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Understanding Transient Response Performance between Controllers for Shell and Tube Heat Exchanger System: Simulated Examination

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Abstract: Technology advancement in process industries widely involves heat transferring using heat exchanger unit. Heat exchanger unit generally used in chemical processes related to energy consumption. Actual purpose of heat exchanger is transferring heat source from hotter fluid to cooler fluid. The main control system challenge for heat exchanger is controlling the temperature according to the control demand (setpoint). This is due to some disturbance phenomena such as leakage, temperature-dependent flow and contact resistance. Therefore, the performance of various control techniques such as feedback PID and feedback-plus-feedforward PID controller are proposed to regulate the temperature of outlet fluid of a shell and tube heat exchanger. Then, system performance is evaluated upon excitation of a unit step response. Overall heat exchanger system is modeled using first order principle and simulation result of two types of controller is compared. From the simulation results, it is found that the combination of feedback and feedforward controller provides significant increase performance of the overall heat exchanger system.

***Index Terms**: Feedback controller, Feedforward controller, Heat exchanger, Transient response.*

I. INTRODUCTION

Temperature control system is widely used in many process industries, power generation plants and boiler systems. In term of plant wide control, heat exchanger is employed to change the temperature involving production and absorption of heat energy between two fluids.

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In practice, an automatic control system design for heat exchanger system can be very demanding due to varying structural and mechanical design [1]. Moreover, developing a generic model for heat exchanger is not an easy task due to dynamic behavior and nonlinearity of process characteristic of itself [2]. Figure 1 shows one of the common configurations of a shell and tube heat exchanger. Shell and tube heat exchanger are also well known of its diversity temperature and pressure range. Two common advantages of shell and tube heat exchanger are less complexity in term of structural development and having larger ratio of heat transfer surface area. In essence, shell and tube exchanger consist of an outer shell with tubes inside. A set of tubes knowns as tube bundle and can be made up of several types of tubes like plain, longitudinally finned and U shape. Heat transferred from one fluid to the other through the walls of tubes to shell. One fluid pump through the tubes, and another fluid pump through the shell surrounding the tube, transfer heat between two fluids. In order to provide feedback path architecture for closed loop control scheme, thermocouples are used to measure fluid temperature.

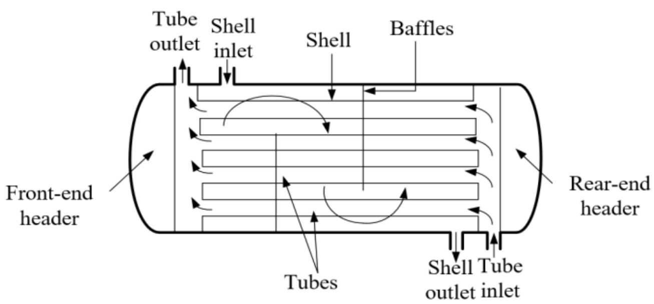

Fig. 1 Common configuration of shell and tube heat exchanger

One of the most significant control rules for heat exchanger is PID controller. In general, PID controller is commonly employed to regulate the outlet temperature of the system at certain desired setpoint. PID controllers are typically used in process control industry due to relatively human friendly structure, its functioning principle easier to implement and understand compare with those advanced controllers [3].

Nevertheless, one of known limitation of PID controller is tends to have higher overshoot due to some disturbance in the system [4].

This research work is an attempt to compare the transient response performance based on different types of PID controller, namely feedback and feedforward system. The major advantage of this approach is to regulate the system temperature of outlet fluid at certain desired setpoint and control overshoot produced by classical PID controller. The normalized transfer function is identified from empirical model.

The complete model of the controllers is developed using MATLAB/Simulink environment and behavior of the system is investigated with present of disturbance effect.

II. LITERATURE REVIEW

In industrial plantwide control, particularly heat exchanger unit, it is significant to regulate outlet fluid temperature of shell and tube heat exchanger at optimal condition thus it can reduce operation and maintenance cost [5]. Many control techniques have been implemented to solve manual-regulation and semi-regulation problem, however, self-regulation issue in temperature control system is remain an open issues [6]. One of common feedback control system used in many process control industries is PID controller. However, one of the limitation of this controller is highly depending on the initial condition, whereby an output will not match with setpoint required if initial condition change [8]. On top of that, an industrial controller should also able to compensate various disturbance factors such as process uncertainties, noise measurement and robustness of the system in developing controllers [7]. This is due to several issues on controlling parameters using conventional methods which lead to improper control action and tends to have higher overshoot due to disturbance [9]. Moreover, improper setting of PID in feedback control loop exhibits high overshoot which is undesirable [10-11]. On the other hand, feedforward plus feedforward control is widely implemented in various control problem to conquered the major disturbance of the controlled process and able to minimize overshoot [12].

