International Conference on Instrumentation, Control & Automation
ICA2009
October 20-22, 2009, Bandung, Indonesia

A Discrete Time Model of Boiler Drum and Heat Exchanger QAD Model BDT 921

Tatang Mulyana*, Mohd Nor Mohd Than, Dirman Hanafi*****

*Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia (UTHM)
Locked Bag 101, Parit Raja, 86400 Batu Pahat, Johor Darul Ta'zim
E-mail: tatang@uthm.edu.my,

**Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia (UTHM)
Locked Bag 101, Parit Raja, 86400 Batu Pahat, Johor Darul Ta'zim
E-mail: mnmt@uthm.edu.my,

***Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia (UTHM)
Locked Bag 101, Parit Raja, 86400 Batu Pahat, Johor Darul Ta'zim
E-mail: dirman@uthm.edu.my

Abstract

A boiler drum and heat exchanger QAD Model BDT921 that is installed in the Control Laboratory is being used as a model plant to achieve the digital control system design since it is analog in nature. The digital control design need a mathematical model of the system is designed. This paper covers a discrete time model of boiler drum and heat exchanger QAD Model BDT 921. The model is obtained from parameter gain values of the real system and then this model will simulate using MATLAB program. The proportional integral differential (PID) controllers are being chosen as the control element in discrete form as the real system is using the same control element. The output responses behave as the second order system with a closed correlation in rise times and peak times compared with data obtained from experiment and simulation results. With regarding to the analysis done, the digital control can be implemented to the boiler drum and heat exchanger control system and for further viewing, to be controlled digitally with computer in the control room.

1 Introduction

Boiler drum and heat exchanger are commonly used in industries in almost all process and power plants to generate steam for the main purpose of electricity generation via steam turbines [1,2]. The real system of boiler drum and heat exchanger QAD Model BDT921 that installed in the Control Laboratory in University Tun Hussein Onn Malaysia (UTHM) is showed in Figure 1 and Figure 2, and the piping and instrumentation drawing (P&ID) of the system is showed in Figure 3. This paper covered the study of overall process operation of boiler drum and heat exchanger as a control system plants. It encompassed the explanations of the roles of each instrument and control elements such as control valves and PID controllers. This paper will cover a discrete time model of the control systems. It then can be analyzed with using MATLAB software to find control response characteristics. After getting the right simulation value for the control system, we go further with the digitization of the simulation. While simulating, the analog to digital converter is not used because of the continuous transfer function was replaced with the discrete transfer function. Therefore, the input signal is processed in discrete function. The discrete transfer function obtained from the continuous transfer function by using certain syntax from MATLAB command window. Sampling time can be changed due to the system requirement.

Figure 1 – The boiler drum and heat exchanger QAD Model BDT 921 (Real system)

Figure 2 - The front panel control of boiler drum and heat exchanger QAD Model BDT 921 (Real system)

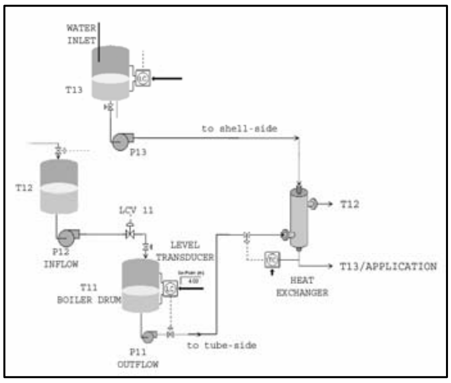

Figure 3 - The P&ID of boiler drum and heat exchanger QAD Model BDT 921 (schematic)

2 Modeling

Boiler Drum Model

The real system of the boiler drum is showed in Figure 4, and the P&ID of the system is showed in Figure 5 [3].

