Inferential Control of a Flash Separator

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***Abstract*—This paper discussed on the study of inferential control system applied on a flash separator by simulation. Application to a flash separator demonstrates the typical analysis steps for inferential control, along with very common inferential variables. The common problems of process control are to deal with long dead time and unable to measure control variable in real time. The inferential control system proposed is an improvement of conventional control system which is an initiative to the real process control problems. The application on flash separator is used to infer the value of ethylbenzene production by measuring the secondary measurements. Based on the simulation, the process control is successfully in practice and produced a satisfying result.**

Keywords— Inferential Control, Advanced Control System, Industrial control, Parameter Estimation.

I. INTRODUCTION

When observing a chemical process in a plant, there are various kinds of processes happen. The study of controlling all the process inside the plant is called process control engineering. Process control in chemical engineering is a study that focus on the application of automatic control. The main objective of process control is to maintain or control a process to be at its desired operating conditions, safely and efficiently, while satisfying environmental and product quality requirements. Safety and profitability of a process can be improved by applied a proper process control in a system. Its shows that controlling a plant is not easy because a plant is tend to be difficult to operate because of its complexity and highly integrated process. As stated by Marumo and Sebusang, control engineering plays an important part in industrial plant in controlling the process always in desired condition [1].

Process control in chemical engineering is a combination of control engineering and chemical engineering disciplines that applied in any process industry for control or maintain the level of production consistency, economy and safety which hard to be achieved by manually control by human. This engineering discipline had been implemented widely in industries such as oil refining, pulp and paper manufacturing, chemical processing and power generating plant. The application of process control engineering can range from the temperature, level, pressure and etc.

In process control study, the conventional type of process control usually used is PID control system. However, the conventional control system which has long-dead time process and automatically tune the parameter of a dynamic process. Generally, the inferential control system is a control system implemented to improve the conventional control system. The term of inferential control is used to measure the composition using measured variables. Basically, inferential control system is a method that controls the composition of product by on-line composition control compared to conventional method which needs a long dead time for laboratory analysis or needs to mount an analyser sensor on the system where the sensor is quite expensive. The principle of inferential control system is measure or predict the variables that can directly measure from secondary measurement. This method has been used almost 2 decades ago

The chemical process involved in this study is the production of ethylbenzene. The production of ethylbenzene required benzene and ethylene as the raw materials. The main equipment that are focused for this study is a flash separator. The flash separator is used to separate between liquid and vapour for the ethylbenzene production. The inferential control system will be applied on the flash separator to get the composition measurement of the liquid stream out from the flash separator. The composition to be controlled is ethylbenzene liquid in mole fraction measurement. The controller used in the process system is PID controller with additional control system

In a production process, there are various types of control system used to control the whole production line. In all of the control methods, the important variables have been measured to meet the desirable condition of the process. However, not all important variables can be measured in real time, fast enough that timely control action based on their measurement. The on-line acquisition of such data may involve difficulties caused by measurement inadequacy technique or low reliability measuring device[2]. There are various reasons for the lack of key measurements. First, some sensitive analyses have not been sufficiently automated to provide reliable measurement without human management. Thus, the measurement only can be obtained from a laboratory. Sometimes, some materials only can be determined its properties at the end of the process. Usually these properties relate to final use of the material such as soap, polymer and food. Second, the cost of installing the real-time measurement sensors is quite expensive compare to conventional sensor for temperature, pressure and level. Third, the sensor may not provide information in timely manner because it might have long processing time to generate the information directly. Finally, there are no directly measurable quantities which it depends on the controlled variable of the system. For example, in a heat exchanger, the controlled variable of the system to be measured is heat instead of composition of the materials. Due to the lack of key measurement in conventional control system, inferential control system is proposed to improve the situation[3]. The implementation of inferential control in a process shows a better performance in controlling the control variables as shown by Parrish and Brosilow [4].

The concept of inferential control system is not directly measure the process variable. The inferential control will measure the compositions by using readily available secondary measurement [5]. Not only that, inferential control also can be used to predict the future measurement of compositions [6]. The inferential control system utilize available secondary measurement such as temperature, pressure and flow to control and estimate the quality of product in a process [4] . The design of an inferential control system is a good example to extract useful information from process data and use it for improving process operation [6]. All sensors in inferential control will measures the physical principles which relate to process variable. For instance, an orifice meter provides pressure difference to measure the flow which it is not a direct measurement. The conventional sensors for temperature, pressure, flow and level is type of direct measurement sensors not inferential. It is because it provides an accurate result and the relationship between sensors and process variable is not specific to a particular process. For example, for orifice meter, the relationship between pressure difference and flow is used in any process but not specifically for a particular process compare to reactor temperature and conversion which it is related to each other that could affect the process and considered as inferential variable. As shown in figure 1 where it shows the block diagram of inferential control.

