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Identification of Co Current Plate Heat Exchanger Model HE158C

Tatang Mulyana[#1]

[#1]Department of Mechatronic &Robotic Engineering,
Universiti Tun Hussein Onn Malaysia (UTHM)
Batu Pahat, Malaysia
tatang@uthm.edu.my

Mohd Nor Mohd Than[#2]

[#2]Department of Mechatronic &Robotic Engineering,
Universiti Tun Hussein Onn Malaysia (UTHM)
Batu Pahat, Malaysia
mnmt@uthm.edu.my

***Abstract* - This paper presents to identifies of co current plate heat exchanger model HE158C using Microsoft Excel Software (MES) and Laplace Transform to obtain its transfer function in s-domain. The simulation is then done by using MATLAB M-file in order to see its step output response. The process modelling in this method are draw graph of data input and output, get the mathematical equation from graph, obtain the transfer function and then simulate with MATLAB. This method gave 4th order of the transfer function. From the simulation, it shows that an exponential infinite pattern of step output response. This is because of the co current plate heat exchanger is nonlinear. The advantage of this paper is prepared data simulation if a system identification method such as linear model structures (ARX, ARMAX, Output Error, and General Polynomial models), nonlinear model structures (NLARX and NLOE models), and nonlinear model structures based on neural networks (NNARX and NNARMAX models) will use in identification of the co current plate heat exchanger model HE158C.**

Keywords – co current plate heat exchanger, Microsoft Excel Software (MES), MATLAB M-file, transfer function

I. INTRODUCTION

A heat exchanger is a device built for efficient heat transfer from one medium to another. The medium may be separated by a solid wall, so that they never mix, or they may be in direct contact [1]. Plate heat exchangers are extensively used in the food processing industries, chemical processing industries, heating and cooling systems. Plate heat exchanger consists of a number of plates embossed with some form of corrugated surface pattern and abutted assembly, with their corrugations forming narrow passages [2]. Heat exchangers may be classified according to their flow arrangement. In co current heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to one another to the other side. Fig. 1 shows the real system of four heat exchanger types model HE158C [3], Fig.2 shows the cold and hot flow rates measurements, Fig. 3 shows the monitor panel, and the schematic diagram is shown in Fig. 4. The schematic diagram for the co current plate is shown in Fig. 5 and Fig. 6 shows temperature distribution in co current plate heat exchanger. Fig. 7 shows a block diagram of co current plate heat exchanger [4]. From the block diagram in Fig. 5, the input of co current plate heat exchanger are hot water flow rate (FT1), cold water flow rate (FT2), hot water inlet temperature (TT1) and cold water inlet (TT2). Meanwhile the output for co-current shell and tube heat exchanger are cold water outlet temperature (TT3) and hot water outlet temperature (TT4).

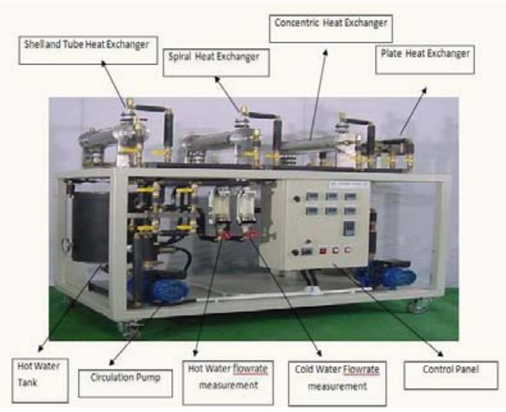

Fig. 1 The real system of four heat exchanger types model HE158C.

Fig. 2 The cold and hot flow rates measurements of four heat exchanger types model HE158C.

Fig. 3 The monitor panel of four heat exchanger types model HE158C.

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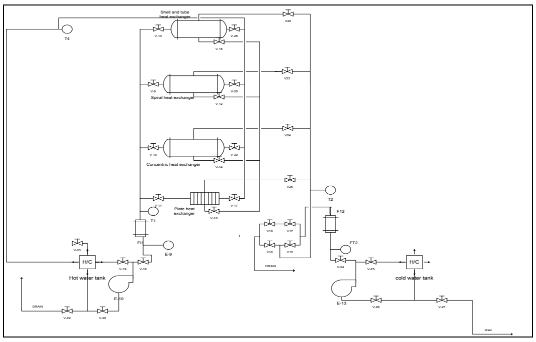

Fig. 4 Schematic diagram of four heat exchanger types model HE 158C.

