Modeling and Simulation of Temperature Control PID Single Loop of a Heat Exchanger Process Control Training System QAD Model BDT921

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Abstract – This paper deals with modeling and simulation of a temperature control PID single loop of a heat exchanger process control training system QAD Model BDT921. The values of transfer function for PID parameters setting have been used in simulation, and these parameters are same as the real system controller. The transfer function result has second order.

Keywords: *Modeling, Temperature Control, PID Single Loop, Heat Exchanger*

INTRODUCTION

Over the past quarter century, the importance of heat exchanger has increased immensely from the viewpoint of energy conservation, conversion, recovery, and successfull implementation of new energy sources. Its importance is also increasing from the standpoint of environmental concerns such as thermal pollution, air pollution, water pollution, and waste disposal. Heat exchangers are used in the process, power, transportation, air-conditioning and refrigeration, cryogenic, heat recovery, alternate fuels, and manufacturing industries, as well as being key components of many industrial products available in the marketplace. From an educational point of view, heat exchangers illustrate in one way or another most of the fundamental principles of the thermal sciences, thus serving as an excellent vehicle for review and application, meeting the guidlines for university studies in the United States and oversees [1]. Common examples of heat exchangers are shell and tube exchangers, automobile radiators, condensers, evaporators, air preheaters, and cooling towers. This paper is to study the heat exchanger process with focussing to temperature control PID single loop. The real system of heat exchanger process control training system QAD Model BDT921 is showed in Figure 1. The modelization for the control system is made using Simulink graphical model. In the process, diagram block is used. This diagram block easing the understanding and modeling the system because it is stated in graphics. Some of the many of the main elements which is widely used for the modelization of the system using Simulink are source, system block diagram, and sinks. The input for the model depends on the value wanted and the form is fixed. The model used is based on control system model in which has been studied while output form is displayed in/not in graphical; graph and output value. The simulation is include continous time system dan discrete time system. The continous time system consist of linear system and modelized non-linear system, mean while the discere time system consist of linear time discere, logic block, and discrete time system. The analysation is an important aspect to certain that the modelization is correct and the model is succeed. This consist of analizing the model form and its characteristics, the analizing of the output and the analizing of the usage of the Simulink components showed in Figure 2 [2].

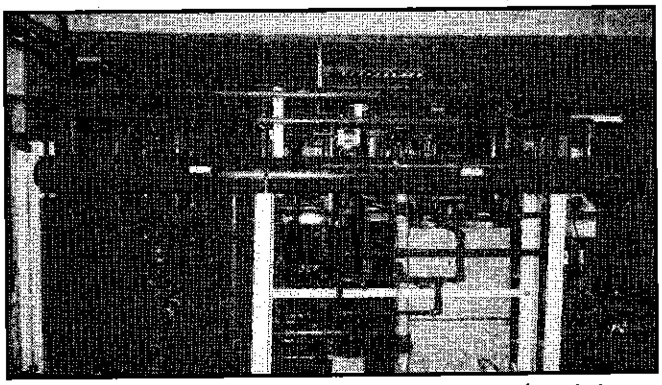

Figure 1 : The real system of heat exchanger process control training system QAD Model BDT921

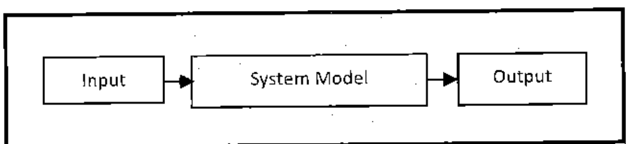

Figure 2 : Three components of simulink model

QAD Model BDT921 plant is used to study PID control in the process of heat exhanger using shell and tube heat exchanger. This process needs product heating until the temperature reached the setpoint, SP. Temperature at the output is measured by RTD Censor (TE14) and scanned by RTD (TIT14). Signal received from TT14 will be transered to PID temperature control, namely TIC11. The schematic of the heat exchanger process with focussing to temperature control PID single loop is showed in Figure 3 [3].

