tanks, are applicable. Unfortunately this system's electric power consumption will not satisfy the steel maker's operation cost reduction and energy saving requirements.

To satisfy such requirements, Primetals Technologies Ltd. has developed an energy-efficient, easily-maintainable pickling system called i Box. This system has a pickling performance equivalent to that of circulation type pickling, while only using the strip driving force to move the acid in the tanks.

## 1. Introduction

The purpose of the pickling tank is to remove the oxidized surface created during hot rolling from the steel strip. Pickling typically uses acids like hydrochloric, sulfuric, nitric or hydrofluoric at an elevated temperature. This paper covers hydrochloric acid type pickling to remove the oxidized surface on low carbon steel strip, including high tensile strength steel.

In recent years, responding to the needs to reduce the weight of car bodies and consequently CO<sub>2</sub> emissions from automobiles and save energy, client steel mills are increasing the production of high-formability, high-tensile strength steel strip (TRIP and/or DP steel)<sup>(1)</sup> These kinds of steel contain more silicon than normal steel, making them harder to pickle. To increase the production of high tensile strength steel, it is necessary to improve pickling performance.

It is generally known that a boundary layer of acid is formed on the strip surface traveling through the pickling tank. In this boundary layer, the acid concentration decreases as the acid is consumed by the reaction with the oxide and descaling time is prolonged. A thicker boundary layer results in longer pickling time. Pickling tank suppliers have tried to reduce this boundary layer thickness through forced circulation by pumping acid to the strip surface through nozzles powered by electric pumps. But this method requires electric energy and agitates the silicon sludge in the tank. The agitated sludge clogs pipes and makes maintenance more difficult and time consuming.

To solve these problems, Primetals Technologies Ltd (herein after Primetals) has developed a new pickling technology called i Box (Immersed Box Pickling Tank), which has the same pickling performance as circulation type pickling tanks without the need of electric pumps.

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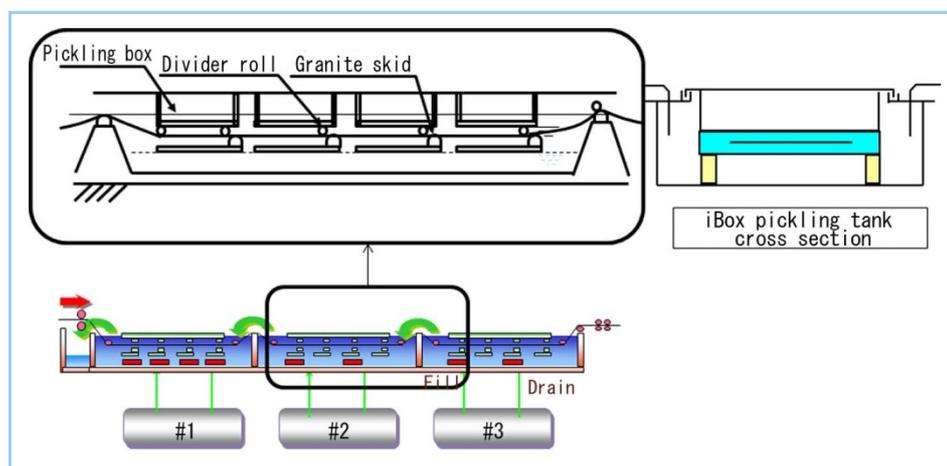
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## 2. Structure of i Box pickling tank

