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Experimental Study of Level and Flow Control

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Abstract: In chemical engineering system, the level and flow control in tanks was very significant but the problem occurred was the accuracy of controller used to control the liquid level in tanks and flow between tanks. The main objective of this study was to discuss and compare the results of changing in derivative time (T_d) in Proportional Integral and Derivative (PID) controller towards the level and flow control where the results was obtained through the application of SOLDAS® IR4.0. Thus, an experimental study of level and flow control was conducted using Level Flow Process Control Training System (Model: SE 665). This SE 665 Model operated using two PID controller to control the loops of level and flow which are FIC-601 and LIC-603. The study was conducted at the Instrumentation and Process Control Laboratory located at Universiti Tun Hussein Onn Malaysia (UTHM), Pagoh. At the end of this study, the change in derivative time (T_d) towards the PID Level and Flow control was showing that the time taken for the process variable (PV) to reach setpoint (SP) for PID level control was longer compared to PID flow control. Besides, it also showed that the PID level control loop was more stable than PID flow control loop during the changing of derivative time (T_d).

Keywords: Level Control, Flow Control, PID Controller, Derivative Time, Process Control

1. Introduction

The level and flow control in tank are very significant in the chemical engineering system. In process system, the level control is a common type of control method and must be controlled by a decent controller. The function of a controller in the level system is to maintain a level setpoint (SP) at a given value and capable to accept new setpoint (SP) values dynamically [1]. The reasons behind the important role of level control in the related industry is due to its variety parameters that is required to be considered in liquid measurement [2]. Meanwhile, the flow control is a control method that is used to transfer materials such as fluids from one location to another location. The typical types of fluids are the one that can flow through the pipe from one side to another. The flow of fluids can be controlled by adjusting the position of valve [3]. Nevertheless, flow control can be implemented through a single loop control and ratio loop control.

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The basic problem that occurs in the industries is the control of the liquid level in tanks and flow between tanks [4]. In the process industries, every fluid required to be pumped, stored in tanks and later to be pumped to another tank. The fluid will be processes frequently by chemically or mixing treatment in the tanks. At the same time, the level of fluid in the tanks must be constantly in controlled whereby it does not exceed the setpoint and the flow between the tanks must be regulated. Thus, this is when the application of Proportional Integral and Derivative (PID) control took places. In controlling the liquids level and flow control, the most essential and compelling control algorithm used is the PID control. PID control is known for its control strategy to control most of the processes in the industrial automation. It is also being said that the three actions control in the PID which are proportional, integral and derivative can take the present error, past error and future error depending on the current rate of change of error into account [5].

In this study, an experimental study is conducted to determine the result of changing in Derivative time, (T_d) for the level control and flow control by using the PID control. The Derivative time, (T_d) indicates the duration of time that the algorithm will plan into the future. Larger corrective action will cause larger Derivative time, (T_d). Therefore, the objective of this study is to discuss the effects of change in Derivative time, (T_d) towards the PID level control and PID flow control.

2. Materials and Methods

For this study, the experiment was conducted using the Level Flow Process Control Training System (Model SE 665). The Level Flow Process Control Training System (Model SE 665) is located at the Instrumentation and Process Control Laboratory in UTHM Pagoh. The control training system used water as the working fluid to operate. Before undergoing any processes, the control training system should be set up accordingly by following the required procedure. The only changed value in this experiment was the derivative time (T_d) while the proportional band (PB) value and integral time (T_i) value was kept constant.

2.1 Level and Flow Control Process Description

The Level Flow Process Control Training System (Model SE 665) as shown in Figure 1 was operated using microprocessor-based controller to manipulate various control parameter in level and flow control. This control training system also is a water process system where the water is stored in the sump tank, T-601 and later is pumped by P-601 to the level tank, T-602. From T-602, the water will flow back to T-601 and there will be two discharge possibilities that are known as the self-regulatory mode and the non-self-regulatory mode. The method that was used to control the instruments for the level and flow control is PID controller. In the process controller, two PID control loops was used which are FIC-601 and LIC-603 to control the flow control loop and level control loop. There was also a switch at the local control panel functioned as a selection of either flow control or level control or combination of both called cascade control. In this study, to control the level control loop, a level transmitter, LT-603 was used to feed signal to level indicating controller, LIC-603 which control the valve FCV-601. As for flow control loop, the orifice flow transmitter, FT-601 was used to send signal to flow indicating controller, FIC-601 which control the valve FCV-601. The results for this study were obtained from the application of SOLDAS® IR4.0 in the form of line graph.

