IMPLEMENTATION OF PID CONTROLLER IN CASCADE MODE FOR LEVEL CONTROL OF A TWO-TANK SYSTEM

by

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Dissertation Submitted In Partial Fulfillment of
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CERTIFICATION OF APPROVAL

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TRONOH, PERAK

DECEMBER 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(NORHASHIMAH LAILI BINTI MOHAMAD ARIFIN)

ABSTRACT

This report discusses the approach used in level controlling of two-tank system. The controller that will be used for this implementation is cascaded PID Controller. The equipments that involve in this project are Mobile Pilot Plant and cascaded PID controller. The controller that will be used is Yokogawa Controller YS170; dual loop programmable controller. Details on the controller is been discussed in this report. The purpose of this project is to improve the efficiency of level control for two tank system by implementing the system in cascade mode rather than in single-loop mode. The level inside the plant cannot be controlled because the plant is meant to control the flow rate of the fluid. External level controller will be attached to the plant for controlling the level of fluid inside the tank. Study on the wiring diagram of the Mobile Pilot Plant is required to trace the correct path for connection of external level controller (Yokogawa YS170) to the pilot plant. Besides that, the study on the wiring diagram of the pilot plant is to understand the signal transmission from the field to the control panel. For Mobile Pilot Plant, the level *measurement is zero-level type*. The position of the transmitter and the tank is at equal zero level. Experiments in single-loop mode had been done and PI Mode Controller gave the best performance. Single-loop mode and cascade mode's performance will be compared. The configuration for cascade mode is still under testing. A lot of study has been done regarding Yokogawa controller and operation for cascade mode. Besides that, some learns on regarding level measurement and the basic concept to the implement the PID controller for this project also been done.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Graceful and the Most Merciful,

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

The ***Mobile Flowmeter Calibration Trainer (Pilot Plant)*** (see Figure 1) is designed and developed for liquid-phase flow measurement, calibration and control usage. There are a few experiment been conducted in order to enhance the understanding of the application related theories and the various process to control the level of the tank. The Mobile Pilot Plant is made up of a Buffer Tank (VE100), Calibration Tank (VE200), various instrumentations, process pumps and a set of interconnected process pipelines. Liquid is pumped from the Buffer Tank through three different flowmeters (Coriolis, Vortex and Orifice) and a pneumatic control valve.

Figure 1: SimExpert Model: SE231B-21 Mobile Trainer

In order to control the level of the two tank system, it is necessary to have level transmitter, level switches, level indicator and level sensor. Level Transmitter is provided for the measurement of liquid level in the Calibration Tank. This level has been calibrated against the mass of water in the Calibration Tank. The accuracy of various flowmeter can be tested.

For Level Switches, there are two level switches provided in the plant, one for each tank. Each level switch is in-turned equipped with a high and a low level contact. These level switches are used in the plant interlocks to protect the operation of the pumps and to prevent overflow of liquid from the tanks. Level Indicator is a digital indicator that is provided for the display of Calibration Tank Level. High and Low level alarms are provided to implement interlocks for certain experiments. (Level Alarm High, LAH and Level Alarm Low, LAL)

Level Sensor consists of three stainless steel rods of High-High (HH), Low-Low (LL) and common is employed to detect the liquid level in a container (tank) that gauges only a specific level, either to detect high level alarm (LAH) or low level alarm (LAL). Once the level sensor detects the specific alarm, pump will stop the liquid flow of the Buffer Tank and the Calibration Tank consequentially. The reading of the Calibration Tank level (in mm) will be displayed at digital Level Indicator, which located at control panel.

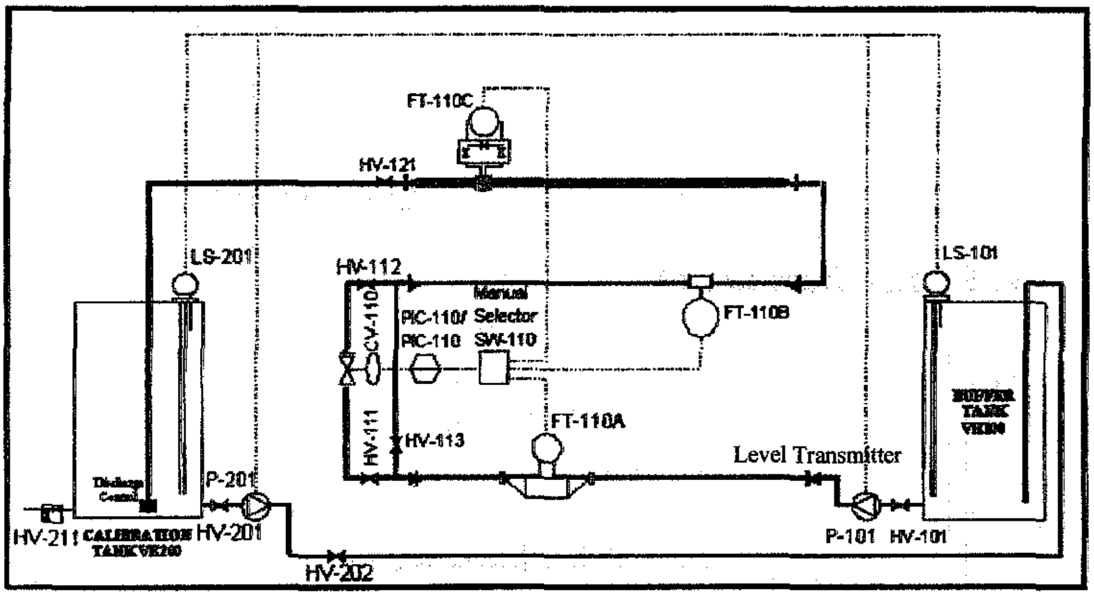


Figure 2: Flow Diagram of the Mobile Pilot Plant

Cascade PID Controller is implemented throughout this project. The purpose of cascaded PID controller is to increase the control performance in terms of efficiency from the previous project which is using two controller techniques; PID

Classical and Modified PID. Yokogawa Controller YS 170 will be used in this project. It is a programmable controller and details on this controller will be discussed in Chapter 2. Two Yokogawa controllers will be used and arranged in cascade mode. One controller will be controlling the flow of the water and another one will be controlling the level of water inside the tanks.