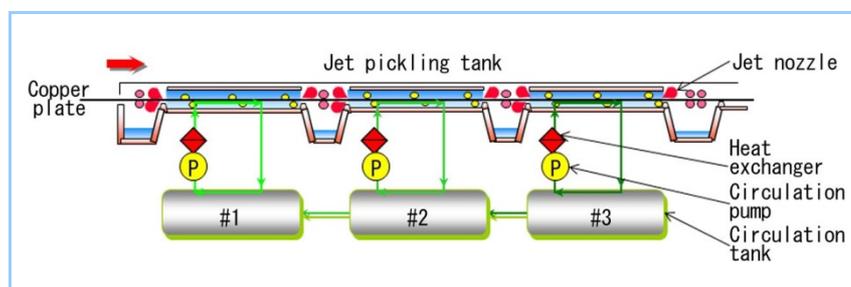
Generally, one pickling line has 3 or 4 acid tanks. **Figure 1** shows the structure of i Box in a pickling tank. Several low-height boxes are immersed in the acid tank. The strip travels through these immersed boxes. Each box has one granite block called a skid and one roll called a divider roll at the exit side of the box. The divider roll and skid create a shearing effect in the acid and reduce the thickness of the boundary layer on the surface of running strip. The re-growth of the boundary layer is restricted by the top and bottom walls of the i Box, which are close to the surface of the strip. Through this effect, it is possible to maintain a high mass transfer ratio of acid to the strip surface and promote the reaction with the oxidized surface.

In addition to that, i Box has two characteristic features. The first is that the heat exchangers required to heat up the acid are installed between the immersed boxes and the acid tank outer wall, in the space through which the acid self circulates inside the tank. The second is that during line stops, the acid is drained from the i Box pickling tank to storage tanks, lowering the acid level in the tank and preventing overpickling of the strip. Just before operation is started, the acid is pumped back to the pickling tank by electrical actuated pumps.



**Figure 1** Schematic diagram of i Box pickling tank

**Figure 2** shows the acid circulation type called jet pickling within Primetals. This type of pickling requires acid circulation from a circulation tank to the jet nozzles through pipes by electric pumps. The acid heat exchangers are installed in the middle of this pipe line to heat up acid. This system is prone to certain problems which the i Box pickling tank can solve, as described in the following chapters.



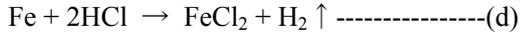
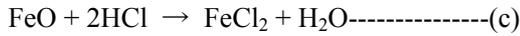
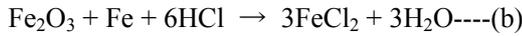
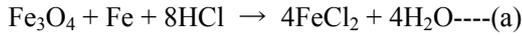
**Figure 2** Example of circulation-type pickling (Jet pickling)

## 3. High-speed pickling performance

### 3.1 Descaling process in pickling tank

This chapter explains the chemical reaction which takes place during pickling. The main composition of the oxidized strip surface after hot rolling is FeO (Wustite), Fe<sub>3</sub>O<sub>4</sub> (Magnetite) and Fe<sub>2</sub>O<sub>3</sub> (Hematite) as shown in **Figure 3**. Each composition is dissolved by acid in the reactions shown in the following chemical formulas from (a) to (d).

Generally  $Fe_3O_4$  (Magnetite) and  $Fe_2O_3$  (Hematite) create  $FeCl_3$  in acid. But in real production lines, since the amount of  $FeCl_3$  in whole pickling tanks is detected less than theoretically estimated. This means base material (Fe) is reacted in whole pickling tank with acid solution to change  $FeCl_3$  to  $FeCl_2$ . So chemical formulas (a) (b) mainly occurs in pickling.



Note) The chemical formulas in this paper have been corrected from a previous paper<sup>(3)</sup>