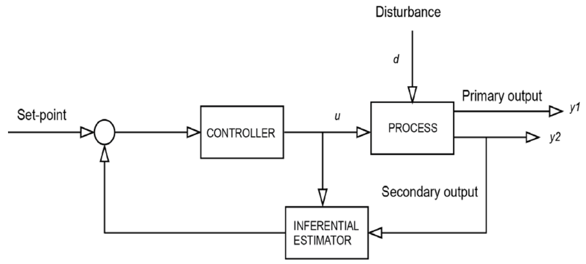

Figure 1: Inferential control system block

From the figure above, the controlled unmeasured variables can be predicted the measurement by using other measurement available in the process. Based on the process, it has two output which is *y1* and *y2* while the disturbance *d,* affects the process. For this model, *y2* and *u* quantities are used to be measurement for prediction on *y1* output. The remains of the process are having the similarity with feedback control system. So, the control system can be considered as inferential control system because the *y1* measurement not gained directly but it measured by using measurement of *y2* and *u.* The inferential estimator is develop using mathematical estimation and represent by equation. In developing the estimator using secondary measurement, the selection of effective variables is important to construct a better predictor in the controller[7]. The estimator need process characterization and parameter estimation before the estimator can be identified[8].

II. METHODOLOGY

The study of inferential control system in a flash separator started with the finding of the variables relationship. The variables involved in the process need to be find. The variables consist of manipulated, process, controlled and disturbance. The relationship between the variables has to be determined. Then, the development of a dynamic process involved in a flash separator by using Aspen HYSYS simulation software is run to analyse the data. The simulation software uses to get a simulation of the process which is has similar parameters with real situation. After that, the transfer function of the process control is develop based on all the variables involved. Then, the control system is simulate using MATLAB-Simulink with transfer function that has been made to represent the behaviour of the process. Finally, the simulation process is run using Aspen HYSYS with real condition of flash separator to collect the data for the study of the problem statement and to achieve the objective of research.

A. *Determination of Variables Relationship*

The inferential control system is method to predict a process composition by using secondary output as a measurement. The compositions that need to be measured in the ethylbenzene production is ethylbenzene[9]. To determine the composition output, a manipulated variable need to be selected as it related to the composition condition which is temperature or pressure. Table 2 shows the variables selected to be involved in the process in order to control the composition output.

Table 1: Variables involved

No	**Variables**	**Properties**	
1	Manipulated	Flow of steam	Flow of vapour outlet
2	Controlled 1	Temperature	Pressure
3	Controlled 2	Product composition	

As stated on the table1, the relationship between manipulated variable with controlled variable 1 and 2 is happen when the manipulated variable change and affect the controlled variable 1. The controlled variable 1 will also affect the change in controlled variable simultaneously. Basically, the main objective is to control the controlled variable 2 by using inferential control system.

B. *Dynamic Process of a Flash Separator*

The scope of the research is focusing on process modelling and simulation. The software used to simulate the process is Aspen HYSYS and MATLAB Simulink. The process of ethylbenzene was chosen to be the process condition of the research and the equipment selected in the process that to be studied is a flash separator. Dynamic process models are very useful during design and operation of chemical processes[10]. The dynamic simulation have been used for decade by control engineer to study process control concept, investigate loop interaction and design control strategies based on the dynamic of the process[11].

The study's aim is to develop the inferential control system on the flash separator unit in the process of ethylbenzene production. The model is put under dynamic condition is because to have a similar condition with real situation during the simulation process. Not only that, the result and data collection is much more reliable to be applied in the real process system. The simulation to collect the data of dynamic process will be tested by using Aspen HYSYS v8.8 where the focus of the simulation on the flash separator. The flash separator will be used as equipment since this study focus is flash separator and the parameter will be set same as a real chemical plant. The dynamic data will be obtained based on the changes of the variables. The changes on every variables will be collected and will be used on the next step in this study. The dynamic process represent the real environment of a chemical plant or chemical equipment during a process. By using the data obtained, the development of the control system will be more accurate and reliable.