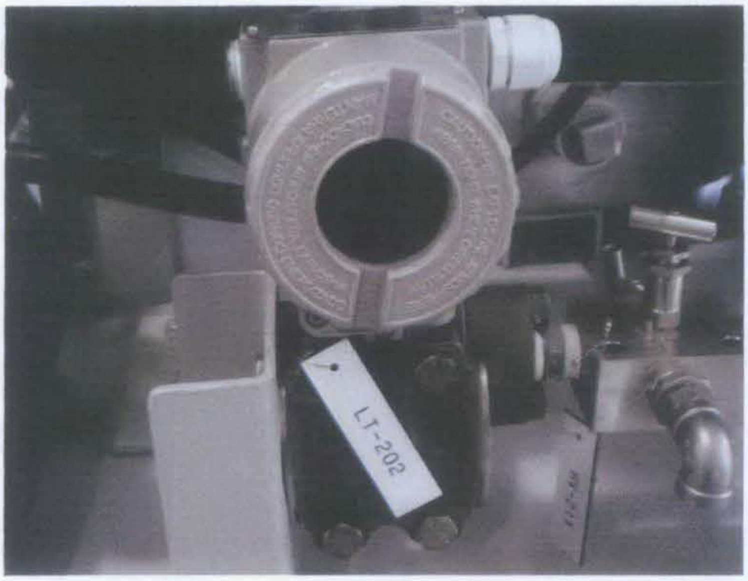


Figure 3: Level Transmitter (LT-202)

1.2 Problem Statement

In Mobile Pilot Plant, the liquid is pumped from the Buffer Tank through three different flowmeters and a control valve to the Calibration Tank. This project is to control the level of two-tank system, but there are no existing controllers that control the water level inside the tank. The system is limited only manipulating the flow control. The controller has to maintain stable levels in the tanks despite of flow variations from the Buffer Tank to the Calibration Tank. The level of water only can be measured, not be controlled because there is only level transmitter being attached to the mobile pilot plant.

Previously, a new controller had been added in order to replace the existing controller. For this project, the aim is to improve the efficiency of the system by cascading two PID controllers instead of one controller. Formerly, it only involves with single-loop mode and it is enable one operation running at one time; either level or flow control. Every time that there are any changes with the variables for different types of controls, the wiring will need to be change and this creates difficulties and errors along the experiment.

1.3 Objective

The main objectives of this project are:

- To implement level controller for controlling the liquid level inside the two tank system.
- To illustrate the application of theories and to enhance the understanding of the level control.
- To identify the best way to increase the efficiency of level measurement by implementing cascade mode to the controller using the same method process parameters, tuning parameters and controller mode of the overall system.

1.4 Scope of Study

The scope of study for this project is to control the level of the liquid flow between the two tanks by using cascaded PID Controller technique. Learning on Plant Process Control System (PPCS) and Industrial Automation Control System (IACS) courses are required for this project. The fundamental of process control principle, control system and feedback operation are been discussed in this course.

For better performance, in dealing with single-loop operation, a selector switch is constructed to be placed at the control valve. By constructing selector switch circuit, the change in the operation is more efficient and can prevent errors. The explanation about selector switch will be discussed in Chapter 2. The study on the level controlling system and its implementation to two tank systems is to be completed within approximately one year (two semesters). The first semester involves research on types of level measurements, types of controllers, constructing the selector switch circuit and cascading the two PID controllers.

It will involve with the implementation of the controllers to the plant. When the hardware implementation has completed, the testing on the plant will be done. Testing for single-loop mode and cascade mode will be done and the results for each mode will be compared. Based on the result obtained, improvement made to the system in order to improve its efficiency.

CHAPTER 2

LITERATURE REVIEW

2.1 Yokogawa Controller (YS 170) [3]

In this project, Yokogawa Controller YS170 will be used for level controlling of two-tank system. YS170 is a dual loop programmable controller. There are two controllers will be used throughout this project, one to control the level and another will control the flow. These two controllers will be connected in cascade mode. There are three modes of operations; Proportional, Integral and Derivative (see Figure 3) A Proportional-Integral-Derivative controller is a generic control loop feedback mechanism widely used in industrial control system. This is a type of feedback controller whose output, a control variable (CV), is generally based on the error between some user-defined set point (SP) and some measured process variable (PV).

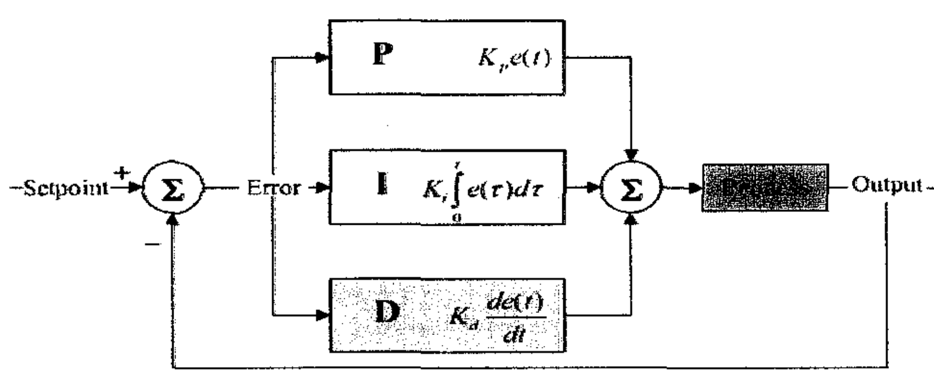


Figure 4: Block Diagram of PID Controller

PID controller job is to maintain the output at a level so that there is no difference (error) between the process variable (PV) and the set point (SP). Once the PID controller has the process variable (PV) equal to the set point (SP), a good PID controller will not vary the output. Besides, the characteristic of PID controller is shown in **Table 1.** *Proportional* value determines the reaction to the current error, the *Integral* determines the reaction based on the sum of recent error and the *Derivative* determines the reaction to the rate at which the error has been changing.