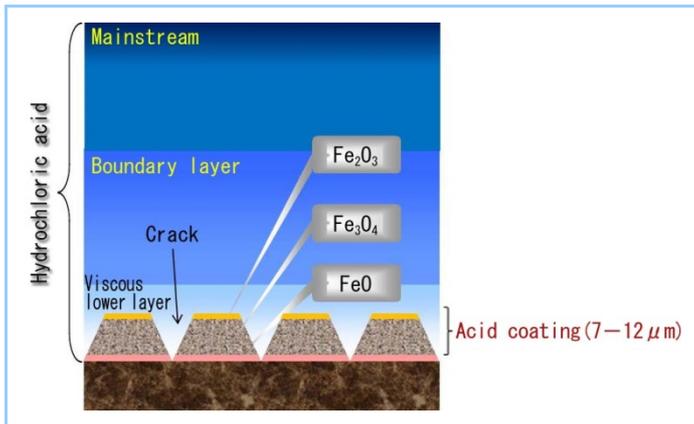


Figure 3 Scale composition and crack

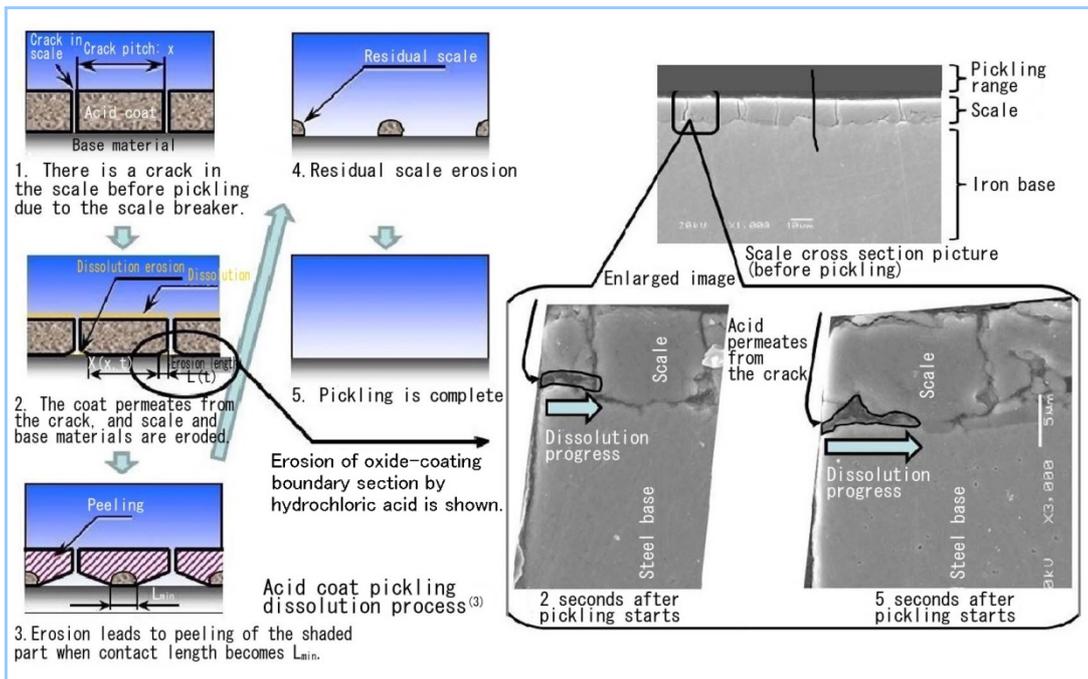


Figure 4 Acid coating pickling dissolution process and appearance of pickling solution in the experiment

There are three steps in the descaling process as shown in Figure 4 (on left side), which was explained in the previous paper<sup>(3)</sup>. In the first step, acid is absorbed into cracks created in the oxidized surface by scale breakers. In the second step, acid dissolves the base metal and FeO. Lastly, in the third step, the oxidized surface is removed from the strip. Primetals has proven this phenomena through experiments.

Figure 4 (on right side) shows the results of the experiments: two magnified photos show the moments of acid dissolving the base metal and FeO, which were taken 2 or 5 seconds after pickling. This indicates that the chemical reactions in formulas (c) and (d) are faster than the reactions in formulas (a) and (b).

### 3.2 Prediction of acid concentration distribution in pickling tank

According to the mechanism of pickling, achieving high speed pickling requires to maintain a high concentration of acid near the strip surface. There have been very few examples how to predict the concentration of acid in pickling through calculations. Primetals have tried to simulate the flow and the concentration dispersion of the acid in the tank by numerical simulations.

Figure 5 shows one example of this simulation. When starting to design the i Box, because the moving strip was the only method to move the acid, Primetals was concerned about the possible lack of agitation of the acid inside and outside the immersed box. However, the simulation results showed that the acid concentration distribution of i Box is similar to that of jet pickling tanks.

