Temperature Control by Heat Exchanger Incorporating with Vibration Type Coiled-tube

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Abstract **- In a hard chrome electroplating process, a heat exchanger is employed to remove the heat produced from high current load and heat of reactions involved in an electroplating tank to maintain an optimal temperature of the plating solution in the range of 47-53°C. If the temperature of plating solution in the electroplating tank is higher than the specified temperature, the metal deposit will become white and milky burning quickly on the edges and the physical properties are deteriorated. This is because in the several plants an original 2 U-shape tube heat exchanger cannot provide insufficiently heat removed out of the electroplating tank.**

This work is aimed at studying alternative design to enhance the heat transfer rate which coils are inserted into the tube and flow-induced vibration is introduced. In addition, to evaluate the effectiveness of the new design heat exchanger, its mathematical model with unknown parameters (i.e. overall heat transfer coefficient, total loss factor) has been developed based on actual plant data. The experimental and simulation results have shown that the implementation of the new design structure with the diameter of 1 inch and the length of 18.66 meters can maintain the optimal temperature. Thus, the new design heat exchanger is applicable to employ in a real continuous hard chrome plating process; the overall heat transfer coefficient is increased about 10% and corresponding to the production of 9.7% per year without any lost regarding to over temperature.

Index Terms **- flow-induced vibration, coil inserted, tube heat exchanger, hard chrome**

I. Introductions

Hard chrome electroplating or functional chrome plating, is a chromium coating process to enhance a thickness and endurance of a work piece. To enhance the thickness of chromium coating procedure is generally in between 2.5 - 500 microns or more. The factors that affect the efficiency of the finished work piece include operating conditions such as a concentration of chromic acid, sulfuric acid, the voltage and current requirements [1,2,3]. In addition, temperature of chromic acid solution is a main variable factor defective cause on work-piece surface.

Mostly, the major problem in hard chrome electroplating manufactory in Thailand is the continuous increase in the temperature of plating solution until over its temperature all waste.

Generally, the heat exchanger is used to remove the heat which is produced from high current load in the electroplating process.

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The appropriate temperature of planting solution is between 47 and 53°C [2,3,4], that will create the standard quality of work. Thus, developing the capacity of heat exchanger is an important factor to consistently retain specific range of temperature of plating solution.

The performance of heat exchanger can be improved to perform a certain heat transfer duty by heat transfer enhancement techniques. Wong-wises and Naphon[4] proposed the review of flow and heat transfer characteristics in curved pipe including the heat transfer coefficient in single-phase and friction factors in single-phase and two-phase. Ref. [3-7] investigated the dynamic characteristic of curved pipes conveying fluid by several methods. The equations of motion are presented with the fluid velocity. The effects of some key parameters on the natural frequency on the pipe system are also shown by their solutions. Ref. [8-12] proposed the effect of transverse vibration on free convection from a horizontal cylinder. They reported that a considerable increase the heat transfer coefficient was obtained with vibration. Cheng and Luan et al. [12] designed the new structure of heat transfer device which can freely vibrate under the influence of fluid flow. They found that the vibration induced by the pulsation flow at the low flow velocity can significantly increase the convective heat transfer coefficient of the nonlinear heat transfer device. For the second technique coil inserted into a flow provide swirling flow of the boundary layer, increase the effective heat transfer area and the turbulence intensity. The swirl induced tangential flow velocity component causes improved fluid mixing between the tube core and the wall region nearby. Thus, Enhancing of the heat transfer by rapid fluid mixing [13]. Ref. [13-18] presented the use of coil insert to pipe/tube leading to a considerable increase in heat transfer. They are reported that a considerable increase the heat transfer coefficient was depend on the Reynolds numbers of fluid flow, coiled pitch ratio and coiled diameters.

This works present a new approach to enhance the heat transfer rate by the flow-induced vibration, insert coiled into the tube of the heat exchanger and constructed in a real plant. Mathematical model was created to represent this system. The better of dynamic equation has been developed by the parameters from optimization method and it can determined the correct values of the overall heat transfer coefficient that cause the temperature of the plating solution out of the range.