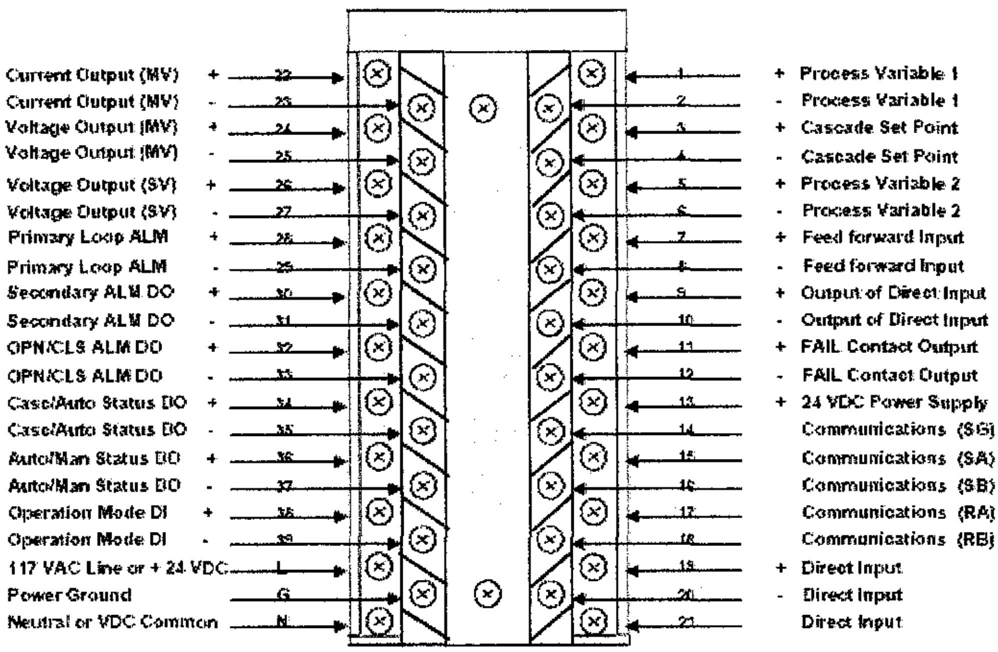


Figure 5: YS170 connection in cascade mode

The manual of YS170 Yokogawa controller is studied in order to get familiar and understand the interface of this controller. The YS170 is programmable controller, whereby the analog and discrete inputs/outputs can be assigned according to the function. **Power Input Connections:** YS170 controller incorporates a universal automatic sensing power supply (P/N E9766YA); e.g. 110AC or 240VDC can be applied to the same power supply card. If the instrument was specified for 220VAC operation, power supply card P/N E9766YR was installed. Figure 4 shows the connection at the back of YS170. The associated pins will be tapped at specific point at the pilot plant.

Table 1: The characteristic of PID Controller

CL RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
K_p	Decrease	Increase	Small Change	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_d	Small Change	Decrease	Decrease	Small Change

Table 2: The characteristics for each PID controller mode

PROPORTIONAL (K_c)	INTEGRAL (T_I)	DERIVATIVE (T_D)
• Correction proportional to error • It operates with a non-zero offset. $MV(t) = K_c E(t) + I_p$ $G_c(s) = \frac{MV(s)}{E(s)} = K_c$ Kc = Controller Gain I_P = Constant /Bias	• The 'persistent' mode • It ensures that the controller archives zero-offset. $MV(t) = \frac{K_c}{T_I}\int_0^{\infty} E(t')dt' + I_I$ $G_c(s) = \frac{MV(s)}{E(s)} = \frac{K_c}{T_I}\frac{1}{s}$ T_I = Controller Integral Time I_I = Constant/ Bias	• The 'predictive' mode • Yields a non-zero offset (time taken shorter) $MV(t) = K_c T_D \frac{dE(t)}{dt} + I_D$ $G_c(s) = \frac{MV(s)}{E(s)} = K_c T_D s$ T_D = Controller Derivative Time I_D = Constant/ Bias

The equation for PID controller:

$$E(t) = SP(t) - CV(t)$$

$$MV(t) = K_c\left[E(t) + \frac{1}{T_I}\int_0^{\infty} E(t')dt' - T_D\frac{dCV(t)}{dt}\right] + I$$

Where; E (t) is the error of the system

SP (t) is the set point of the system

CV (t) is the control variable of the system

MV (t) is the manipulated variable of the system

Kc is the feedback controller gain
T_i is Integral time
T_D is the Derivative time
} Tuning constant

The output from these three terms, the proportional, the integral and the derivative terms are summed to calculate the output of the PID controller. Tuning constants are adjustable and affect the dynamic performance of the system.

2.2 Cascade Controller

A cascade control combines two feedback controllers, with the primary controller's output serving as set point of secondary controller [1]. The design should conform to the design criteria in table below.

Table 3: The criteria of cascade mode controller

Cascade control design criteria
Cascade control is desired when
1. Single-loop control does not provide satisfactory control performance.
2. A measured secondary variable is available.
A secondary variable must satisfy the following criteria;
1. The secondary variable must indicate the occurrence of an important disturbance.
2. There must be causal relationship between the manipulated and secondary variables.
3. The secondary variable dynamics must be faster than the primary variable dynamics.

Cascade control is one of the most successful methods for enhancing single-loop control performance. It reduces both the maximum deviation and integral error for disturbance responses. Cascade uses an additional measurement of a process variable to assist in the control system. Cascade control uses an additional, "secondary" measured process input variable that has the important characteristic that it indicates the occurrence of the key disturbance [1].