C. *Transfer Function Development*

After identify the dynamic, the transfer function that represent the dynamic model is find out The transfer function will represent the dynamic of the process based on the input and output data. The transfer function of a system provides a summary of the input or output response and the output ratio of the system. The transfer function can be obtained by simple algebraic manipulations of the differential equations that describe the system.

The method will be used in this study is using the MatLAB software. The data obtained from dynamic simulation will be used in system identification software to estimate a transfer function. There are several technique in finding a transfer function of a process. The technique using the system identification is chosen as it generate a good estimation and faster compare than other methods. The data will be used in this step are manipulated and controlled variables as input and output respectively. The transfer function will be used one variables as input and produce two output.

The transfer function then will be tested in a simulation of a feedback controller. The aims is to observe the ability of a controller to control the process by applying the transfer function gained from the estimation. The response of the process based on the controller is expected to meet the desired condition as set during the early of the process of the simulation.

D. *Inferential Control Development*

Based on the transfer function made, then it implemented on the inferential control simulation. The MATLAB Simulink software is used to design, tune and analyse the inferential control proposed. The development inferential control consist of the estimation of estimator of the system. Estimator is found out by several methods as it used to predict the output of a process. The good estimator will contribute in a success inferential control[12].The estimator will use the variables data obtained from the dynamic simulation. The estimator expression will be estimated using the system identification in MatLAB software to study the relationship between the variables. In contrast with transfer function, the estimator will used two variables as input while produced one estimated output which known as predicted control variables.

Generally, the input data is used to predict or estimate the output. From the output produced, the controller will control the system using the estimator data and the input data to control the composition of the product to meet desired condition of the process.

III. RESULTS AND DISCUSSION

A. Determination of Variables Relationship

The variables involved in the process was determined in order to be used in the dynamic simulation. The variables was determined based on Ideal Gas Law where it state that the number of moles of gas is directly proportional to pressure. The concept of the simulation is to study the changes of ethylbenzene composition in liquid stream due the changes of pressure in vessel. Based on the theory, the mole of gas will increase as the pressure increase where at the same time the mole of the liquid stream will decrease. Hence, the variables was determined based on the theory and will be tested on the simulation test to analyse the relationship among the variables. The type of the variables to be determined are manipulated and controlled variables. The type of variables determined are shown in table 2.

Table 2: Variables relationship

No	Variables	Properties
1	Manipulated	Mass flowrate of vapour outlet
2	Controlled 1	Product composition
3	Controlled 2	Pressure of vessel

From these variables determined, the relationship between manipulated variable and controlled variables will be tested in simulation test as it will be applied for development of inferential controller. In the application to the inferential controller, it is used to predict the unmeasured/primary variables from the measured /secondary variables. Based on the variable determined, the controlled variable 1 (product composition) will be the unmeasured/primary variables to be predicted and the controlled variables 2 (pressure of vessel) are the measured/secondary variables. Generally, the aim is to determine the type of variables for the used for transfer function development.

B. Dynamic Process of a Flash Separator

The dynamic process of the flash separator was run by using the simulation software Aspen HYSYS v8.8. The process involved in the flash separator was production of ethylbenzene. The aim is to understand the changes of the variables from the dynamic simulation of flash separator. The flash separator was set up based on the parameters from a process of ethylbenzene production in a process plant as mentioned in the chapter 1. The simulation only simulated on the flash separator only and not the whole process plant. The figure 2 shows the diagram of the flash separator process flow in the simulation

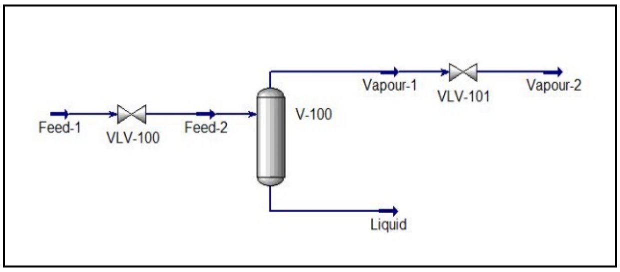

Figure 2: Flash separator process flow

The variables involved in the process were mass flowrate of vapour stream, pressure of the vessel and the mole fraction of the ethylbenzene in the liquid stream. The simulation was simulated the process by changing the percentage of the valve opening (VLV-101). The changes of the valve opening was expected will affect all the variables involved .As mentioned above, the aim of the simulation is to understand the changes of the variables of the dynamic process of the flash separator. The valve was opened gradually from 10% to 100% of opening with every 10% increment. The increment of the valve opening were done after the flow rate of the stream stabled. In the figure 3, 4 and 5, it shows that the changes happened on those variables due to the manipulation of the valve opening during the simulation.