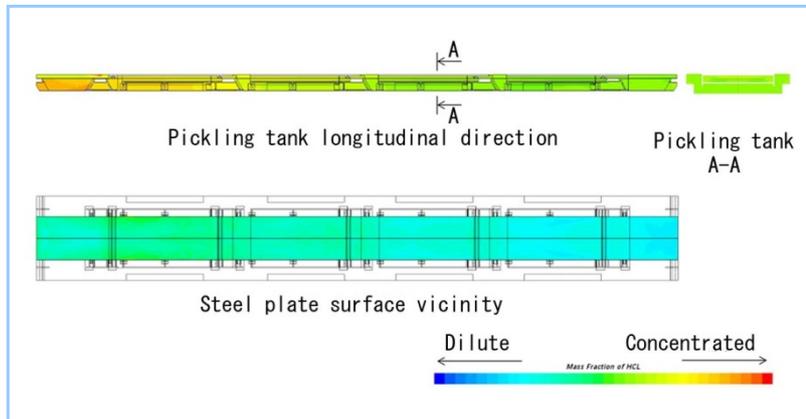


Figure 5 Acid concentration distribution in pickling tank

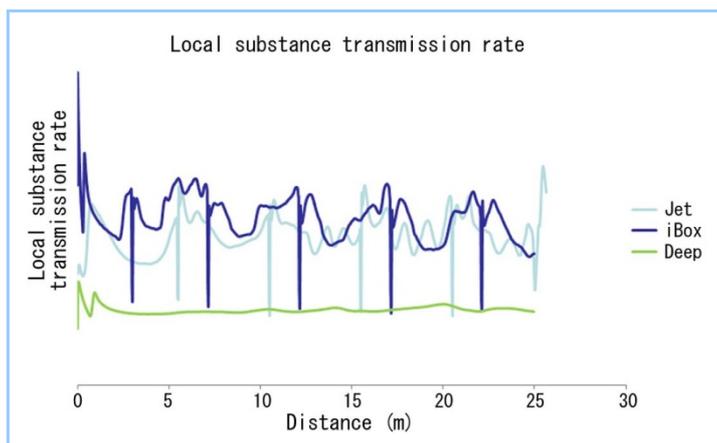


Figure 6 Mass transfer ratio distribution in pickling tank

Next, Primetals focused on the acid concentration distribution on the strip surface. The area after the divider rolls has a high acid concentration because of the thin boundary layer created by the rolls. After the rolls, the thickness of the boundary layer grows, leading to a decreased acid concentration on the strip surface. Figure 6 shows this phenomena: the horizontal line indicates the distance from the entrance of acid tanks and the vertical line indicates mass transfer ratio. This figure also shows the predicted data for jet pickling and conventional deep tank pickling. Based on this analysis, there is no difference between i Box and jet pickling. In the future, this numerical analysis shall be further enhanced for continued improvements of i Box pickling tank technology.

## 4. Energy efficiency and maintainability of i Box

### 4.1 Energy saving by means of circulation-free system

In general, the temperature of the acid is kept at approximately 85-90 degree C for high chemical reaction of the acid. The heated acid also has the function of heating the strip, which enters the pickling tanks at room temperature. The required heating energy for the strip must be supplied by steam fed heat exchangers immersed in the tank. Conventional forced circulation type pickling systems have external heat exchangers installed in the middle of the acid circulation pipes. The forced circulation systems incur the following two additional energy losses:

- (1)The first is electrical energy of electric circulation pump.
- (2)The second is heating loss from the circulation pipes and tank surface.

i Box is different on these points, as i Box has self-circulation flow of acid inside the tank. The driving force for the circulation of the acid is supplied by the movement of the strip. This causes the acid to flow along the tank towards the outlet and increase the acid level near the outlet compared to that by the inlet. The space between the immersed boxes and the tank outer wall allows the acid to flow back towards the inlet side of the tank. Locating the heat exchangers in this path, makes it possible to heat up the acid without the need of electric pumps or pipes, thus eliminating heat losses from the pipes. Table 1 shows the a comparison of heat loss data for two pickling systems.