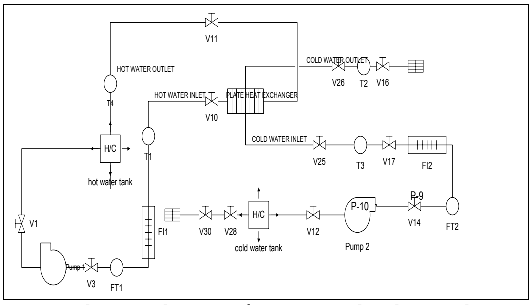

Fig. 5 Schematic diagram of co current plate heat exchanger

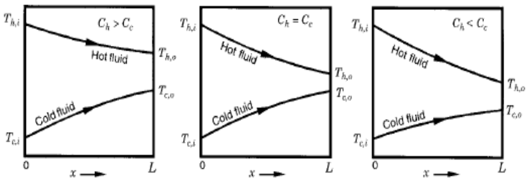

Fig. 6 Temperature distribution in co-current plate heat exchanger

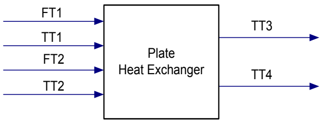

Fig. 7 Block diagram of co current plate heat exchanger.

II. METHODOLOGY

The identification of the co current plate heat exchanger is determined by using MES and s-transformation to obtain its transfer function in s-domain. After all the experimental data of the plate heat exchanger is finish taken the laboratory, the graph of input and output data can be draw and sketch by using Ms Excel Software in t-domain. Data for a set of 10 measurements will be taken for each mode of operation. First operation is when the cold water flow rate (FT2) will be varied in the range of 2, 4, 6, 8, 10 Litre/min. The hot water flow rate (FT1) and temperature will stay approximately constant at about 10 Litre/min and 50̊C respectively. Second operation is when the hot water flow rate (FT1) is varied and cold water flow rate (FT2) will be constant. Data reading for the experiment based on flow rate and temperature. The data will be taken every minute 1 until minute 5. The MES method use a polynomial equation in t-domain is

$$y(t) = a_n t^n + a_{n-1} t^{n-1} + \ldots + a_2 t^2 + a_1 t + a_0 \qquad (1)$$

Transformation of t-domain to s-domain is shown in Table 1, and Table 2 shows the description of plate heat exchanger model HE158C.

TABLE 1:
TRANSFORMATION T-DOMAIN TO S-DOMAIN

Equation In t-domain	**Equation In s-domain**
1	$1/s$
t	$1/s^2$
t^2	$2/s^3$
t^3	$6/s^4$
t^4	$24/s^5$
t^5	$120/s^6$

TABLE 2
DESCRIPTION OF PLATE HEAT EXCHANGER MODEL HE158C

Item	**Description**
Plate Heat Exchanger	Nominal Surface: $0.50m^2$ Plate material: 316 stainless steel/copper brazed

III. RESULT AND DISCUSSION

Table 3 – Table 7 show data experimental co current plate heat exchanger for 1 – 5 minutes. After the reading had been taken, used the MES methods, and sketches the graph, it shows in Fig. 8 and Fig. 9. Table 8 shows transfer function equation of co current plate heat exchanger. To base on Equation (1), Table 1, and Table 8 can find each transfer equation for Fig. 8 and Fig. 9, as example is given equation (2):

$$y(t) = -0.0208t^4 + 0.2417t^3 - 0.9792t^2 + 1.7583t + 47.8 \qquad (2)$$

$$Y(s) = -0.0208(24/s^5) + 0.2417(6/s^4) - 0.9792(2/s^3) + 1.7583(1/s^2) + 47.8(1/s) \qquad (3)$$

$$U(s) = 10/s \qquad (4)$$

$$TF11 = \frac{4.78s^4 + 0.1758s^3 - 0.1958s^2 + 0.1450s - 0.0499}{s^4} \qquad (5)$$

The same way as example, for Fig. 6 and Fig. 7 will obtain each transfer function as shown in Table 9 and Table 10.