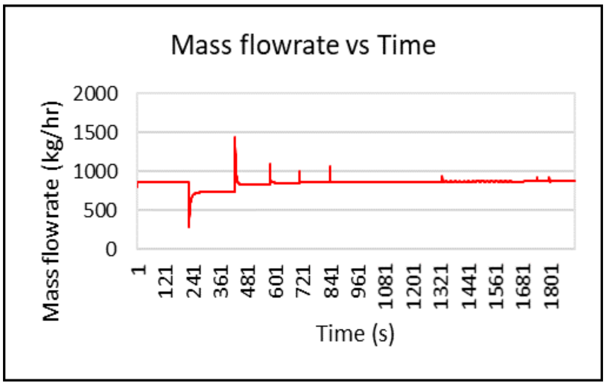

Figure 3: The change of mass flowrate against time

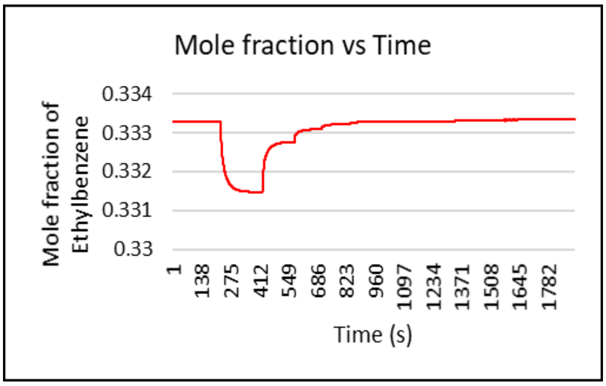

Figure 4: The change of mole fraction against time

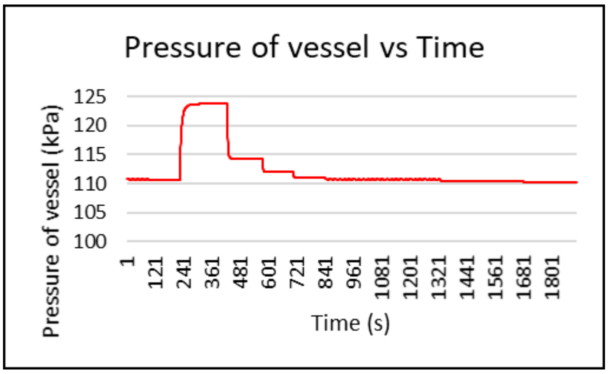

Figure 5: The changes of pressure of vessel against time

From the figures 3, 4 and 5, it shows the changes happened on the variables due to the valve opening changes during the simulation. Generally, based on the data collected, the relationship between the mass flowrate, pressure of vessel and mole fraction of ethylbenzene is as the mass flowrate decrease, the pressure of the vessel increase and at the same time the mole fraction of ethylbenzene will decrease. From these data obtained, the data were accepted to be used because the changes were satisfactory for the development of the transfer function and inferential control system.

C. Transfer Function Development

Transfer function is a mathematical function relating the output or response of a system. The development of the transfer function was done based on the data collected from the dynamic process simulation. The transfer function can be obtained by simple algebraic manipulations of the differential equations that describe the system. In this study, the transfer function of the process was calculated using the application in the MatLAB called system identification. It used the data or the variables data collected to estimate the transfer function. The transfer function generated was first order transfer function. From the variables relationship determination, the input is mass flowrate and the output are pressure of vessel and ethylbenzene composition. The general first order transfer function is shown in equation below.

$$y(s) = \left[\frac{K}{\tau s + 1}\right] \quad (1)$$

Where:
K is the process gain
τ is the time constant

From the analysis of the data collected, the transfer function was estimated. The applications of system identification in the MatLAB was used as the medium to estimate the transfer function of the process. The transfer function estimated was made based on the input and output of the process. For this transfer function, it was made based on the single input and multiple output of the process. The input of the process is the flowrate of the stream out and the output are pressure of the vessel and mole fraction of the ethylbenzene. The estimated transfer function is shown in equation below.