Figure 4 - The real system of boiler drum QAD Model BDT 921

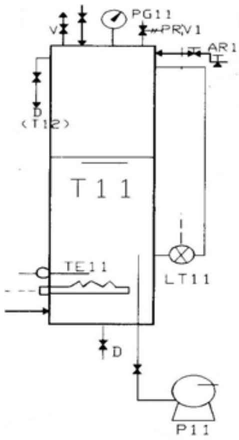

Figure 5 - The P&ID of boiler drum QAD Model BDT 921

Hot water in the boiler drum is supplied by tank T12 through pump P12. This water flow is controlled by valve LCV11. Level transmitter is used to measure the hot water level in the boiler drum. The reading of the transmitter level is sent to the level controller (LIC11) that will compare the instant value with the setting value. The feedback value will then processed and controlling the valve of LCV11 either to open or close. This action will make sure the leveling process is under control. Figure 5 shows the P&ID of boiler drum QAD Model BDT 921 that single loop PID control system for the experiment done. A tank T11, which can be opened (the vent is opened to atmosphere) or closed (pressurised with air with the vent closed), is used to simulate the boiler drum. It has a level transmitter (LT11) to measure the tank level of both an opened or closed tank. Knowing the overall process of boiler drum, make it possible to represent the system process with block diagram. From the block diagram, it will display the graphical figure of connection between the system variables. Plant system process block diagram is showed in Figure 6. The parameter gain value for boiler drum model is showed in Table 1 [1,3]. System modeling is involving mathematical process for each of the subsystem. That's mean for each subsystem, there is a mathematical representation. To find out the variables, two important value need to be known. Those are the input range and the output range parameter [5,6].

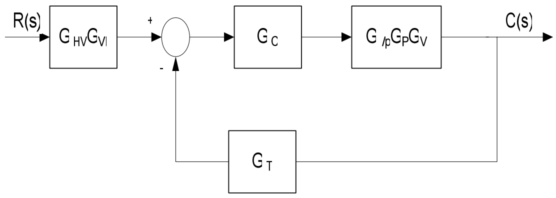

Figure 6 – Block Diagram for boiler drum control system

Table 1 – Parameter gain values for boiler drum model

Parameter gain	Value
Boiler tank transfer function, G_P	1/500s
Current to pressure converter, $G_{I/P}$	0.0527
Level transmitter, G_t	0.16
Level set to voltage converter, G_{HV}	0.04
Voltage to current converter, G_{VI}	4
level control valve, G_V	1144
Gain of PID controller, G_C	variable

Base on the block diagram in Figure 6 with $R(s)$ as input and $C(s)$ and as output, and parameter gain values in the Table 1, therefore the transfer function can be written as equation (1).

$$\frac{C(s)}{R(s)} = \frac{0.019G_C}{s + 0.019G_C} \qquad (1)$$

Controller gain depends on the control mode set by the user. By applying various types of controllers, the transfer function for single loop controller can be written as equation (2) below.

$$G_C = 100/PB \qquad (2)$$

Where G_C is controller gain and PB is proportional band (determine by user). By applying the above equation, for the proportional controllers (P control), the transfer function is shown in equation (3).

$$\frac{C(s)}{R(s)} = \frac{1}{\left(52.63/G_C\right)s + 1} \qquad (3)$$

From this transfer function shown that the system is a first order and the time constant obtained (i.e. 52.63/G_C) will be used to compare with the result in experiment. The equation (4) shows the proportional plus integral controller (PI control).

$$PI(s) = G_C\left(1 + 1/T_i s\right) \qquad (4)$$

Where T_i is integral time. By applying equation (4) for the proportional plus integral control (PI control), the transfer function for this type of continuous signal is shown in equation (5).

$$\frac{C(s)}{R(s)} = \frac{0.019G_C s + \left(0.019G_C/T_i\right)}{s^2 + 0.019G_C s + 0.019 G_C/T_i} \qquad (5)$$

Equation (5) gives a second order system response. With PB setting is 10 and Ti setting is 30s, the transfer function become as equation (6) below.

$$\frac{C(s)}{R(s)} = \frac{0.19s + 0.0063}{s^2 + 0.19s + 0.0063} \qquad (6)$$

While obtaining a continuous response, it then converted to discrete form by using MATLAB at 2 seconds time sampling as shown in equation (7) [7].

$$\frac{C(z)}{R(z)} = \frac{0.3259z - 0.305}{z^2 - 1.663z + 0.6839} \qquad (7)$$

Heat Exchanger Model

The real system of the heat exchanger QAD Model BDT 921 is showed in Figure 7, and the P&ID of the system is showed in Figure 8 [4].