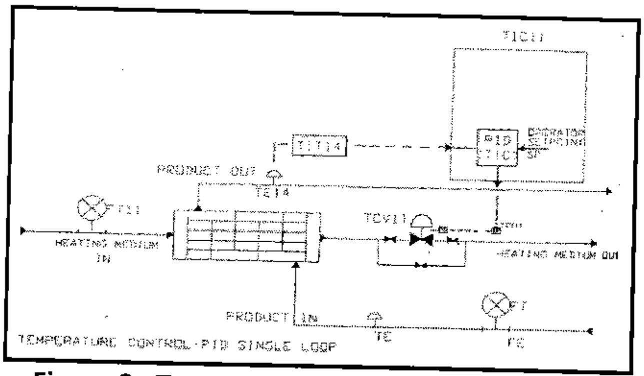

Figure 3 : Temperature control PID single loop

Any changes of the temperature value that has been fixed will be corrected by the TCV11 valve controller, which controlled the quantity of the heat medium input in the heating process in heat exhanger. There are three term: Proportional (P), Derivative (D), and Integral (I) needed to reach the perfect heat exchanger. The heat transfer process has a leakage possibility, that is thermal capacity leakage. The process also has a dead time. That is why the process is slow. Thus, the proportional band (PB) and derivative (D) that have a low values are essential to TCV11 controller to heighten the control responses. Integral (I) is also essential to lower the offset from the PB. To minimalize the heat capacity leakage during the heat exchange process, the input valve control TCV11 is more likely paired with the heat exchanger output. This is to make sure that the shell and tube of the heat exchanger is always filled with medium heating although the valve control is closed. The modelization started with building the basics components to represent the real one like the diagram block shown on the Figure 4 [3,4,5,6].

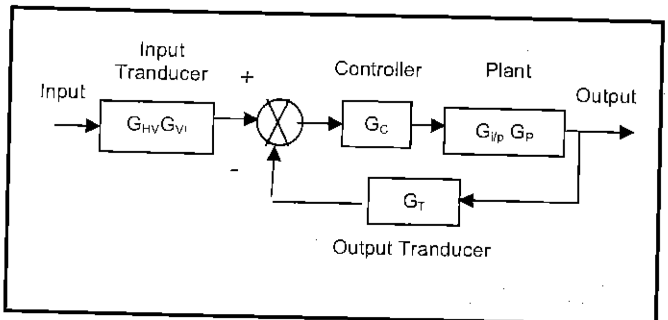

Figure 4 : Diagram block of temperature control PID single loop based on the real system modeling

Where:

G_{HV} = gain of temperature to voltage values converter

G_{VI} = gain of voltage to current values converter
G_C = gain of PID controller
$G_{i/p}$ = gain of current to pressure values converter
G_P = gain of plant
G_V = gain of valve
G_T = gain of temperature transmitter

The values for the gain above is determined through the Manual Book QAD BDT921 [1, 6]. The gain values are:

a) **G_{HV} (temperature to voltage values converter gain):**

Input values = 1-5 V
Setting of temperature values = 0-300 Celcius
Gain = 4 / 300 = 0.0133 V / Celcius

b) **G_{VI} (voltage to current values converter gain):**

Input values = 1-5 V
Output values = 4 – 20 mA
Gain = 16 mA / 4V = 4 mA/V

c) **G_C (PID controller gain):**

The controller gain is a gain in which is set to PID. The gain is depended on the fixed value by the operator. PID will shown value that is depended to a control process system used and the value can change variedly.

d) **$G_{i/p}$ (current to pressure values converter gain):**

Input values = 4 – 20 mA
Output values = 3 – 15 psig
Gain = 12 / 16 mA = 0.0527 kg/cm^2 mA

e) **G_V (TCV gain):**

The TCV gain is depended on the open and close flow valve control of heating fluids. From the study, the corelation between pressure and parcentage of the opening valve is 0.01* valve. The valve influenced the flow of the fluids which flowing in and out the heat exchanger. Because of the valve used in the plant is non-linear, the linearity is needed. After the process of linearity, the final gain for TCV is 21400.

f) **G_T (temperature transmitter gain):**

Input valuesNilai masukan = -10–220 Celcius
Output values = 4 – 20 mA
Gain = 16 / 210 = 0.076 mA / Celcius

g) **G_P (plant gain):**

Refering to [3,6], the plant gain is 0.8/(2.55s+1) in the perfect state in which the term value is assumed fully transferred from one to the other plant without any resistances. The formula used is [3,6]:

$$T = \frac{\rho CV}{U_A} \quad (1)$$

Where:

- T = thermal time constant
- ρ = fluid density
- C = heat capacity
- V = heat exchanger volume
- U_A = total heat transfer coefficient

$$\tau = \frac{V}{q} \quad (2)$$

Where:

- τ = holdup time in the fluid
- q = fluid flowrate

Equation (1) and (2) combined to equation (3):

$$G_p = \frac{1 - e^{\frac{-\tau}{T}}}{Ts + 1} \quad (3)$$

Equation (3) is the basic for plant gain used. The following values is determined from experiment of the gain.

Table 1 : Parameter and values for gain of plant in equation (1) [3,6].

Parameter	Value
U_A	0.1125 kW/m^2 C°
C	4.187 kJ/kg C°
P	1.087 kg/ m^3
V	0.063 m^3
q	0.01584 m^3 / s

By using the values from the Table 1 into the equation (3), the plant gain determined is as the following equation (4):

$$G_p = \frac{0.8}{2.55s + 1} \quad (4)$$

From the the data and information gained, the complete modelization for the temperature control system of heat exchanger is as deduced in Table 2 [6]:

Table 2 : Parameter and values for Figure 4

Parameter	Value
G_{HV}	0.000053
G_C	variable
$G_{i/p}\, G_P\, G_v$	$\frac{9022.28}{2.55s+1}$
G_T	0.076

Based on the general diagram block in Figure 4, closed loop for this control system is shown on Figure 5.

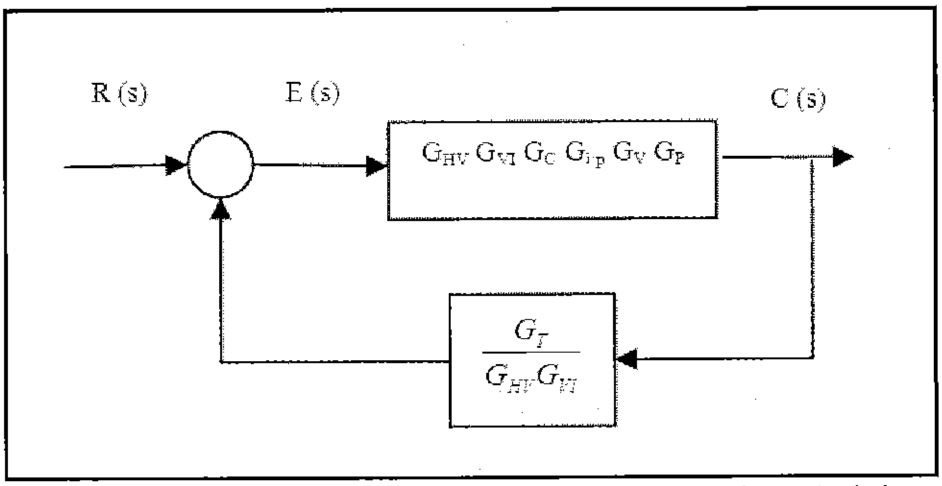

Figure 5 : Closed loop diagram block of temperature control PID single loop

The closed loop transfer function of the temperature control of heat exchanger is [6]:

$$\frac{C(S)}{R(S)} = \frac{G_{HV}G_{VI}G_C G_{IP}G_V G_P}{1+G_{HV}G_{VI}G_C G_{IP}G_V G_P\left(G_T / G_{HV}G_{VI}\right)} = \frac{G_{HV}G_{VI}G_C G_{IP}G_V G_P}{1+G_T G_C G_{IP}G_V G_P} \quad (5)$$

The equation (5) can be represented in diagram block is showed in Figure 6.