From the single input, the output are:

$$y(1) = \left[\frac{0.0002099}{s + 0.538}\right]$$

$$y(2) = \left[\frac{0.07195}{s + 0.5476}\right]$$

The value of transfer function obtained from the system identification represent the ratio of output to input of the system. The first transfer function of the process represent the response of the changes of the mole fraction of ethylbenzene in liquid stream (unmeasured variables) while the second transfer function represent the response of the pressure vessel of the process (measured variables). These transfer function represent the changes due to the input changes which is mass flowrate of the vapour stream. Then, the estimated transfer function was tested in the feedback control block for PID controller test in MatLAB Simulink. The figure 6 shows the Simulink block diagram for simulation.

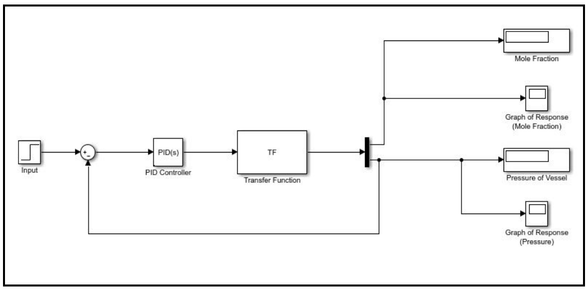

Figure 6: Simulation block diagram in Simulink

The test was run to observe the ability of the PID controller to control the process represent by the transfer function. The test will show the actual performance of the PID controller in handling the change in set point and a change in the process. The first test of the simulation was not meet the desired criteria where the output response show a negative off-set from the set point. Then, the PID controller was tuned to achieve desired settling criteria. As shown in figure 7 below, the graph response show the output of the process meet the set point of the process. It shows the PID controller able to control the secondary controlled variable (measured variables) which is pressure of the vessel to meet it desired final value. While in figure 8 shows the result of the ethylbenzene mole fraction changes affected by the changes of the pressure in vessel.

As conclusion, the transfer function of the process are accepted to be used since the response of the output are satisfied. It shows the PID controller able to control the pressure as the controlled variable in the feedback block diagram. Since it was satisfied, the transfer function was used in the development of inferential control in the next step of this study.

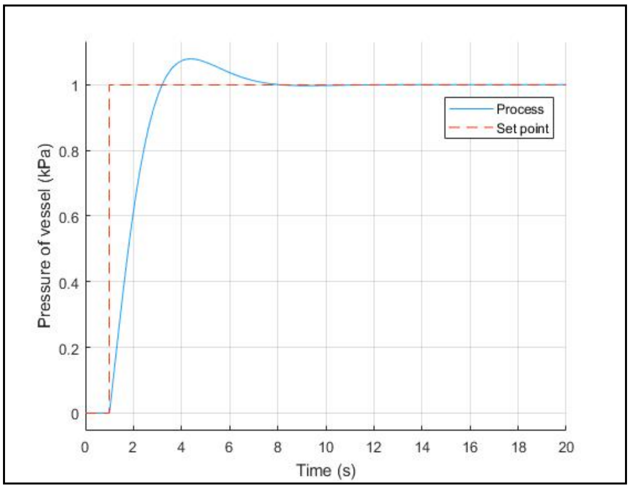

Figure 7: The graph response of pressure of vessel

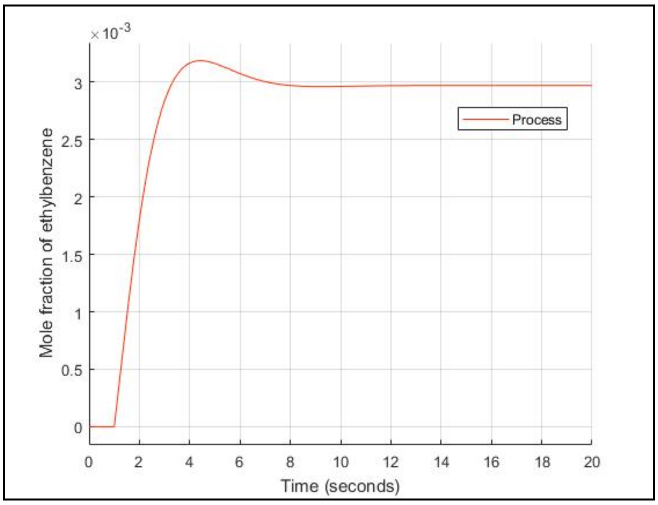

Figure 8: The graph response of mole fraction

D. *Inferential Control Development*

The basic concept of the inferential control is to control or estimate the primary output (unmeasured variables) by using the secondary output (measured variables) from a process. The inferential control was applied to the flash separator in order to control the mole fraction of ethylbenzene with only using pressure as the measurement. The important part of inferential control system is the estimator of the system where it used to control or measure the unmeasured variables using measured variables in the process. The estimator of the inferential control was estimated using the data obtained from the dynamic simulation and was estimated using the system identification application in MatLAB in order to get the relationship between variables involved. To be specific, the system identifications analysis is used to understand on how the response changes when any of input variables changes.