II. The new design structure

The essence of vibration is the mechanical energy continuously accumulates and dissipates. The medium flow in the heat exchanger may cause the energy build-up due to the fluid viscosity. Therefore, it is almost impossible to completely avoid the vibration of the heat transfer device. In fact, a weak vibration of the heat transfer device always

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occurs when the fluid flow in curved pipe. The describe case include water-hammer, turbulence-induced vibration, partial-flow regime, pump noise, pulsating flow etc. In the present work we attempt to create a new type of tube heat exchanger which can vibrate under the influence of the fluid flow.

The original tube heat exchanger was designed in normal characteristic 2 pieces of U-tube which is immersed along the height of electroplating tank. The new design structure is different from the conventional one used in a real plant. The characteristic of this device is curved tubes which are jointed by the straight tubes with 30^o of depressing angle. The main body consists of four circular titanium tubes as shown in Figure 1.

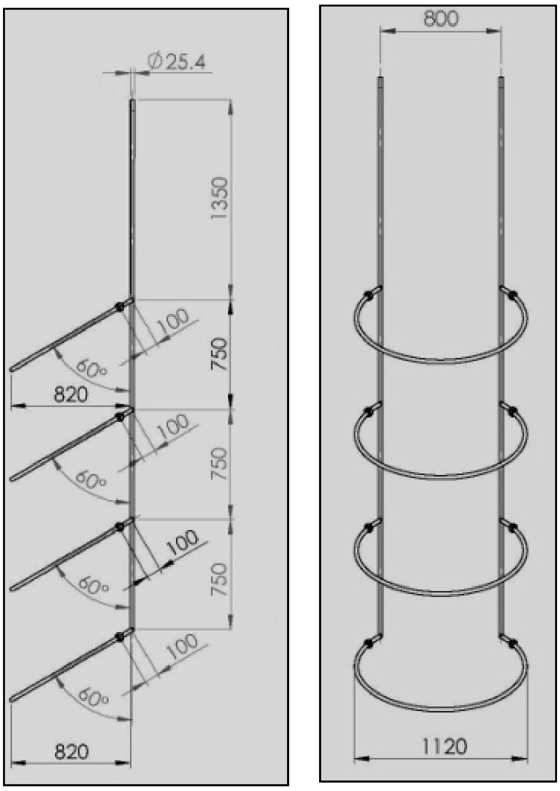

Fig. 1 The front/side view of the new design structure

The freely vibrate occurs at the bottom of circular tube when the fluid flow through the curved structure. Moreover, inside the titanium tube is added the titanium spring along the curved tube for increase the faying surface between cooling water and circular titanium tube.

III. Mathematical model

A process studied in this work consists of an electroplating tank, as show as Figure 2. Let T denotes the temperature and Q denotes the energy rate. The heat transfer between the electroplating tank is connected with a cooling system can be described that the heat produced from the electrical load is removed by an internal heat transfer coil. Starting with the water flow rate, F_w with temperature, T_{win} is flowed through the internal coiled-tube heat exchanger immersed in the plating solution, with have the temperature T_s. At that time, the heat is transferred from the plating solution to raise the water temperature in the coiled-tube up with temperature, T_{wout}. The water left out of the electroplating tank is transferred to the cooling water tank. The water from the cooling water tank has pumped as input of the cooling tower and output of cooling water which is passed the cooling process will be storage in the cooling water tank again. After that the cooling water has pumped to the coiled-tube heat exchanger.

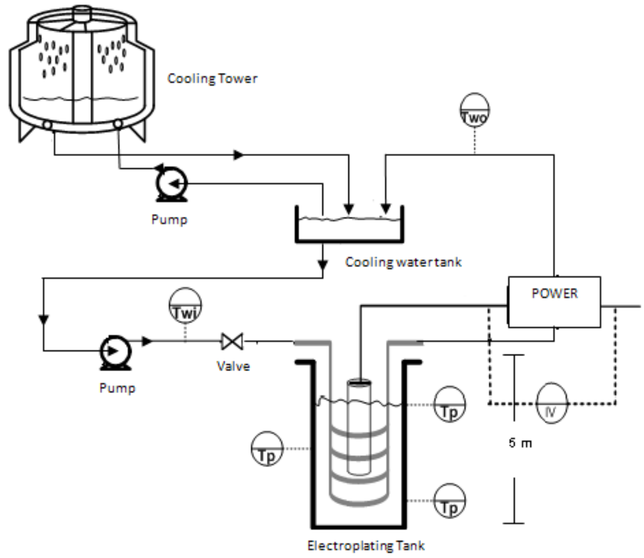

Fig. 2 A cooling system for a hard chrome plating process.