**Table 1 Comparison of Energy Consumption (Ratio with Jet Pickling Tank as 100 Given)**

Description		Circulation type (jet pickling)	i Box
Electrical energy	Average	100	18
Radiation from pickling tank and circulation system (excluding heat from temperature increases in steel strip)	Pickling tank	100	162
	Circulation system	100	0
	Total	100	76

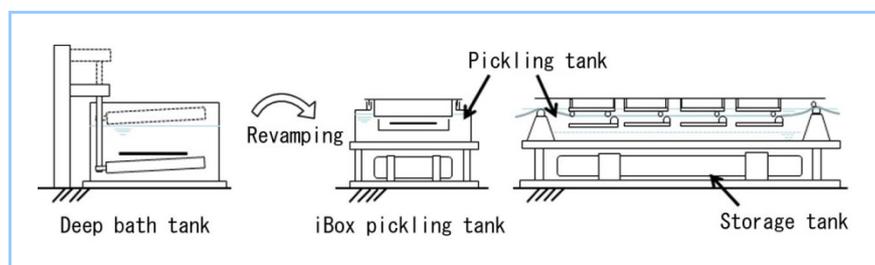
## 4.2 Enhance maintenance performance

Recent mass production of high tensile strength steel has increased the amount of silicon sludge created and remaining in the acid tank. In forced circulation type tanks, this sludge accumulates in the circulation pipes and gradually crystallizes, eventually blocking the acid flow in the pipes, resulting in pipe breaks and acid leaks. Periodical cleaning is necessary, but is very difficult because of sludge crystallization. In contrast, i Box does not require pipes for acid circulation. The silicon sludge simply sinks to the bottom of the tank. By pulling the easily removable heat exchangers, the sludge accumulated at the bottom of the tank circulation path can be removed. In addition, the heat exchangers are easily cleaned offline.

## 5. Flexible designing of i Box

Pickling lines installed in developed countries during the 1950's have reached the end of their useful life and require tank replacements. These lines must also be able to produce hard to pickle materials like high tensile strength steel and satisfy reduced energy requirements. i Box is one of best options for the replacement of aged pickling tanks.

Primetals have developed several types of i Box designs to revamp conventional deep pickling tanks. Deep pickling tank lines have no sub-tank used in i Box for acid storage during tank maintenance. By installing the i Box in the upper part of the space occupied by the deep tank and the sub-tank in lower part, as shown in Figure 7, the cost of revamping can be minimized. Primetals has continued to improve the design of the i Box technology to suit the specific requirements of all customers.



**Figure 7 Reformed-type i Box pickling tank**

## 6. Conclusion

This paper explained the advantages and high performance of i Box, using the results of numerical analysis, among others. Further optimization of the i Box pickling tank flow state by means of the herein described numerical analysis will contribute to design improvements. The client's growing demands for energy saving and maintenance-free characteristics are driving these

improvements.

Despite being an indispensable process in pickled/cold-rolled steel strip manufacturing, the pickling process is being researched and developed less than other production processes. Primetals has supplied a large worldwide share of continuous picklers. By closely working with this installed base and through continued R&D efforts, Primetals will help improve productivity and cost savings of clients.

## References

1. Tatsuya NAKAGAITO et al., Influences of Si and Al on Mechanical Properties of Low Alloy TRIP-assisted Multiphase Steel Sheets, *Tetsu-to-Hagané* Vol. 97 No. 5 (2011) pp. 35-43
2. Shibatomi, N. et al., Development of New Type Jet Pickling, *Mitsubishi Heavy Industries Technical Review* Vol. 29 No. 3 (1992) pp.177-183
3. Hirai, E. et al., Present State and Future Trend of Pickling Technologies, *Mitsubishi Juko Giho* Vol. 36 No. 6 (1999) pp. 308-311