The important feature in the cascade structure is **the way the controllers been connected.** The output of the primary loop's controller will adjust the set point of the secondary loop's controller in the cascade structure. The secondary controller set point is equal to the primary controller output. Thus, the secondary controller loop is essentially the manipulated variable for the primary controller loop. For this project, level controller will be the primary loop and the flow controller as secondary loop. Flow has much faster response compared to level.

The secondary variable must satisfy three criteria;

1. It must indicate the occurrence of an important disturbance.
2. Must be influenced by the manipulated variable.
3. The dynamics between the final element and the secondary must be much faster than the dynamics between the secondary variable and the primary controlled variable.

In cascade's connection, the correction towards the error is done faster and resulting better performance of the system. The secondary loop must be faster than the primary loop in order the get a better result. As in practice, the flow will be assigned as secondary loop in this project meanwhile level is for primary loop.

Control theory of cascade loop deals with the behavior of dynamical systems. The desired output of a system is called the *reference*. When one or more output variables of a system need to follow a certain reference over time, a controller manipulates the input to a system to obtain the desired effect on the output of the system.

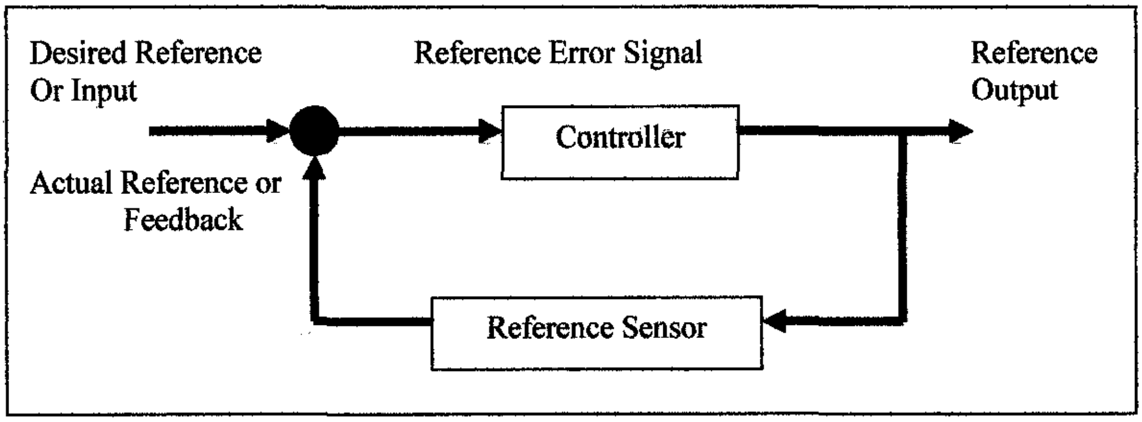


Figure 6: Block Diagram of Control Loop

Theoretically, the effectiveness of cascade structure can be known by calculating its performance using simulation (MATLAB) and compare with single-loop control performance of the same systems.

2.3 Operation of Mobile Pilot Plant (SE231B-21)

The understanding on the operation of the plant is achieved by running the Mobile Pilot Plant. The plant is mainly used to control the flow of the liquid inside the tank. There is also a level indicator to display the level of the liquid inside the tank. The process of transferring liquid from tank VE-100 to tank VE-200 and from tank VE-200 to tank VE-100 been observed [5]. The steps taken to operate the Mobile Pilot Plant are shown in the flow chart below.

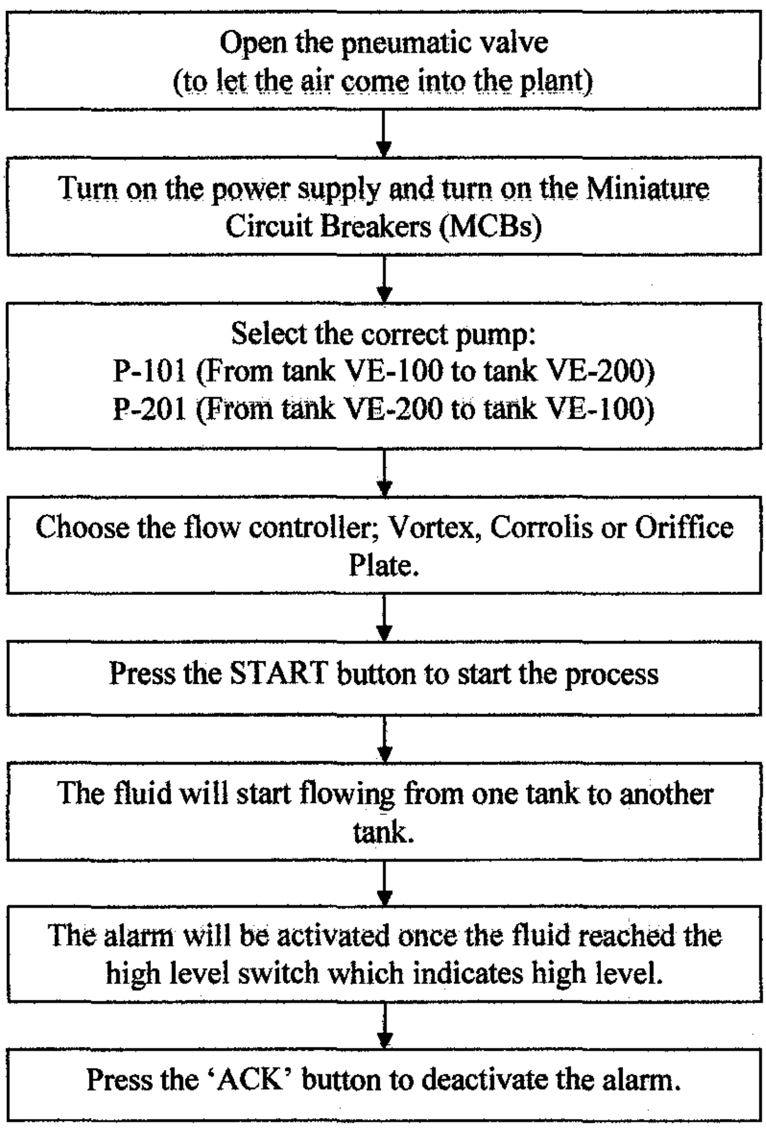


Figure 7: The process flow for Mobile Pilot Plant

The flow of the fluid inside the tank can be controlled by adjusting the opening of the hand valve from 0% to 100%. Hand valve, HV-100 will be opened and HV-101 will be closed when transmitting fluid from tank VE-100 to tank VE-200. Hand valve HV-101 need be closed in order to avoid the fluid to flow back into tank VE-100. HV-100 will be closed and HV-200 will be opened when transmitting fluid from tank VE-200 to tank VE-100. More details on the operation of mobile pilot plant are elaborated in Chapter Four.