In the application of inferential control system, the response is mole fraction of ethylbenzene while the input variables are mass flowrate of vapour stream and the pressure of the vessel. The variables for this step was divided into two category which are input and output. For this estimator, the equation estimated was based on two inputs and single input. It is difference with the transfer function development because in this step the estimator will estimate the mole fraction of the ethylbenzene with using mass flowrate and the pressure of the vessel as the inputs variables. The equation of the estimator estimated is shown below.

$$y = \frac{9916 \times 10^{-7}}{s + 0.1461}(u1) + \frac{0.0009994}{s + 0.3459}(u2)$$

Where:
y is the composition estimated (output)
$u1$ is the mass flowrate value (input)
$u2$ is the pressure value (input)

From the equation estimated, it was applied in the control block in Simulink. As shown in plate 9, the control block is a complete inferential control used in Simulink for the simulation. From the diagram, the input of the estimator are mass flowrate and pressure of the vessel. From these input, the estimator will estimate the mole fraction as output

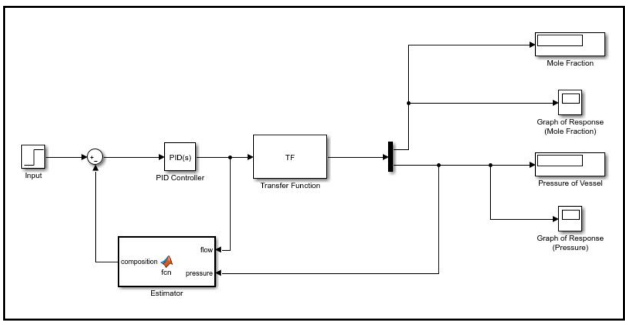

Figure 9: Inferential control block

As stated before, the inferential control applied was used to control the composition of ethylbenzene in mole fraction by using the measurement of pressure. After the transfer function and estimator were estimated, the simulation was run to obtain the data based on the estimator estimated. The simulation was run to test the capability of the estimator to estimate the value of the response as expected before. The initial and final value of the process was set up such as the following value in table3 below.

Table 3: Initial and final value

Test	Initial Value	Final Value
1	0.300	0.333
2	0.333	0.250
3	0.250	0.400
4	0.400	0.333

From the value above, the response of the process were illustrate in a response graph. The response graph is shown in the figure 10 below where it shows the output of the process which is the changing of the mole fraction

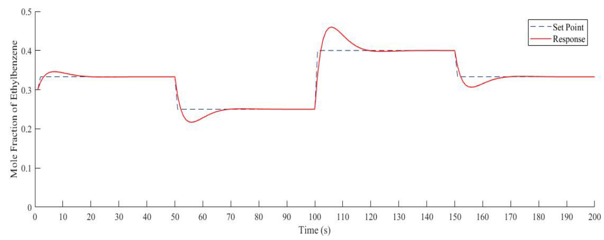

Figure 10: The response graph based on set point

Based on the graph, it shows the response of the process being control by the inferential control to meet the desired value. The set point of the graph is the desired value need to be achieved by the controller. The set point was set with different value to observe the response from the controller to meet the desired value.

The inferential control tested show a satisfactory result where the controller able to control the process by using the measured variables. The inferential control estimator provide a good estimation based on the response illustrated. Therefore, the inferential control applied on the flash separator was succeed. It is therefore concluded the inferential control is a good approach to be used in order to control unmeasured variables

IV. CONCLUSION

The inferential control of a flash separator was studied and the objectives of this research where to find the dynamic relation between variables and propose an inferential control system for a flash separator were achieved. The inferential control system studied based on the application on the flash separator is a better alternative in order to solve the real process control problem that always occur in process plant. From all the result, it is shown that the inferential control system is capable to estimate the controlled variables which helps in contributes a good operation in process plant.

ACKNOWLEDGMENT

The authors would like to thank the Faculty of Chemical Engineering, UiTM for the facilities support given for this work. Not only that, thanks to supervisor Puan Zalizawati Binti Abdullah for the continuous support and guidance in every step throughout the process. This final year project was prepared as a fulfilment for the Degree of Bachelor of Engineering (Hons) Chemical.

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