Figure 1: Level Flow Process Control Training System (Model SE 665)

2.2 Experimental Procedure

a) Flow Process Control Start-up Procedure

To start off, all valves in the Level Flow Process Control Training System (Model SE 665) was set according to the flow control initial valve position where the valves will be put into open, close and partially open positioned. The sump tank, T-601 was filled with at least 90% of water before starting the operation. The pressure regulator was set to 3 bar to control the pressure of water by reducing the high input pressure to the controller lower output pressure. Later, the control panel power system was switch on and the operation was set to flow indicating controller, FIC-601 to engage the flow control loop. This flow control loop was running in a closed loop where the feedback system was used to send a feedback signal to the controller for performance improvement if there is an error occurred. The flow indicating controller, FIC-601 was put into manual mode followed by running the water circulation pump, P-601. Lastly, the flow measurement was set to 40 LPM using the flow transmitter, FT-601.

b) PID Flow Control Procedure

The procedure started by setting the proportional band (PB) to 100, integral time (T_i) to 6 seconds and derivative time (T_d) to 0 second. The setpoint (SP) was adjusted to 20 LPM during the flow indicating controller, FIC-601 was in manual mode. The flow measurement, FT-601 value was matched with the setpoint (SP) by tuning the output gradually at the control panel. The tuning was done manually by setting the flow transmitter, FT-601 value to 20 LPM more or less at the control panel. Then, the paperless recorder function was turned on to record and plot the line graph of flow control loop. The flow control loop was recorded in manual mode around 1 minutes and later changed to auto mode as it is easier to control the variables. A load change was stimulated by closing the hand valve, HV615 for 3 seconds and was open back to its original position. This action was implemented to observe the response of flow control loop towards a disturbance. The experiment proceeds with changing the value of setpoint (SP) to 30 LPM and the flow control loop response was observed based on the changed of setpoint (SP). Both load change and setpoint (SP) change had caused the line graph of flow control loop to be stabilized automatically since the control mode was set to auto. After the line graph was stable, the paperless recorder was turned off and the control mode was put back to manual. The experiment was repeated two time by using two different value of derivative time (T_d) while keeping the value of proportional band (PB) and integral time (T_i) constant as shown in Table 1 and all the results obtained was analyzed and compared.

Table 1: Derivative time (T_d) value for flow control

Proportional band (PB)	Integral time (T_i), s	Derivative time (T_d), s
100	6	5
100	6	10

c) Level Process Control Start-up Procedure

The start-up procedure for level control begun with setting the valves position to open, close and partially open according to the level control initial valve position (self-regulating). The pressure regulator, PCV-601 was set to 3 bar to control pressure of water. At control panel, the power system was switch on and the control mode was set to level indicating controller, LIC-603 to produce the level control loop. This level control loop also operated in a closed loop system. The level indicating controller, LIC-603 was set to manual and the water circulation pump, P-601 was turned on. For level control, the water flowrate was set approximately to 40 LPM at flow indicator, FI-601 by adjusting the hand valve, HV617. The level control tank, T-602 started to fill with water after a period and the water level reading on level control tank, T-602 was shown at the level transmitter, LT-603. The water level reading for level control tank, T-602 was set to 1000 mmH_2O by regulating the hand valve, HV620.

d) PID Level Control Procedure

The PID level control operated by setting the proportional band (PB) to 100, integral time (T_i) to 6 seconds and derivative time (T_d) to 0 second. The level control mode was put into manual mode and the setpoint (SP) was adjusted to 500 mmH_2O. The progress in level control was quite slow compared to flow control due to the adjustment of setpoint (SP). Later, the level measurement, LT-603 was set to match the setpoint (SP) value by tuning the output gradually. The paperless recorder function was turned on to record and plot the line graph of the level control loop in manual mode about 1 minute and changed to auto mode later as it is more convenient to control the variables value. A load change occurred to give disturbance to the level control loop by opening the hand valve, HV620 for 20 seconds and returned to its original position. Make sure the water inside the level control tank, T-602 was not empty. Next, a setpoint (SP) changed was implemented to study the response of level control loop where the setpoint (SP) was set to 750 mmH_2O. The level control loop was stabilized automatically during both load change and setpoint (SP) change due to the setting of auto control mode. After the level control loop stable, the paperless recorder function was turned off and the control mode was put back into manual mode. The experiment was repeated 5 times using different value of derivative time (T_d) while keeping the value of proportional band (PB) and integral time (T_i) constant as shown in Table 2 and all the results obtained was analyzed and compared.