TABLE 3
EXPERIMENTAL DATA OF CO CURRENT PLATE HEAT EXCHANGER MODEL HE158C AT MINUTE=1

FT1 (LPM)	**FT2 (LPM)**	**TT1 (˚C)**	**TT2 (˚C)**	**TT3 (˚C)**	**TT4 (˚C)**
10	2	50.8	31.4	48.8	46.2
10	4	51.1	31.4	48.5	43.8
10	6	50.3	31.3	46.3	41.4
10	8	50.1	31.3	45.1	39.8
10	10	49.7	31.2	43.4	38.2
2	10	49.2	31.2	36.0	32.2
4	10	50.2	31.3	39.7	33.6
6	10	49.6	31.3	40.9	35.0
8	10	49.0	31.3	41.4	36.0
10	10	48.9	31.3	42.4	37.4

TABLE 4
EXPERIMENTAL DATA OF CO CURRENT PLATE HEAT EXCHANGER MODEL HE158C AT MINUTE=2

FT1 (LPM)	FT2 (LPM)	TT1 (˚C)	TT2 (˚C)	TT3 (˚C)	TT4 (˚C)
10	2	50.9	31.5	49.0	46.2
10	4	51.1	31.4	48.3	43.6
10	6	50.3	31.3	46.2	41.4
10	8	50.1	31.3	44.8	39.7
10	10	49.8	31.2	43.3	38.1
2	10	49.2	31.2	35.6	32.0
4	10	50.3	31.3	39.7	33.6
6	10	49.4	31.3	40.7	34.9
8	10	48.9	31.3	41.7	36.3
10	10	48.7	31.3	42.5	37.5

TABLE 5
EXPERIMENTAL DATA OF CO CURRENT PLATE HEAT EXCHANGER MODEL HE158C AT MINUTE=3

FT1 (LPM)	FT2 (LPM)	TT1 (˚C)	TT2 (˚C)	TT3 (˚C)	TT4 (˚C)
10	2	51.0	31.5	49.1	46.3
10	4	51.0	31.4	48.2	43.5
10	6	50.3	31.3	46.2	41.4
10	8	50.2	31.3	44.7	39.6
10	10	49.7	31.2	43.3	38.0
2	10	49.3	31.2	35.4	31.9
4	10	50.2	31.4	39.7	33.6
6	10	49.3	31.3	40.5	34.7
8	10	48.7	31.3	41.7	36.3
10	10	48.5	31.3	42.4	37.5

TABLE 6
EXPERIMENTAL DATA OF CO CURRENT PLATE HEAT EXCHANGER MODEL HE158C AT MINUTE=4

FT1 (LPM)	FT2 (LPM)	TT1 (˚C)	TT2 (˚C)	TT3 (˚C)	TT4 (˚C)
10	2	51.0	31.5	49.3	46.3
10	4	50.8	31.4	48.0	43.4
10	6	50.3	31.3	46.2	41.3
10	8	50.0	31.3	44.6	39.5
10	10	49.4	31.2	43.1	38.0
2	10	49.3	31.2	35.2	31.8
4	10	50.2	31.3	39.5	33.4
6	10	49.3	31.3	40.3	34.6
8	10	48.6	31.3	41.7	36.2
10	10	48.5	31.3	42.3	37.5

TABLE 7
EXPERIMENTAL DATA OF CO CURRENT PLATE HEAT EXCHANGER MODEL HE158C AT MINUTE=5

FT1 (LPM)	FT2 (LPM)	TT1 (˚C)	TT2 (˚C)	TT3 (˚C)	TT4 (˚C)
10	2	51.1	31.5	49.3	46.4
10	4	50.8	31.4	47.7	43.3
10	6	50.2	31.3	46.2	41.3
10	8	49.8	31.3	44.5	39.5
10	10	49.3	31.2	42.9	37.9
2	10	49.3	31.2	35.1	31.8
4	10	50.2	31.3	39.1	33.5
6	10	49.4	31.3	40.3	34.5
8	10	48.7	31.3	41.6	36.2
10	10	48.5	31.3	42.3	37.5