Figure 7 - The real system of heat exchanger QAD Model BDT 921

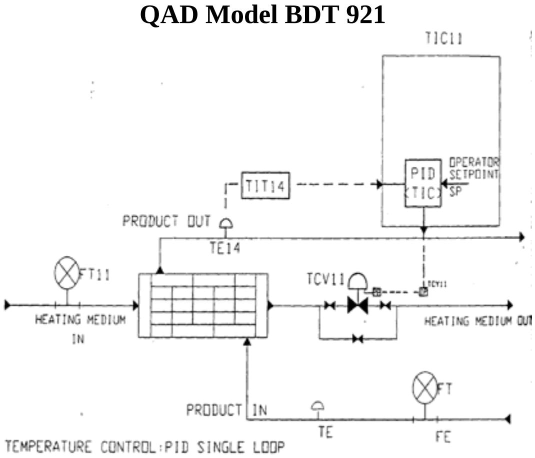

Figure 8 – The P&ID of heat exchanger QAD Model BDT 921

The heat exhanger using shell and tube heat type. 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. 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 same as like as knowing the overall process of boiler drum, the plant system process block diagram of the heat exchanger is shown in Figure 9. The variable for each of the subsystem is showed in Table 2 [1,4].

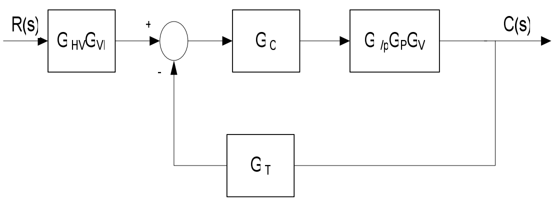

Figure 9 – Block Diagram for heat exchanger control System

Table 2 - Parameter gain values for heat exchanger model

Parameter gain	Value
Gain of temperature to voltage values converter, G_{HV} x Gain of voltage to current values converter, G_{VI}	0.000053
Gain of PID controller, G_C	variable
Gain of current to pressure values converter, $G_{i/p}$ x Gain of plant, G_P x Gain of valve, G_v	$\frac{9022.28}{2.55s+1}$
Gain of temperature transmitter, G_T	0.076

The transfer function for proportional control (P control) in the first order can be written as equation (8) with G_C as in equation (2) and $R(s)$ as input and $C(s)$ and as output.

$$\frac{C(s)}{R(s)} = \frac{G_C}{G_C + 53.13s + 20.83} \quad (8)$$

The transfer functions in the second order, which involving proportional and integral control (PI control) as in equation (9).

$$\frac{C(s)}{R(s)} = \frac{0.048 G_C T_i s + 0.048 G_C}{(2.55 T_i)s^2 + (T_i + 0.048 G_C)s + 0.048 G_C} \quad (9)$$

Whereas G_C for the proportional band (PB) and integral time (T_i) as in equation (10).

$$G_C = (100/PB)\left(1 + \frac{1}{T_I s}\right) \quad (10)$$

The transfer function in the second order, which involving proportional, integral and derivative control (PID control) as in equation (11).

$$\frac{C(s)}{R(s)} = \frac{0.048 G_C T_D T_I s^2 + 0.048 G_C T_I s + 0.048 G_C}{(2.55 T_I + 0.048 G_C T_D T_I)s^2 + (T_I + 0.048 G_C)s + 0.048 G_C} \quad (11)$$

Whereas G_C for the proportional band (PB), integral time (T_i) and derivative time (T_d) as in equation (12).

$$G_C = (100/PB)\left(1 + \frac{1}{T_i s} + T_d s\right) \quad (12)$$

Equation (11) gives a second order system response. With PB setting is 20, Ti setting is 24s and Td setting is 6s, the transfer function become as equation (13).

$$\frac{C(s)}{R(s)} = \frac{34.13s^2 + 5.688s + 0.237}{62.59s^2 + 5.701s + 0.2376} \quad (13)$$

While obtaining a continuous response, it then converted to discrete form by using MATLAB at 0.5 seconds time sampling as shown in equation (14) [9].

$$\frac{C(z)}{R(z)} = \frac{0.5453z^2 - 1.045z + 0.5011}{z^2 - 1.955z + 0.9555} \quad (14)$$

3 Result

Boiler Drum Result

After getting the transfer-function representation from the block diagram, it then analyzed by using MATLAB program. The output display is the characteristic of the system modeled. Parameters are set from experiment values. Therefore, comparison can be made between two signals. Figure 9 shows the simulation of transfer function by using the specified PI setting.