III. HEAT EXCHANGER MODEL

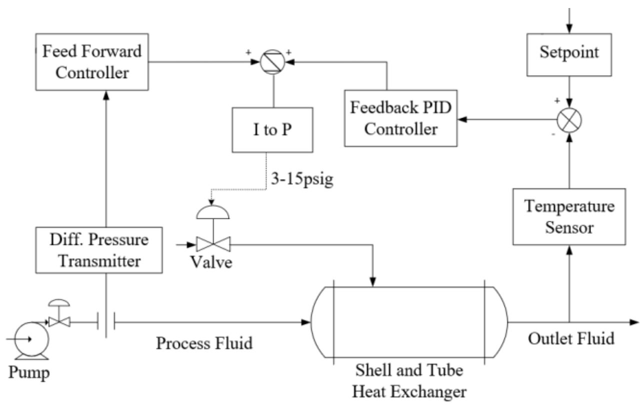

Fig. 2 Schematic diagram of heat exchanger system

Figure 2 illustrates a typical arrangement of heat-exchanger unit. The process flow is started by pumping process fluid from storage tank. A thermocouple is used to measure fluid temperature in the feedback path, the valve used is fail-close type due to reverse acting characteristic of the feedback controller. In order to achieve the desired temperature, the current to pressure converter will be automatically regulate with certain control signal, 4-20mA.

In this paper, two different assumptions have been considered. First, the inflow and outflow rates are identical, resulting fluid level maintains constant in shell and tube heat exchanger. Nevertheless, as simplification purpose, amount of heat stored inside insulating wall is neglected. Meanwhile, it is inheritable to ignore disturbances factor for any heat exchanger configuration whereby the disturbances can categorize in term of flow and temperature variation of input fluid.

Considering the transport delay, the system is written as FOPTD as expressed in Equation 1.

Most of nonlinearity system can approximated as First Order Plus Delay Time (FOPTD) or Second Order Plus Delay Time models (SOPDT).

The general form of FOPTD can be expressed as Equation 1:

$$G(s) = \frac{k_p e^{-TDs}}{Ts+1} \qquad (1)$$

The reduction technique is used to reduced SOPDT model to FOPDT model using frequency response-based model.

The general form of SOPDT model can be expressed as Equation 2:

$$G(s) = \frac{k_p e^{-TDs}}{(T_1 s+1)(T_2 s+1)} \qquad (2)$$

Linearized mathematical model of heat exchanger is obtained using experimental data. Experimental data for shell and tube heat exchanger process present as Table 1.

Control valve specification	1.6 kg/sec
Control valve time constant	3sec
Sensor Temperature	50-150°C
Sensor time constant	10sec
Heat Exchanger Process gain	0.47 kg/sec
Process time constant	50 sec
Converter current range	4-20 Ma
Converter pressure range	3-15 psig
Valve function	3s+1
Converter rate	0.75
Disturbance function	30s+1
Sensor function	10s+1
Time delay	19 sec

Figure 3 and 4 show the block diagram implementation of feedback and feedback-plus-feedforward with PID controller of shell and tube heat exchanger system respectively. A general equation for PID controller can be presented as:

$$Gc(s) = K_C(1 + \frac{1}{T_i s} + T_d s)$$

For PID controlling parameters, Ziegler- Nichols closed loop regulation method applied for experimental setup present as:

$K_c = 3$

$T_i = 0.39$

$$T_d = 9.8$$

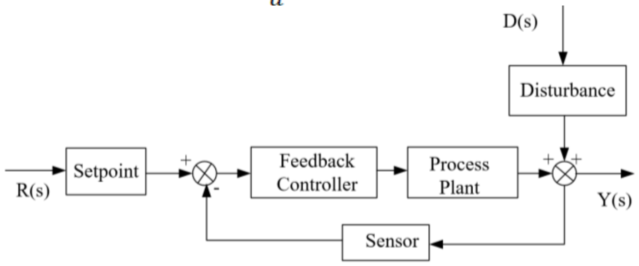

Fig. 3 Block Diagram of Feedback Path of PID Controller

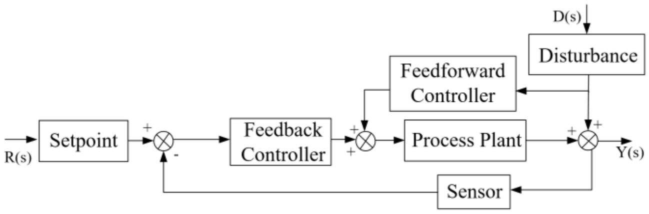

Fig. 4 Block Diagram Feedback-plus-Feedforward with PID Controller

IV. RESULTS AND DISCUSSION

Simulation work is carried out to evaluate the performance of feedback-feedforward PID control scheme with respect to transient response in time domain specification. Figure 5 represent Simulink block of the shell and tube heat exchanger system with PID as a feedback controller and feedback-plus-feedforward controller. By analyzing the unit step response, Feedback-plus-feedforward control with PID controller have better performance than feedback control with PID controller. The results simulation of the controllers as shown as Figure 6. Table 1 shows the comparison transient response between the controllers.

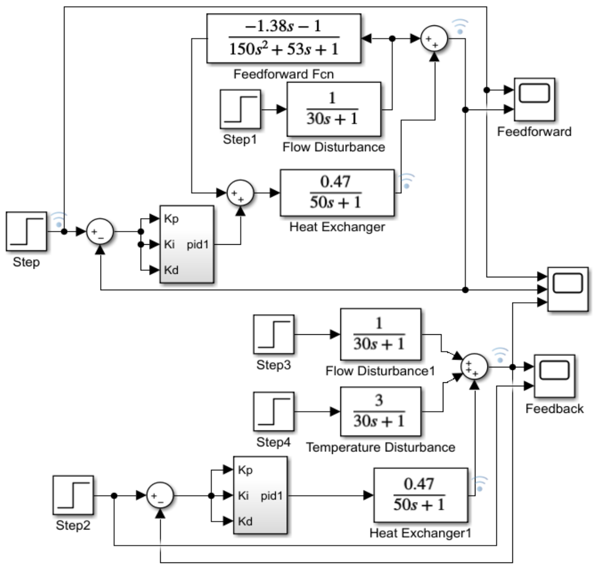

Fig. 5 Matlab/Simulink model of feedback and feedback plus feedforward PID controller in shell and tube heat exchanger system

Unit step response of different PID controllers is shown in Figure 7.

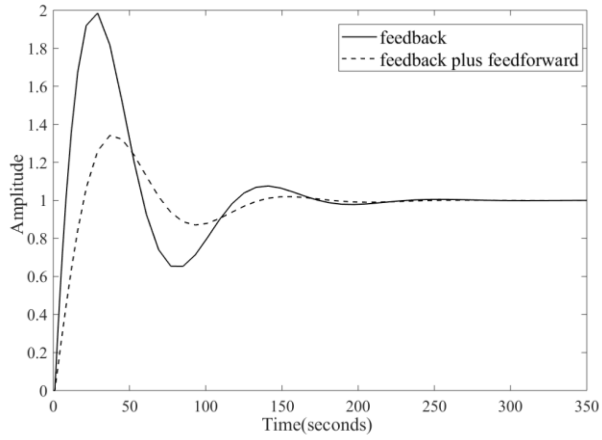

Fig. 7 Response between Feedback and Feedback-plus-Feedforward Controllers.

Table. 1 shows the transient response for unit step input

	Feedback Controller	Feedback-plus-Feedforward Controller
Rise Time (Tr)	4.3392	5.5349
Settling Time (Ts)	82.6071	73.4173
Settling Min	0.6535	0.8704
Settling Max	1.9852	1.3416
Overshoot	98.5163	34.1622
Undershoot	0	0
Peak	1.9852	1.3416
Peak Time (Tp)	61	62

V. CONCLUSION

The temperature control is a very crucial controls part in most of the industrial application. In this paper different types of controller (feedback and feedback-plus-feedforward) is designed to regulate the shell and tube heat exchanger's outlet fluid temperature. The feedback-plus-feedforward control system is used to optimize the performance of anti-disturbance ability in the heat exchanger system. The performance analysis of the system controllers is evaluated based on transient response. Hence the overall mathematical model component of dynamic heat exchanger system is successfully studied and develop using MATLAB Simulink. Simulation result shows Feedback-plus-Feedforward controller along with PID controllers performs better result with minimum overshoot and shortest settling time compared with feedback controller. Future work will consider implementation on Internal Based Model Control for competent temperature control of the heat exchanger system. The performance of the system will be compared with Feedback and Feedback-plus- Feedforward controller.

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