TABLE 8
TRANSFER FUNCTION EQUATION

Transfer Function	Description
$TF11=\frac{TT3}{FT2}$; $TF12=\frac{TT4}{FT2}$	FT1, TT1 and TT2 are constants FT2 is input variable TT3 and TT4 are output variables
$TF21=\frac{TT3}{FT1}$; $TF22=\frac{TT4}{FT1}$	FT2, TT1 and TT2 are constants FT1 is input variable TT3 and TT4 are output variables

TABLE 9
TRANSFER FUNCTION EQUATION WHEN FT1 IS CONSTANT AND FT2 IS VARIABLE

Output Response Equation in t-domain

$$TT3(t)=-0.0208t^4+0.2417t^3-0.9792t^2+1.7583t+47.8$$
$$TT4(t)=0.0167t^4-0.2t^3+0.8333t^2-1.35t+46.9$$

Transfer Function in s-domain

$$TF11=\frac{4.78s^4+0.1758s^3-0.1958s^2+0.1450s-0.0499}{s^4}$$
$$TF12=\frac{4.69s^4-0.1358s^3+0.1666s^2-0.12s+0.04}{s^4}$$

Output Response Equation in t-domain

$$TT3(t)=0.0083t^4-0.1167t^3+0.5417t^2-1.1333t+49.2$$
$$TT4(t)=0.0042t^4-0.0583t^3+0.2958t^2-0.7417t+44.3$$

Transfer Function in s-domain

$$TF11=\frac{4.92s^4-0.1133s^3+0.1083s^2-0.07s+0.0199}{s^4}$$
$$TF12=\frac{4.43s^4-0.0742s^3+0.0592s^2-0.035s+0.0101}{s^4}$$

Output Response Equation in t-domain

$$TT3(t)=0.0042t^4-0.0583t^3+0.2958t^2-0.6417t+46.7$$
$$TT4(t)=0.0125t^4-0.1417t^3+0.5375t^2-0.8083t+41.8$$

Transfer Function in s-domain

$$TF11=\frac{4.67s^4-0.0642s^3+0.0592s^2-0.035s+0.0101}{s^4}$$
$$TF12=\frac{4.18s^4-0.0808s^3+0.10752s^2-0.085s+0.03}{s^4}$$

Output Response Equation in t-domain

$$TT3(t)=0.0083t^4-0.1167t^3+0.5917t^2-1.3833t+46$$
$$TT4(t)=0.0792t^4-0.7917t^3+2.7708t^2-4.0583t+41.8$$

Transfer Function in s-domain

$$TF11=\frac{4.6s^4-0.1383s^3+0.1183s^2-0.07s+0.0199}{s^4}$$
$$TF12=\frac{4.18s^4-0.4058s^3+0.5542s^2-0.475s+0.19}{s^4}$$

Output Response Equation in t-domain

$$TT3(t)=0.0042t^4-0.1417t^3+0.0958t^2-0.0583t+43.4$$
$$TT4(t)=-0.0125t^4+0.1417t^3-0.5375t^2+0.7083t+37.9$$

Transfer Function in s-domain

$$TF11=\frac{4.34s^4-0.0058s^3+0.01923s^2-0.085s+0.0101}{s^4}$$
$$TF12=\frac{3.79s^4+0.0708s^3-0.1075s^2+0.085s-0.03}{s^4}$$