For this study, the mass conservation models are developed under the steady state condition whereas the energy conservation equations are derived base on the dynamic condition of the actual plant data. The energy conservation model of the electroplating tank are composed of energy input (power input), the heat transferring of the coiled-tube heat exchanger and the heat loss to surrounding. The energy conservation of the electroplating tank and internal coiled-tube heat exchanger are:

$$\frac{dT_s}{dt} = \frac{(IV) - U_o A_{ht}(\Delta T_{lm}) - Q_{loss}}{\rho_s V_s Cp_s} + F_T \quad (1)$$

$$\frac{dT_{wo}}{dt} = \frac{F_w(T_{wi} - T_{wo})}{A_o L} + \frac{U_o A_{ht}(\Delta T_{lm})}{\rho_w Cp_w A_o L} \quad (2)$$

Where $$\Delta T_{lm} = \frac{(T_s - T_{wi}) - (T_s - T_{wo})}{\ln \frac{(T_s - T_{wi})}{(T_s - T_{wo})}} \quad (3)$$

IV. Results and discussions

The aim of multi-objective optimization is determined the unknown parameters in eq. (1) such as overall heat transfer coefficient (U_o) and total loss factor (F_T). This section provided for comparison the performance of the heat exchanger between the original and a vibration type coiled-tube heat exchanger (new design).

Assumptions made regarding the development of the models are:

- the physical properties, density, heat capacity of the plating solution and the water to be constant in the temperature range,
- the volume of the plating solution in the electroplating tank is assumed constant,

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- the temperature water in the internal tube heat exchanger is linearly changes with the distance in the flow direction. And the heat transfer between air and the coil outside the electroplating tank is neglected,

Referring to the models developed, an unknown parameter such as an overall heat transfer coefficient based on the heat exchanger area (U_o) and total loss factor (F_T) needed to be determined. The randomized 2 batch sampling of the electroplating process were considered to simulate the overall heat transfer coefficient (U_o) and the total loss factor (F_T) from the actual plant data. The property of fluids and the parameters of units are presented in Table 1 and the initial value of the variables is given in Table 2 for the electroplating process batch 1, 2, 5, 6 respectively

TABLE 1
NOMINAL VALUES FOR THE PROCESS PARAMETERS

ρ_s	1,174.4	kg/m^3
ρ_w	995.60	kg/m^3
Cp_w	4.18	kJ/kg$^\circ$C
V_s	7.0	m^3
$A_{o(Coiled-Tube)}$	1.58	m^2
$A_{o(U-Tube)}$	0.96	m^2
m_w	0.664	m^2

TABLE 2: THE INITIAL VALUE OF VARIABLES

U-Tube Heat Exchanger	Batch 1	T_s	53.97 $^\circ$C
		T_{wo}	36.86 $^\circ$C
		IV	2.5 x 5.5 kW
	Batch 2	T_s	46.60 $^\circ$C
		T_{wo}	34.90 $^\circ$C
		IV	2.5 x 5.5 kW
Coiled-Tube Heat Exchanger	Batch 5	T_s	45.33 $^\circ$C
		T_{wo}	34.46 $^\circ$C
		IV	3.5 x 6.5 kW
	Batch 6	T_s	47.23 $^\circ$C
		T_{wo}	35.70 $^\circ$C
		IV	3.2 x 5.5 kW