Table 2: Derivative time (T_d) value for level control

Proportional band (PB)	Integral time (T_i), s	Derivative time (T_d), s
100	6	1
100	6	6
100	6	12
100	6	30
100	6	60

2.3 Proportional Integral and Derivative (PID) Control

This experiment had applied the Proportional Integral and Derivative (PID) controlled method since it is the most adaptable and easy methods. Besides, it provides the best performance of controlled parameter such as conveniently adjust parameters where an integral controller delivers zero steady state error and derivative controller produce quick response [6]. A Proportional Integral and Derivative (PID) controller is a comprehensive feedback controller that were used widely in industrial control system. In the feedback control system, the Proportional Integral and Derivative (PID) controller was functioned as the compensator that consists of three elements of the controller that determine the output with the following characters:

i. Proportional (P) action adjusts the controller output according to the size of error which is the present error.
ii. Integral(I) action eliminated the steady state offset which is the past error.
iii. Derivative (D) action foresee the future error which is the prediction of future error.

By combining the three elements which are proportional, integral and derivative, the equations that describes its action is as below where $\mathrm{K_p}$ is the proportionality constant, $\mathrm{K_i}$ is the integral constant, and $\mathrm{K_d}$ is the derivative constant.

$$\text{Controller output} =$$

$$\mathrm{K_p} \times \text{error} + \mathrm{K_i} \times \text{integral of error} + \mathrm{K_d} \times \text{rate of change of error} \qquad \textit{Eq.1}$$

The above equation also can be written as below where $\mathrm{T_i}$ is the integral time and $\mathrm{T_d}$ is the derivative time.

$$\text{PID controller output} =$$

$$\mathrm{K_p}\left(\text{error} + \frac{1}{\mathrm{T_i}} \times \text{integral of error} + \mathrm{T_d} \times \text{rate of change of error}\right) \qquad \textit{Eq. 2}$$

3. Results and Discussion

All result for this study was observed based on the response of level control loop and flow control loop towards the load change and setpoint (SP) change using different value of derivative time (T_d). The results obtained was display in the form of line graph. Each line consists of three colors that represented the process variable (PV) blue color, setpoint (SP) red color and manipulated variable (MV) green color. The process variable (PV) is the variable that quantify the performance or quality of the output, setpoint (SP) is the desired value for the process and the manipulated variable (MV) is the input variable that are adjusted dynamically to keep the process variable (PV) near the setpoint (SP). There is also a yellow vertical line that indicate the time of start and end process. Later, the results were analyzed and compared based on the performance of level control loop and flow control loop.