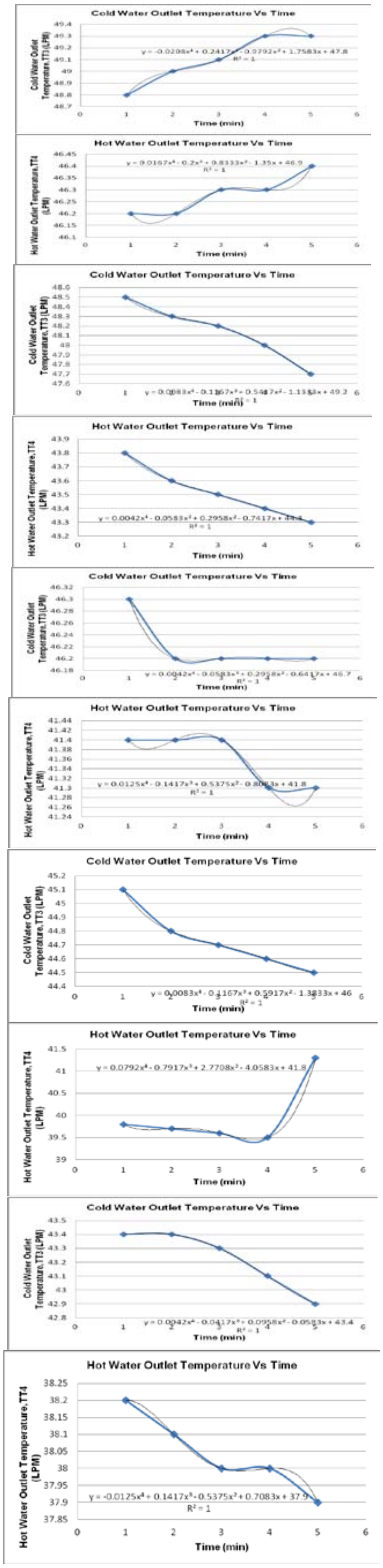

Fig. 8 Co current plate heat exchanger graph when FT2 is variable and FT1 is constant.

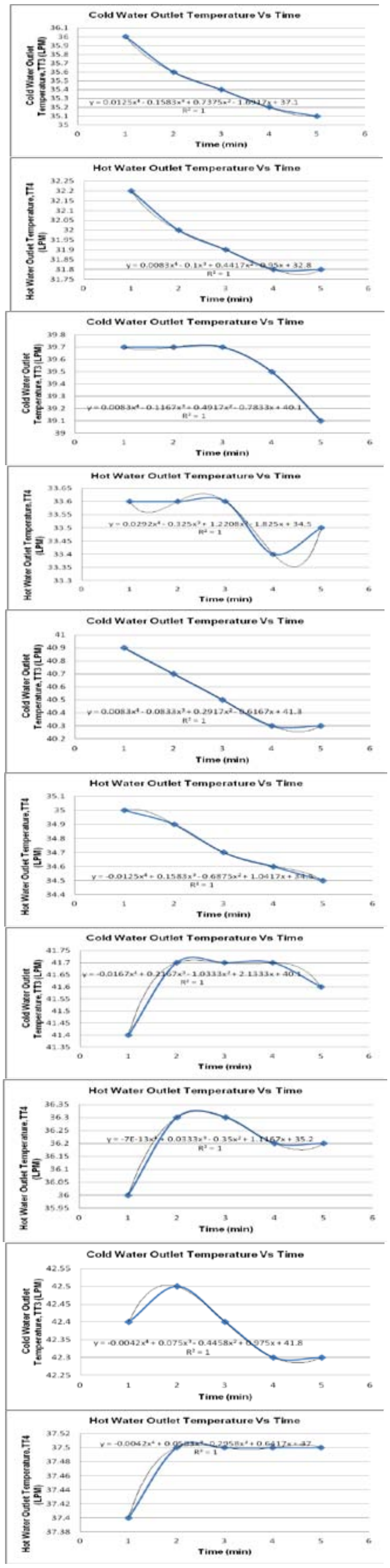

Fig. 9 Co current plate heat exchanger graph when FT1 is variable and FT2 is constant.