At the Mobile Pilot Plant, there are three flowmeters that been used to measure the flow of the water inside the plant. There are Coriolis Flowmeter, Vortex Flowmeter and Orifice Flowmeter. While performing the experiment, only one flowmeter will be choosing to be the main flowmeter. The reading of the chosen flowmeter will be displayed at Flow Controller FIC-110 at the plant.

Coriolis Flowmeter is the Master Flowmeter. It operates on the principle of Coriolis force. Coriolis force is an artifact of the earth's rotation. With the principle, mass flow rate can be measured independent of changes in fluid density and temperature. It is therefore a true mass flowmeter. Coriolis are capable of measuring true liquid Mass flow, volumetric flow and liquid density.

Vortex Flowmeter will be tested against the Master Flowmeter. It operates on the principle of vortices created when a bluff body is present in the flow steam (like a flag pole). It is a volumetric flowmeter whose flow measurement is dependent on the density of the flowing fluid. The motion of the fluid swirling rapidly around a center is called a vortex. The speed and rate of rotation of the fluid are greatest at the center, and decrease progressively with distance from the center.

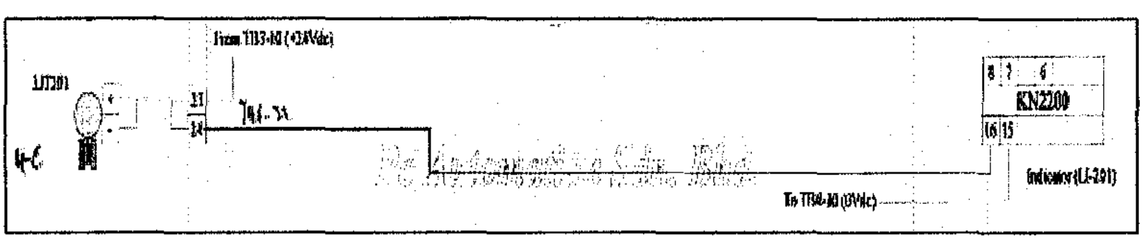
Orifice Assembly and d/p Flowmeter also will be tested against the master flowmeter same as vortex flowmeter. It operates on the principle of *pressure drop due to an orifice plate in the flow stream.* The difference in pressure between the upstream and downstream of the orifice plate is proportional to the square of volumetric flow across the orifice. It is a volumetric flowmeter whose flow measurement is dependent on the density of the flowing fluid [5].

An orifice plate is a device used to measure the rate of fluid flow. It uses the same principle as Bernoulli, which there is a relationship between the pressure of the fluid and the velocity of the fluid. When the velocity increases, the pressure decreases and vice versa. An orifice plate is basically a thin plate with a hole in the middle, and usually placed in a pipe in which fluid flows.

2.4 Wiring Diagram

The objective of studying the wiring diagram of mobile pilot plant is to understand the type of signal being sent from the field instrument, and the connection inside the plant. The signal sent from the instrument field is in the form of analog signal (5-20 mA) and is converted to digital signal at the controller part (1 to 5V).

The connection from the level transmitter to the terminal block is been traced from the wiring diagram. This is done in order to find the correct path to tap the connection for level controller to the plant. Inside LCP-Loop Drawing, it has three parts; the field, the panel-internal and panel-front.



Field Panel-Internal Panel-

Front

Figure 8: LCP Drawing for LIT201 (Level Transmitter)

From the LCP Loop Diagram, the LIT201 is connected to Terminal Block 6 (TB6) at point 23 and 24. At TB6, there are resistor 250 ohm been connected to it. The purpose of this resistor is to convert the 4-20mA signal to 1-5V signal. The signal from the field instrument is in current. By introducing 250 ohms, the signal will be converted to voltage. The level indicator at the panel front will received 1-5V signal from the field. The 250 ohm is a high precision resistor, where the accuracy of this resistor is plus minus 0.01. Figure 7 shows the high precision resistors that been used to convert from analog to digital signals.