3.1 Results

a) PID Flow Control

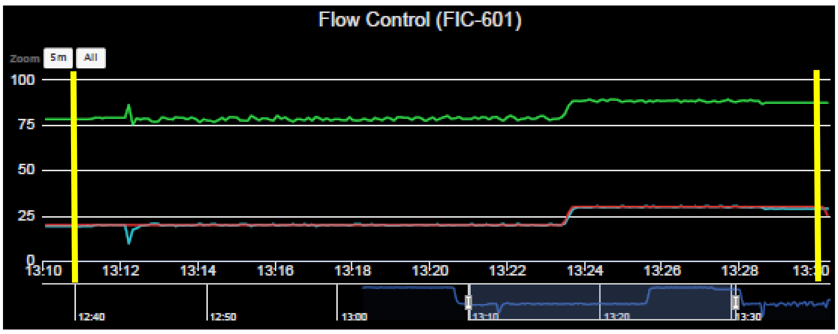

Figure 2: Graph result for derivative time (T_d) of 0 second

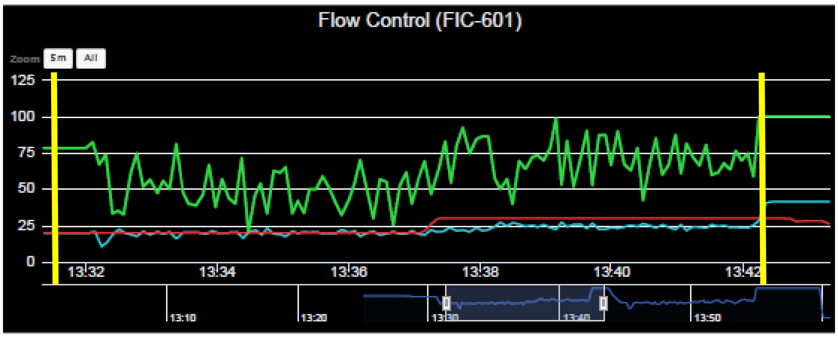

Figure 3: Graph result for derivative time (T_d) of 5 seconds

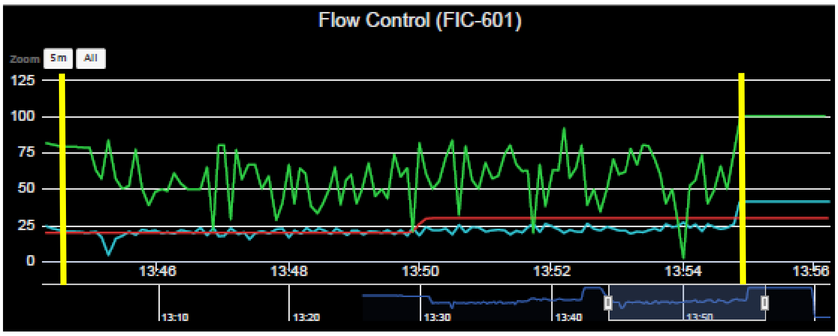

Figure 4: Graph result for derivative time (T_d) of 10 seconds

b) PID Level Control

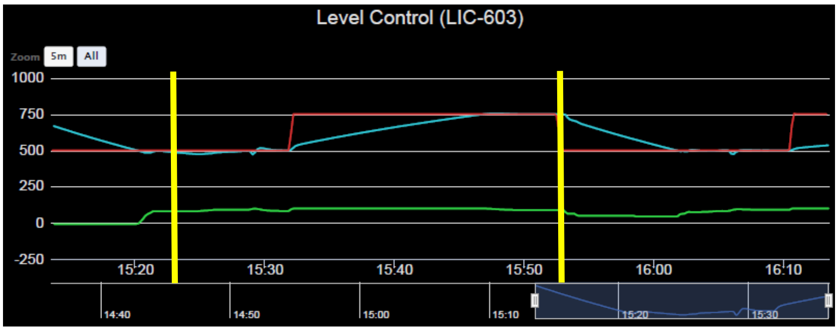

Figure 5: Graph result for derivative time (T_d) of 0 second

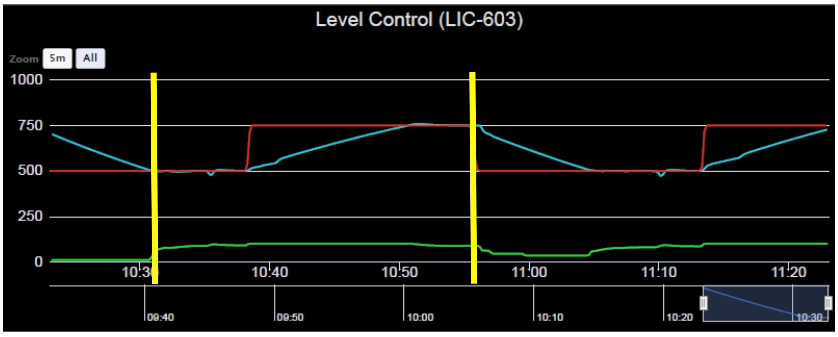

Figure 6: Graph result for derivative time (T_d) of 1 second

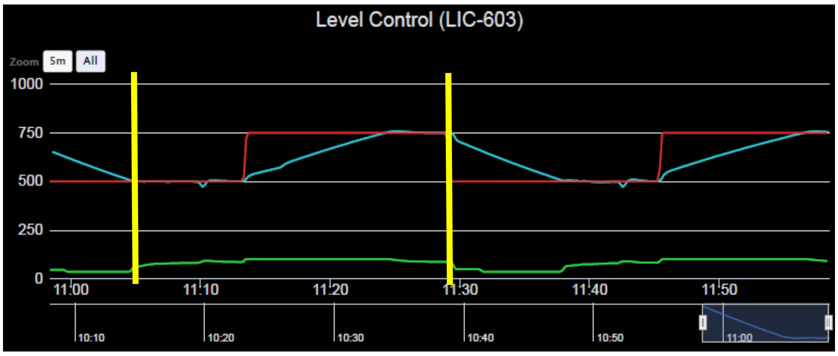

Figure 7: Graph result for derivative time (T_d) of 6 seconds

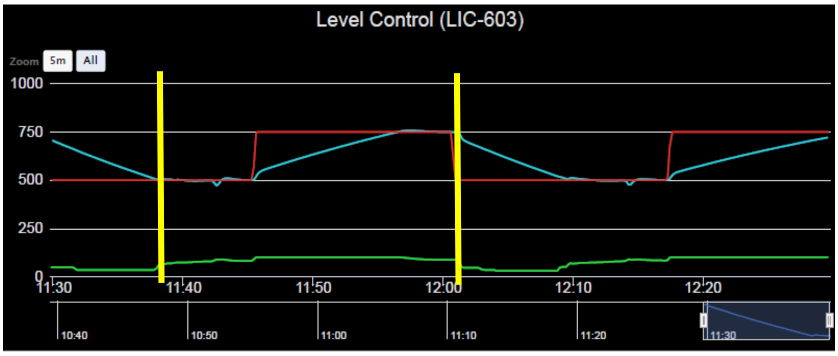

Figure 8: Graph result for derivative time (T_d) of 12 seconds

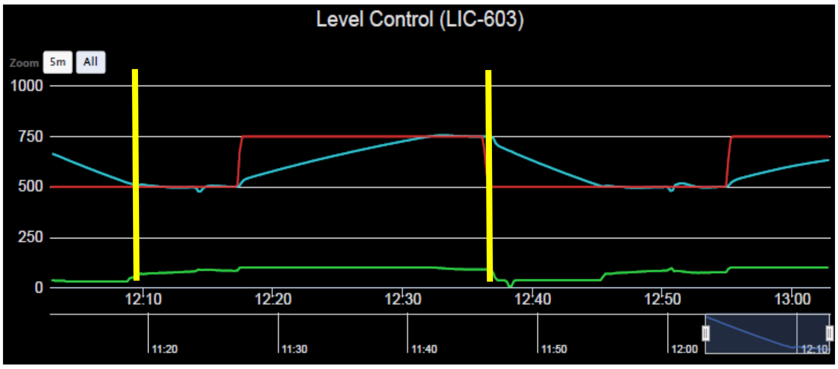

Figure 9: Graph result for derivative time (T_d) of 30 seconds

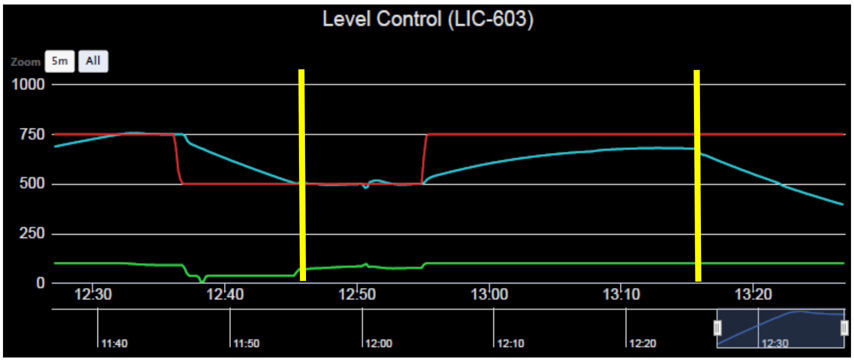

Figure 10: Graph result for derivative time (T_d) of 60 seconds

3.2 Discussions

a) PID Flow Control

Based on the results obtained, it shows that there was a sudden spike of oscillation for all changes in derivative time (T_d). The spike or kick occurred during the load change when the hand valve, HV615 was closed for 3 seconds. The line continues to oscillate until it was stable by using the PID controller, FIC-601. Next, there was an abrupt rise of setpoint (SP) line followed by process variable (PV) line when the setpoint (SP) was change from 20 LPM to 30 LPM. During this phase, some of the oscillation was in control and some was uncontrol. From Figure 2, the process variable (PV) line was almost intertwined with the setpoint (SP) line. The number of oscillations also lower by almost one oscillation seen in Figure 2 compared to Figure 3 and Figure 4 that consists more than 1 oscillations. Besides, the time taken for the process variable (PV) to stabilized after changes of setpoint (SP) was below 1 minute which is faster compared to the other figures. As for Figure 3 and Figure 4, both have an increase number of oscillations which is more than 1 oscillation and the time taken for the process variable (PV) to stabilize after changes of setpoint (SP) was more than 1 minutes which is longer compared to Figure 2. However, Figure 3 showed a better performance of variables where the process variable (PV) line has lower number of oscillations compared to Figure 4. Furthermore, Figure 3 and Figure 4 showed that the process variable (PV) line was far from the setpoint (SP) line after the changes of setpoint (SP) and the period for both lines to mingle is longer by more than 1 minutes compared to Figure 2.