TABLE 10
TRANSFER FUNCTION EQUATION WHEN FT2 IS CONSTANT AND FT1 IS VARIABLE

Output Response Equation in t-domain $TT3(t) = 0.0125t^4 - 0.1583t^3 + 0.7375t^2 - 0.6917t + 37.1$ $TT4(t) = 0.0083t^4 - 0.1t^3 + 0.4417t^2 - 0.95t + 32.8$ **Transfer Function in s-domain** $TF21 = \frac{3.71s^4 - 0.0692s^3 + 0.1475s^2 - 0.095s + 0.125}{s^4}$ $TF22 = \frac{3.28s^4 - 0.095s^3 + 0.0883s^2 - 0.06s + 0.02}{s^4}$
Output Response Equation in t-domain $TT3(t) = 0.0083t^4 - 0.1167t^3 + 0.4917t^2 - 0.7833t + 40.1$ $TT4(t) = 0.0292t^4 - 0.325t^3 + 1.2208t^2 - 1.825t + 34.5$ **Transfer Function in s-domain** $TF21 = \frac{4.01s^4 - 0.0783s^3 + 0.0983s^2 - 0.07s + 0.0199}{s^4}$ $TF22 = \frac{3.45s^4 - 0.1825s^3 + 0.2442s^2 - 0.195s + 0.0701}{s^4}$
Output Response Equation in t-domain $TT3(t) = 0.0083t^4 - 0.0833t^3 + 0.2917t^2 - 0.6167t + 41.3$ $TT4(t) = -0.0125t^4 + 0.1583t^3 - 0.6875t^2 + 1.0417t + 34.5$ **Transfer Function in s-domain** $TF21 = \frac{4.13s^4 - 0.0617s^3 + 0.0583s^2 - 0.05s + 0.0199}{s^4}$ $TF22 = \frac{3.45s^4 + 0.1042s^3 - 0.1375s^2 + 0.095s - 0.03}{s^4}$
Output Response Equation in t-domain $TT3(t) = -0.0167t^4 + 0.2167t^3 - 1.0333t^2 + 2.1333t + 40.1$ $TT4(t) = -7E-13t^4 + 0.0333t^3 - 0.35t^2 + 1.1167t + 35.2$ **Transfer Function in s-domain** $TF21 = \frac{4.01s^4 + 0.2133s^3 - 0.2067s^2 + 0.13s - 0.04}{s^4}$ $TF22 = \frac{3.52s^4 + 0.1117s^3 - 0.07s^2 + 0.02s}{s^4}$
Output Response Equation in t-domain $TT3(t) = -0.0042t^4 + 0.075t^3 - 0.4458t^2 + 0.975t + 41.8$ $TT4(t) = -0.0042t^4 + 0.0583t^3 - 0.2958t^2 + 0.6417t + 37$ **Transfer Function in s-domain** $TF21 = \frac{4.18s^4 + 0.0975s^3 - 0.0892s^2 + 0.045s - 0.01}{s^4}$ $TF22 = \frac{3.7s^4 + 0.0642s^3 - 0.0592s^2 + 0.035s - 0.0101}{s^4}$

The average transfer function for Table 9 and Table 10 are

$$TF11 = \frac{4.662s^4 - 0.0292s^3 - 0.1092s^2 - 0.115s + 0.0101}{s^4} \quad (6)$$

$$TF12 = \frac{4.26s^4 - 0.1252s^3 + 0.156s^2 - 0.126s + 0.048}{s^4} \quad (7)$$

$$TF21 = \frac{4.008s^4 + 0.0203s^3 + 0.0016s^2 - 0.008s + 0.023}{s^4} \quad (8)$$

$$TF22 = \frac{3.48s^4 + 0.0005s^3 + 0.0132s^2 - 0.021s + 0.01}{s^4} \quad (9)$$

The total transfer function from equation (6) - (9) to refer Figure 5 is shown in equation (10) that is

$$TF(s) = \begin{bmatrix} TF11 & TF12 \\ TF21 & TF22 \end{bmatrix} = \begin{bmatrix} \frac{TT3(s)}{FT2(s)} & \frac{TT4(s)}{FT2(s)} \\ \frac{TT3(s}{FT1(s)} & \frac{TT4(s)}{FT1(s)} \end{bmatrix} \quad (10)$$

The total transfer function in equation (10) is simulated using MATLAB M-file as shown in Fig 10.