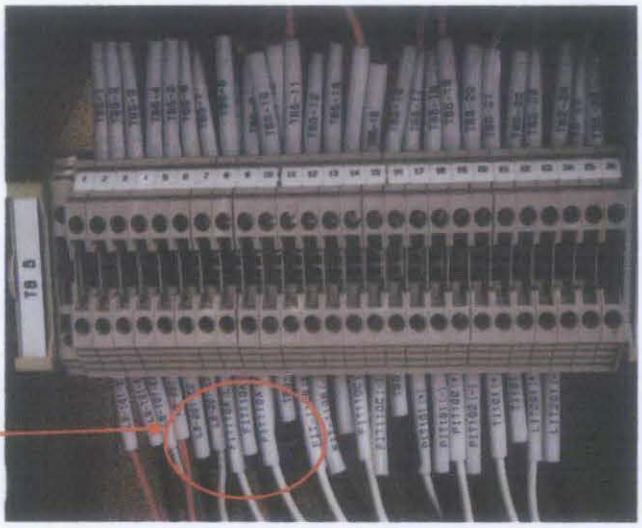


Figure 9: Terminal Block 5

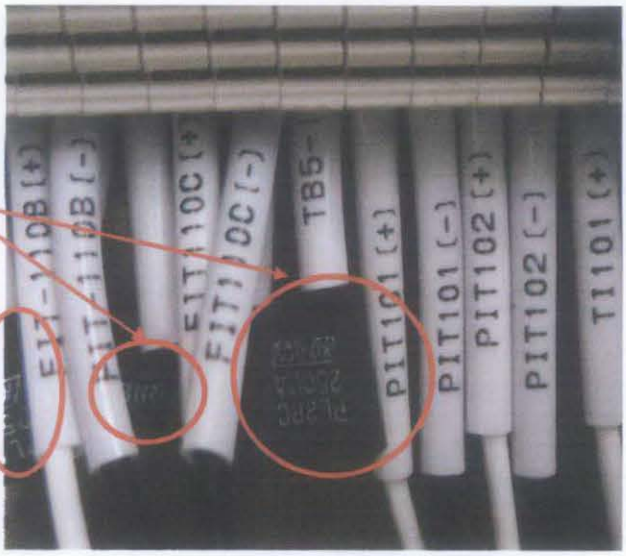


Figure 10: High Precision Resistors

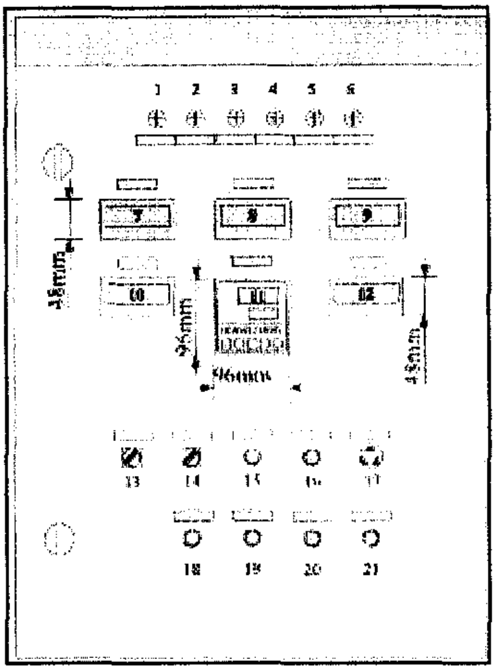


Figure 11: Local Control Panel for external layout

Figure 10 shows the Local Control Panel for external layout [5]. The components that attached to the Local Control Panel including:

- AC Power On
- DC Power On
- Coriolis Flow Indicator
- Vortex Flow Indicator
- Orifice Flow Indicator
- Flow Controller
- Acknowledgement Push Button
- Emergency Push Button

2.5 Selector Switch

This switch is attached to the control valve while performing the single-loop testing. This switch is function to switch the plant from *level control to flow control* or vice versa easily. The purpose of this selector switch is to avoid the deficient environment among FYP students since this plant involves with single-loop mode and it is enable only one operation running at one time.

The construction of the selector switch is taught by the laboratory technician. This selector switch will be used to control the control valve at the plant. The main equipments that are needed are regular toggle switch and relay 24V [7]. This switch is only be used in single-loop operation. In cascade, this switch is not needed.

2.6 Level Measurement

There are three types of level measurements (zero level, zero elevation and zero suppression) that are categorized accordingly to the position (level) of the level transmitter to the tank. For this pilot plant, it is *zero-level type* of level measurement being since the position of the transmitter and the tank is at equal zero level. For *zero elevation* the transmitter is positioned at higher level than the base of the tank and for *zero-suppression*, the pump is located at lower level than the tank. The position of the transmitter affects in the calculation which takes pressure into consideration.

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

The main objective of this project is to implement PID controller for level control and make some improvement on the efficiency of the system by running it in cascade mode.