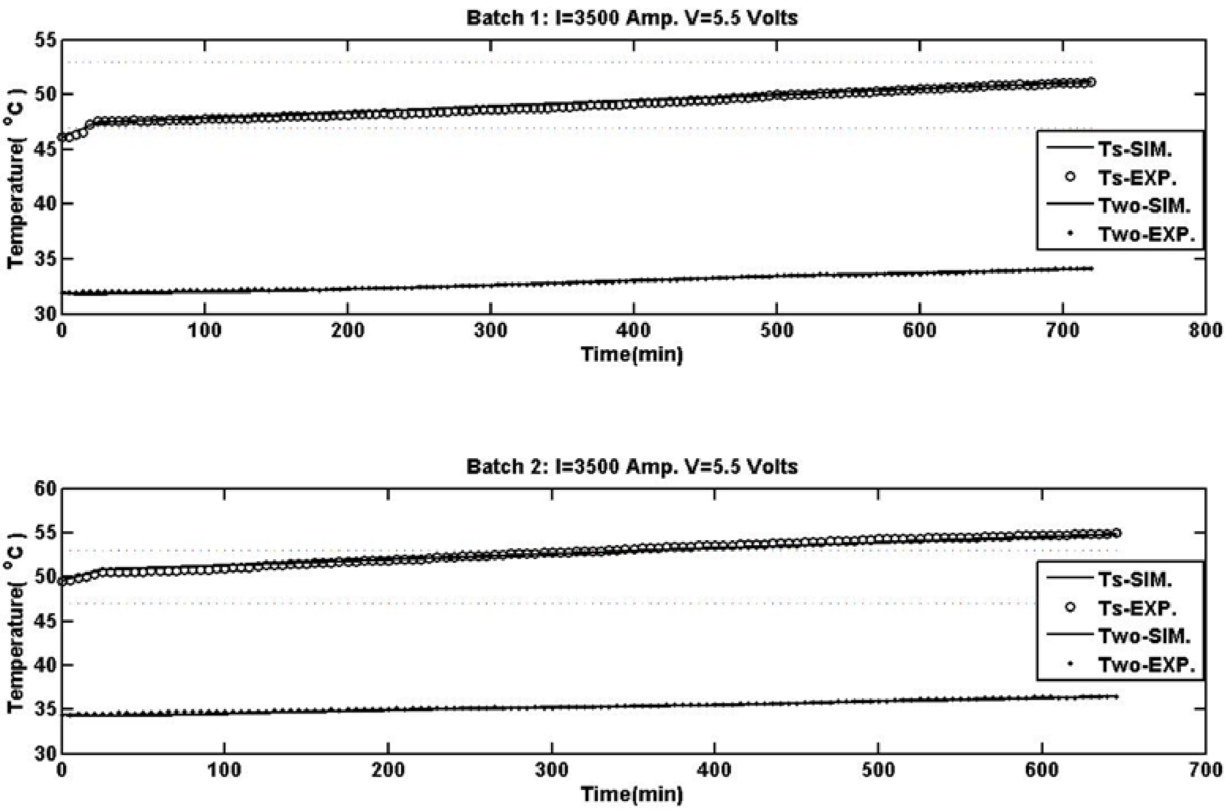

Fig. 3 The temperature profile of the plating solution and the water out with actual plant data of the U-tube heat exchanger batch 1 and 2.