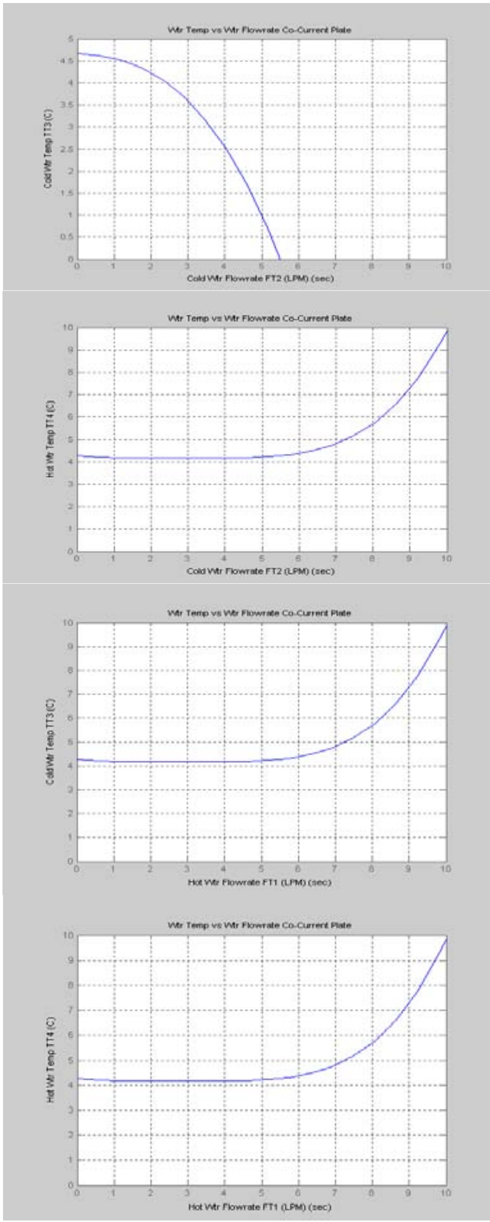

Fig. 10 Output response co current plate heat exchanger.

From the results in Fig. 8 and Fig. 9 could be seen that the all experiments data could be stated as equality 4^{th} order polynomial with quite good accuracy. Therefore could be considered that the transfer function of the co current plate heat exchanger was enough to be represented until 4^{th} order in s-domain. Afterwards if this transfer function was being simulated using MATLAB in Fig. 10, could be seen that the output TT3 descended in an exponential manner against to the input FT2 but increased in an exponential manner against to the input FT1. In the meantime the output TT4 increased in an exponential against both two inputs, FT1 and FT2.

IV. CONCLUSIONS

For the conclusion, this paper has identified a co current plate heat exchanger model HE158C using MES and Laplace Transform methods. The identified is obtained shown the transfer function where as the input are hot water flow rate (FT1) and cold water flow rate (FT2), and as the output are cold water outlet (TT3) and hot water outlet (TT4). This method gave 4th order of the system, that is

$$TF(s) = \begin{bmatrix} TF11 & TF12 \\ TF21 & TF22 \end{bmatrix} = \begin{bmatrix} \frac{TT3(s)}{FT2(s)} & \frac{TT4(s)}{FT2(s)} \\ \frac{TT3(s}{FT1(s)} & \frac{TT4(s)}{FT1(s)} \end{bmatrix}$$

$$TF11 = \frac{4.662s^4 - 0.0292s^3 - 0.1092s^2 - 0.115s + 0.0101}{s^4}$$

$$TF12 = \frac{4.26s^4 - 0.1252s^3 + 0.156s^2 - 0.126s + 0.048}{s^4}$$

$$TF21 = \frac{4.008s^4 + 0.0203s^3 + 0.0016s^2 - 0.008s + 0.023}{s^4}$$

$$TF22 = \frac{3.48s^4 + 0.0005s^3 + 0.0132s^2 - 0.021s + 0.01}{s^4}$$

From the simulation resulted, it shown that an exponential infinite pattern of step output response. This is because of the co current plate heat exchanger is nonlinear. The heat exchanger model HE158C is a facility that was installed in UTHM and it is open-loop system, and it to be a closed-loop system needs a mathematical model of this model. A system identification deal with the problem of building mathematical model and this paper shows a simple method to obtain a mathematical model of co current plate heat exchanger model HE158C. Many methods in system identification such as linear model structures (ARX, ARMAX, Output Error, and General Polynomial models), nonlinear model structures (NLARX and NLOE models), and nonlinear model structures based on neural networks (NNARX and NNARMAX models). The advantage this paper is prepared data simulation if a system identification method will use in identification of the co current plate heat exchanger model HE158C.

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