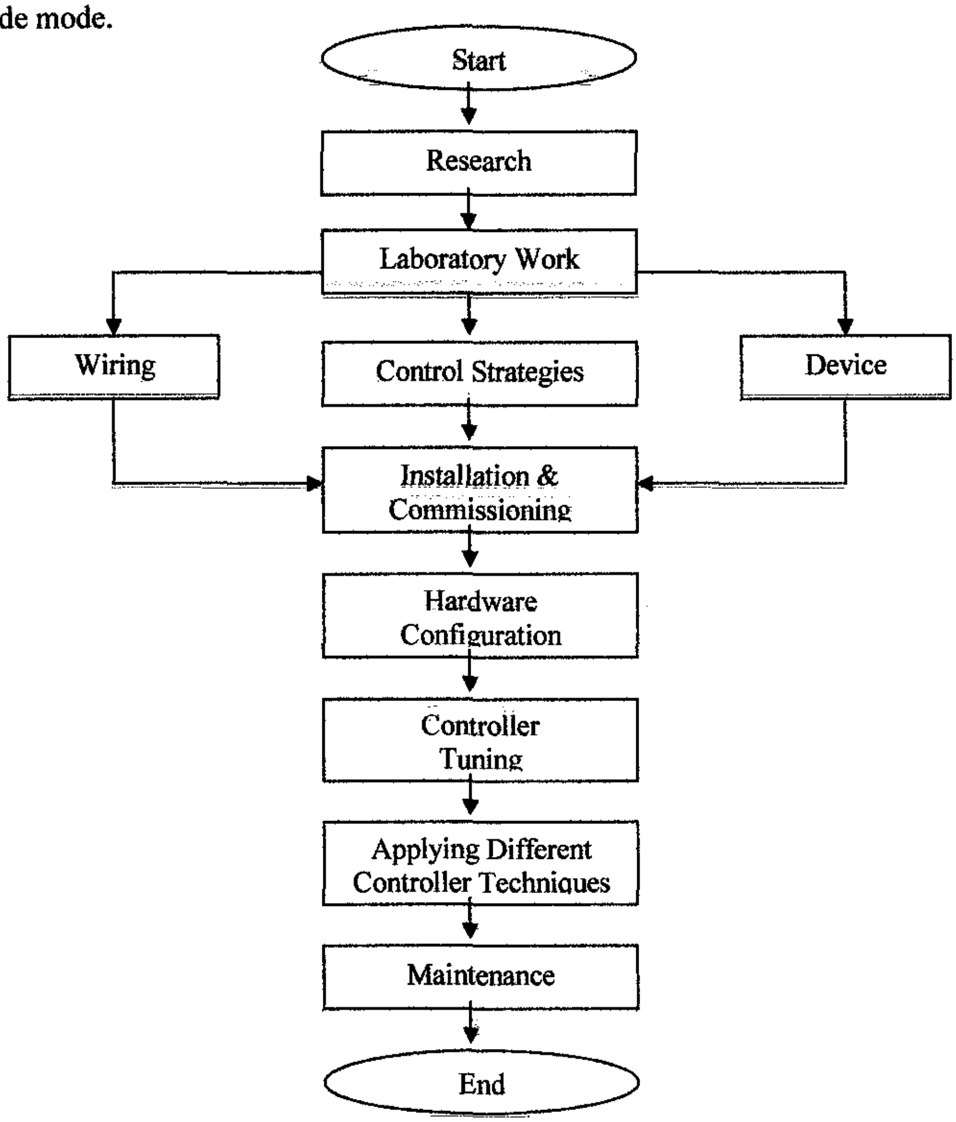


Figure 12: Flow chart representation of the project implementation

Researches about chosen topic
The studies concerns on level control and applying cascade mode to the system instead of single loop mode.

Carry out several experiments towards the overall operation of the plant
To enhance understanding on the plant's operation and to select the flowmeter that can give the best performance (accurate calibration) as the reference flowmeter.

Implement Single Loop Mode Operation
Find the correct point to append the single-loop controller to the pilot plant.
Implement the selector switch to the plant in single-loop mode.
Find the mode of controller that gives the best performance and obtain the coefficients of the mode by using try and error method

Attach flatbed chart recorder to the plant
This recorder is use to record all the data or output from the controller for calculation and observation. The trend of Process Variable (PV) and Set Point (SP) are been displayed clearly.

Implement Cascade Mode Operation
Do the wiring for cascade mode at the controller. Change the configuration setting at the controller according to the manual. Find the mode of controller that gives the best performance of cascade mode and obtain the coefficients of the mode by using try and error method.

Controller Tuning
Provide self-tuning function automatically in order to obtain optimum values of PID parameters.

Implement different type of controller technique
Compare and analyze the difference between single-loop mode and cascade mode performance.

Figure 13: Specification of overall tasks and project phases

Trial and error method been used in order to fine tune the parameters in single-loop. All the coefficients for the controllers are determined using this method. Each and every time random values were key-in inside the controller, the response of the Manipulated Variable towards the performance of the system been observed and analyzed.

3.1.1 Trial and Error Method

In both modes, Single-loop and cascade mode, trial and error method will be used in order to obtain the controller's mode parameters such as Proportional Gain (Kp), Integral Time (Ti) and Derivative Time (Td). This method is easier to implement than ultimate gain sensitivity test. Ultimate sensitivity test is not preferable because the parameters will be based on constant that been obtained from the graph. There is only flatbed recorder available to give out the graph from the system. The scale from this recorder is not very accurate and will lead to error in calculating the parameters. Before performing this testing, the normal range of Proportional Gain (Kp), Integral Time (Ti) and Derivative Time (Td) been identified and the value that obtained from the experiment will be referred to those values as reference.

3.2 Operation of Single-Loop Tuning

a. Ensure the air supply for the control valve has been connected.
b. Turn on the MCBs inside the control panel.
c. Connect the level controller and flet bed recorder to the pilot plan.
d. Turn on the power supply of the pilot plan.
e. Increase the opening of the control valve from the level controller to 50%. Set the SV1 =5 mm H_20.
f. Turn on pump P101 and P201. See the response between PV abd SP and manipulate the opening of control valve. After PV settles at PV's value, change the controller from Manual mode to Auto Mode.
g. Increase SP from 5 to 10.03 to 15.01 and the response between SP and PV will be recorded by the recorder.

3.3 Control Loop Performance Characteristics

The control design process begins by defining the performance requirements. Control system performance is often measured by applying a step input function at the Set Point (SP) and then the Process Variable (PV)'s response towards the step change been recorded. Commonly, the response is quantified by measuring defined waveform characteristics as shown in *Figure 14.*

- *Rise Time* is the amount of time taken by the system to response from 10% to 90% of the steady-state value (final value).
- *Overshoot* is the amount of process variable that exceeds the steady-state value.
- *Settling time* is the time required for the process variable to settle within a certain percentage of the final value.
- *Steady-state error* is the difference between the final values of process variable with set point value.