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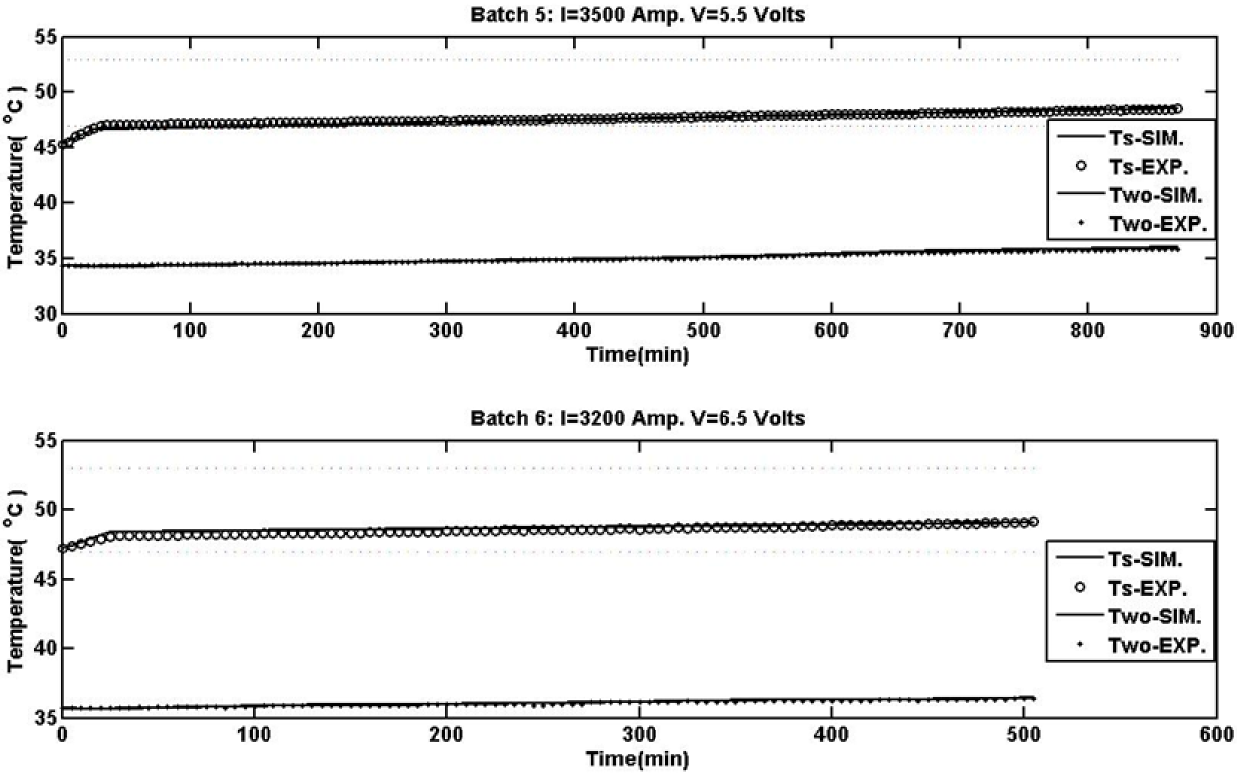

Fig. 4 The temperature profile of the plating solution and the water out with actual plant data of a vibration type coiled-tube heat exchanger batch 5 and 6.

The actual plant data was used to find the value of overall heat transfer coefficient (U_o) and total loss factor (F_T) for heat transferring both types of the heat exchanger. The simulation results were compared with the actual plant data. The simulation results of batch 1 and 2 were presented in the figure 3 and the plating solution temperature profile varied with time was accurately fitted with the actual data. At the beginning of both batches, the plating solution temperature tended to increase due to heat generated by the high electric current, then the plating solution temperature continuous increased over the optimal temperature range in the batch 2 (second batch in successive operation). The figure 4 showed the simulation results of batch 5 and 6, the plating solution temperature varied with time was fitted with the actual data. In the second batch (batch 6) after the first batch, it was found that the plating solution temperature slightly increased but remained within the optimal temperature range (47-53°C).

On the figure 3 and 4, the trend of the cooling water out temperature from simulation was fitted with the collected data (red dot) and slightly increased.

The behavior in the term of the heat generated by the IV values was changed as step changes. At the beginning of the plating process (0-30 min), the value of IV was adjusted higher than the operating setting value to induced chromium to hold all area of work pieces. Then it was tuned by actual data.

The determined values of the overall heat transfer coefficient (U_o) and the total loss factor (F_T) by the multi-objective optimization method were given in table 3.

Table 3: The correct values of U_o and F_T

Batch	Parameter		ISE
	U_0 (Watt/m^2 °C)	F_T (°C/sec)	
1	490.8	0.025	6.08×10^{-2}
2	495.7	0.029	1.24×10^{-1}
5	549.9	0.010	3.31×10^{-2}
6	551.6	0.007	3.65×10^{-2}

V. Conclusion

According to the success result of “A vibration type coiled tube heat exchanger” experimentation shows its capacity of maintaining the specific temperature range of plating solution, which is 47-53°C. This new design heat exchanger can provide high heat transfer rate resulting in the overall heat transfer coefficient of 550.7 W/m^2°C comparing to the overall heat transfer coefficient of 493.2 W/m^2°C of the original machine. This test proves that the new heat exchanger’s capacity in an overall heat transfer coefficient can be increased about 10%. In summary, the calculated total loss factors (F_T) are 2.7×10^{-2} and 8.5×10^{-3} °C/sec for original and new heat exchangers respectively. The simulation results have shown that the developed models give a good of the plating solution temperature with small error. In addition, the new design tube heat exchanger is applicable to employ in the real continuous hard chrome plating process and corresponding to the production of 9.7% per year.

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