b) PID Level Control

For level control, the results also showed an abrupt spike or kick that occurred during the load changed. But the load changed was implemented by opening the hand valve, HV620 for 20 seconds and the valves was closed partially. Like flow control, the process variable (PV) line was stabilized using PID controller, LIC-603. Then, the setpoint (SP) was changed from 500 $\mathrm{mmH_2O}$ to 750 $\mathrm{mmH_2O}$ where a sudden rise of setpoint (SP) line followed by process variable (PV) line was observed. From these figures, every value of derivative time (T_d) showed different time taken to stabilize the process variable (PV) after the load change. Figure 5, Figure 6, Figure 7, Figure 8 and Figure 9 showed that they almost have the same time taken which is around 1 to 3 minutes to stabilize the process variable (PV) line while Figure 10 showed that it took more than 3 minutes to stabilize the process variable (PV) line. Besides, Figure 10 also displayed greater number of oscillations which is more than 1 oscillation compared to other figures. During the changed of setpoint (SP) value, Figure 5 and Figure 10 took the longest time which is more than 10 minutes for the process variable (PV) line to reach the setpoint (SP) line. But Figure 10 showed that the process variable (PV) line was not able to each the setpoint (SP) line after several time. This is due to constant error where it caused the derivative action to remain the same. Nevertheless, Figure 8 showed the shortest time taken which is around 7 to 8 minutes for the process variable (PV) line to reach the setpoint (SP) line after a setpoint (SP) changed from 500 $\mathrm{mmH_2O}$ to 750 $\mathrm{mmH_2O}$.

c) Results Comparison for PID Level and Flow Control

Both PID level and flow control showed different pattern of line graph for results changes in derivative time (T_d). In PID flow control, the process variable (PV) line oscillates actively when the derivative time (T_d) was increased. The period of oscillations also increased within the increase of derivative time (T_d). This is because flow was categorized as a fast-acting control loops where it contributes to the inherent unstableness. Moreover, flow control tends to have noisy process which can affected the control loop and tend to have short time constant. Meanwhile, PID level control showed that the process variable (PV) line has minimum oscillation as the derivative time (T_d) increased compared to the PID flow control. The PID level control also displayed that the process variable (PV) line was more stable and in control. This is due to the slow acting control loop in level that caused the application of derivative action to be effective since it has long time constant. Nevertheless, since flow control is a fast-acting control loop, the time taken for the process variable (PV) line to reach the setpoint (SP) line was quite fast which is below 1 minute compared to the level control that took longer time which is more than 10 minutes for the process variable (PV) line to reach the setpoint (SP) line.

4. Conclusion

Based on the achieved results, it can be concluded that the values of derivative time (T_d) can give positive and negative influences towards the level and flow control. This is because, higher number of derivative time (T_d) can caused unstable performance of process variable (PV) for flow control but good performance of process variable (PV) for level control. The performance of the process variable (PV) can be measured by the number of oscillation present from the results. Besides, the increased value of derivative time (T_d) can make the level and flow control to react quickly if there is a change in setpoint (SP) and load change since derivative time (T_d) is for prediction horizon. Moreover, PID flow control exhibit an active oscillation when the derivative time (T_d) increased. This is because flow is a fast-acting control loop that consists shorter time constant. Meanwhile, PID level control produce minimum oscillation due to slow acting control loop that consists longer time constant. Therefore, the time taken for the process variable (PV) to reach the setpoint (SP) in PID flow control is 1 to 2 minutes which is faster than PID level control. Several recommendations can be done to accomplish decent outcome for this study such as below:

i. The performance of the process variable (PV) for level and flow control can be improved by tuning the PID controller. This is because a good tuned of PID controller can be used well in many complicated processes. There are several methods of tuning such as the Ziegler-Nichols tuning method and Cohen-Coon tuning method.
ii. The reading of process variable such as flow transmitter and level transmitter can be more accurate by calibrating. Calibrate is commonly used to ensure the reading of a measurement instrument are consistent.
iii. To use the PI controller for flow control since the derivative action in PID controller is useless as flow control is a fast-acting control loop.

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