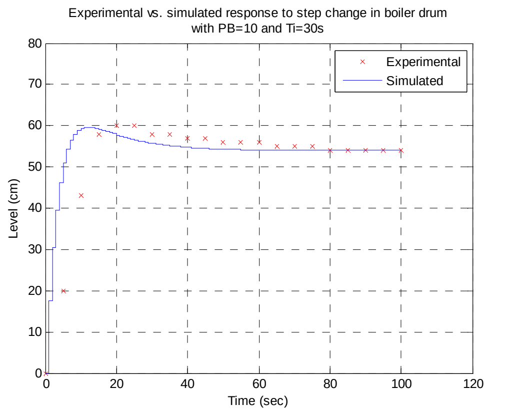

Figure 9 – Comparison simulation using z-domain transfer function with 2s sampling time and measured response of experiment to step change in boiler drum for PB = 10 and Ti = 30s

Second order system has some criteria that useful to be the comparison tools or data between signals. For a better understanding, each of the amplitude value at a specific time is compared between signals as shown in Figure 9. To make a comparison between the experiment signal and the MATLAB signal, the data is gathered in one graph that sharing the same time at x-axis. Both signals are set to unit step input signal and the final value is 54 cm. Starting point is set to zero. With reference to Figure 9, each of the time value is shown in Table 3. General observation from the simulation result shows that the system behaves like a second order system. The results have a little bit difference in analysis (see Table 3). Low controller gain setting made it response as nearly as the real system.

Table 3 - Comparison data obtained from experiment and with simulated.

Signal types	**Time (s)**		
	Rise Time, Tr	**Peak Time, Tp**	**Settling Time, Ts**
Experiment	10s	20s	65s
Simulated	8s	10s	60s
Difference	2s	10s	5s

Heat Exchanger Result

Figure 10 shows the simulation of discrete transfer function by using the specified PID setting. The values of transfer function for PID parameters setting have been used in simulation is PB 20, Ti = 24s, and Td = 6s.

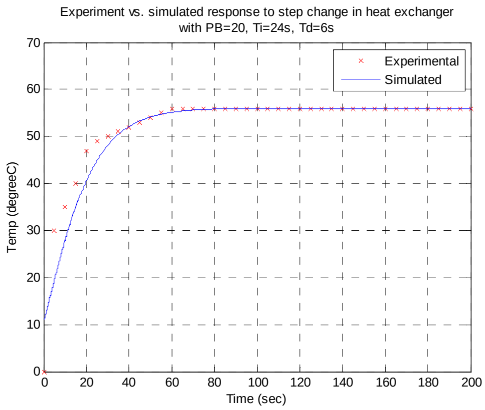

Figure 10 – Comparison simulation using z-domain transfer function with 0.5s sampling time and measured response of experiment to step change in heat exchanger for PB = 20 , Ti = 24s, and Td = 6s

With reference to Figure 10, each of the time value is shown in Table 4. General observation from the simulation result shows that the system behaves like a second order system. The results have a little bit difference in analysis (see Table 4). Both signals are set to unit step input signal and the final value is 55 degree Celsius.

Table 4 - Comparison data obtained from experiment and with simulated.

Signal types	**Time (s)**		
	Rise Time, Tr	**Peak Time, Tp**	**Settling Time, Ts**
Experiment	65s	60s	65s
Simulated	60s	65s	70s
Difference	5s	5s	5s

4 Conclusion

Mathematical model for a process control plant is important because it provides key information as to the nature and characteristic of the system which is vital for the investigation and prediction of the system operation. The set of equations that make up that model is an approximation of the true process. This paper proposes an alternative way to obtain the modeling of a boiler drum and heat exchanger. The model of boiler drum and heat exchanger process control training system QAD Model BDT921 from the transfer function result has second order.

Acknowledgement

The author would like to thank **Universiti Tun Hussein Onn Malaysia** for supporting this research under the Short Term Research Grant.

References

[1] IR Raymond Chong, Shao Fen, Manual of QAD Model BDT 921/M3, "Boiler Drum and Heat Exchanger Process Control Training System". Unpublished

[2] Belinda Chong Chiew Meng (2002), "Modelling of a Hot Water System Drum and Heat Exchanger Process Control Training System", THESIS UTM

[3] Afrodi Bin Ali and Tatang Mulyana (2005), "Digital Control Design for the Boiler Drum (QAD Model BDT921)", Final Project KUiTHO.

[4] Hairul Azhar Bin Rahim and Tatang Mulyana (2005), "Digital Control Design for the Heat Exchanger (QAD Model BDT921)", Final Project KUiTHO.

[5] Charles L. Phillips (1990). Digital Control System Analysis and Design, 2nd edition, Prentice Hall

[6] Norman S. Nise (2004) "Control System Engineering", 4th Edition, New Jersey; John Wiley

[7] Palm, Wilson J. (2005). "Introduction to MATLAB 7 for Engineers", 2nd edition, Boston McGraw-Hill