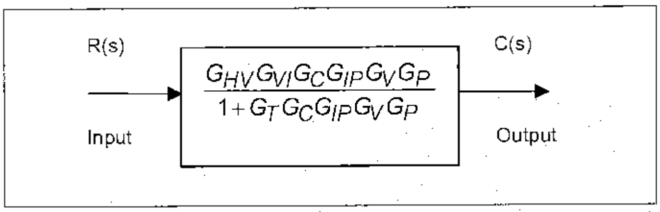

Figure 6 : Simplified of Figure 5

Referring to [3,4,5,6], the transfer function in the second order, which involving proportional band, integral and derivative:

$$\frac{C(s)}{R(s)}=\frac{0.048G_C T_D T_I s^2+0.048G_C T_I s+0.048G_C}{(2.55T_I+0.048G_C T_D T_I)s^2+(T_I+0.048G_C)s+0.048G_C} \qquad (6)$$

Whereas G_C for the proportional band (PB), integral (T_I) and derivative (T_D) is:

$$G_C=(100/PB)\left(1+\frac{1}{T_I s}+T_D s\right) \qquad (7)$$

Equation (7) is a transfer function for designed PID controller, and this equation will be used to form another type of simulink model.

SIMULATION

The values of transfer function for PID parameters setting have been used in simulation is showed in Table 3.

Table 3 : The values of transfer function for PID parameters setting.

PID Parameters Setting	Transfer Functions
$PB=20\%$ $T_I=24s$ $T_D=6s$	$\frac{34.13s^2+5.688s+0.237}{62.59s^2+5.701s+0.237}$
$PB=10\%$ $T_I=50s$ $T_D=12s$	$\frac{118.5s^2+23.70s+0.4740}{128.8s^2+23.76s+0.4751}$
$PB=20\%$ $T_I=50s$ $T_D=12s$	$\frac{118.5s^2+11.85s+0.237}{62.59s^2+11.85s+0.237}$
$PB=40\%$ $T_I=50s$ $T_D=12s$	$\frac{71.09s^2+5.925s+0.119}{128.9s^2+5.939s+0.119}$

The simulation results from the Table 4 is showed in Figure 6.

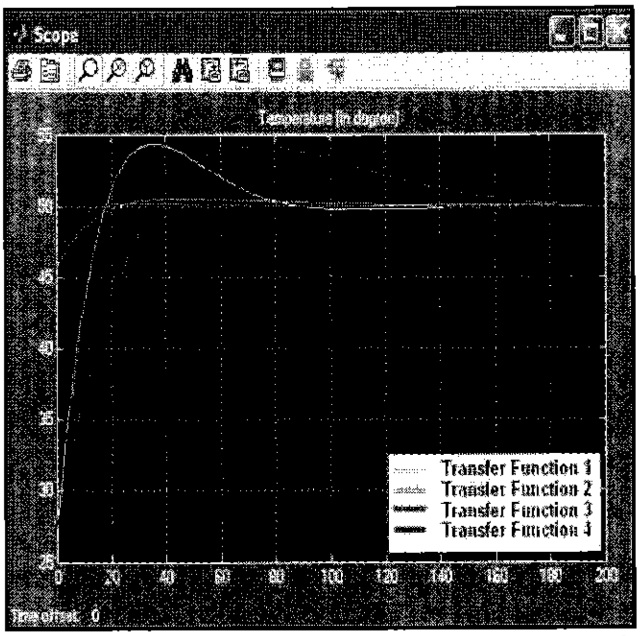

Figure 6 : Simulation result comparison with all transfer function

The simulation comparisons of the all transfer functions have been done is showed in Table 4.

Table 4 : Comparison results between simulations and experiments.

Transfer Function	PID Parameters Setting	T_S	T_p
1	$PB = 20\%$ $T_I = 24s$ $T_D = 6s$	100s	35s
2	$PB = 10\%$ $T_I = 50s$ $T_D = 12s$	100s	35s
3	$PB = 20\%$ $T_I = 50s$ $T_D = 12s$	70s	20s
4	$PB = 40\%$ $T_I = 50s$ $T_D = 12s$	190s	70s

CONCLUSION

This paper proposes an alternative way to obtain the modeling of a heat exchanger. The model of a temperature control PID single loop of heat exchanger process control training system QAD Model BDT921 from the transfer function result has second order. The transfer function can be written down as:

$$\frac{C(s)}{R(s)} = \frac{0.048G_C T_D T_I s^2 + 0.048G_C T_I s + 0.048G_C}{(2.55T_I + 0.048G_C T_D T_I)s^2 + (T_I + 0.048G_C)s + 0.048G_C}$$

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