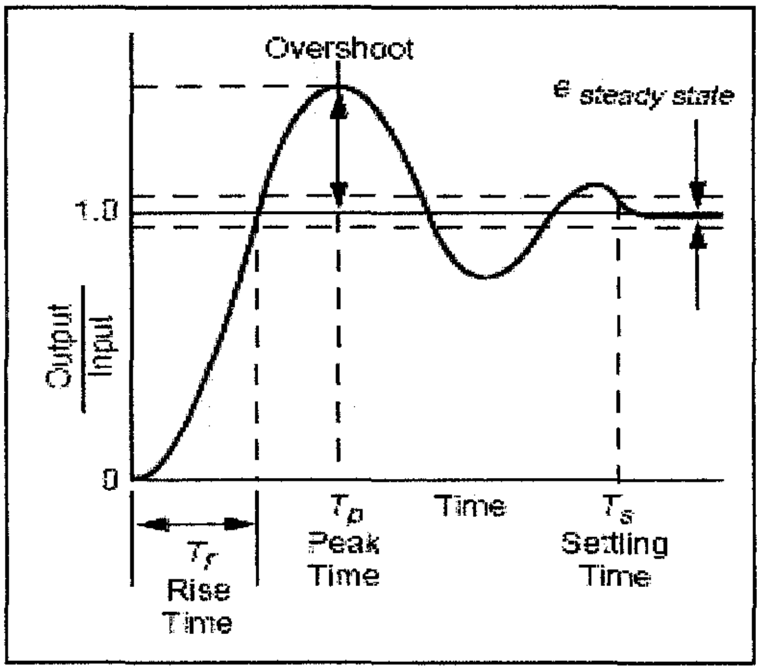


Figure 14: Response of a typical PID control loop performance

3.4 Cascade Connection

There are two loops in cascade mode. The inner loop is the disturbance to the system [1]. The outer loop is our main process measurement that needs to be control. For this project, **level will be the primary loop** and **flow will be the secondary loop.** In Chapter 4, disturbances for level are discussed and one of the disturbances is the flow rate. Therefore, flow is selected to be the secondary loop of this cascade mode configuration.

3.5 Tools

3.5.1 Equipment /Hardware

- The Mobile Flowmeter Calibration Trainer (Pilot Plant)
- Yokogawa Single Loop Programmable Controller YS170
- External Variable Resistor
- Flatbed Recorder Chart
- Jumper Wire
- Toggle Switch
- Electrical tools-aid (screwdriver, cutter,etc)

3.5.2 Software

- Matlab Simulink

CHAPTER 4
RESULT AND DISCUSSION

4.1 The Performance of Different Flowmeters

Several experiments on comparative study of different flowmeters had been carried out to observe the performance between Coriolis (110A), Vortex (110B) and Orifice (110C) Flowmeter. The level measurement (mm) is taken for duration of three minutes of liquid flow rate from the buffer tank to the calibration tank. The results are shown below in Table 4.

Table 4: The differences of performance between three flowmeters

MV (%)	CORIOLIS		VORTEX		ORIFICE		LEVEL ($mm\ H_2O$)
	FIZ A 110 A	TOT A 110 A	FIZ B 110 B	TOT B 110 B	FIZ C 110 C	TOT C 110 C	3mins
20	12.20	37.88	12.22	36.81	0.00	0.00	
40	29.50	89.19	29.33	86.81	27.49	82.53	19.21
60	40.96	124.52	40.57	121.99	38.41	116.92	26.96
80	43.55	132.87	43.28	130.56	41.23	124.69	28.61
100	43.54	132.79	43.39	131.14	41.28	124.54	28.76

Remarks:

- Minimum perceptible flow measurement : 12.20 L/min
- Maximum perceptible flow measurement : 43.54 L/min
- Best performance of flowmeter : Coriolis Flowmeter
- Inaccuracy flowmeter : Orifice Flowmeter

Table 5: Different Flowmeters Performance with Level

MV (%)	CORIOLIS		VORTEX		ORIFICE		LEVEL
	FIZ A	TOT A	FIZ B	TOT B	FIZ C	TOT C	
40	29.50	89.19	29.33	86.81	27.49	82.53	19.21
45	32.54	101.34	32.25	98.95	30.27	93.99	21.39
50	35.95	109.78	35.43	106.09	33.43	101.70	23.39
55	38.60	119.08	38.23	114.96	36.23	109.87	25.11
60	40.76	130.85	40.53	122.33	38.25	116.83	26.43
65	42.61	126.78	42.25	123.19	39.73	118.95	27.13
70	43.32	131.87	42.85	129.76	40.43	123.73	28.24
75	43.47	134.86	43.15	132.27	40.79	126.69	28.77
80	43.59	130.60	43.28	128.15	41.23	122.72	**29.09**

Figure 15: Level Measurement versus Valve Opening

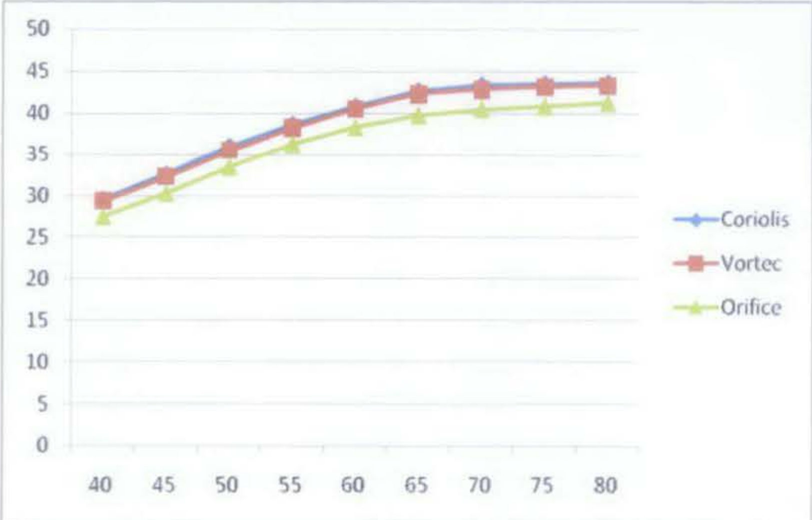


Figure 16: Flow Measurement versus Valve Opening

4.1.1 Analysis of Data

This experiment was conducted to get better understanding on the performance of different flowmeters; Coriolis, Vortex and Orifice and to observe the correlation between the flow rate and the level measurement. In level control, it is not necesary to use all those three flowmeters to run this project. Coriolis flowmeter will be selected as Master Flowmeter due to its better efficiency .

The liquid level had been measured for different valve opening and the time taken was three minutes. The maximum level of the liquid is **30mm H_2O over 50mm H_2O** calibrated water according to the setting from the controller. However, it is difficult to achieve this target value since there is propagation delay between the signals which had been transmitted from the level transmitter to the digital level indicator. The highest level that can be achieved from the experiment is 29.09 mm H_2O. There are several factors that affects the water level inside the tank.

The major factor for water level inside the tank is the **flowrate** of the water flowing inside the tank itself. There are three flowmeters that been used in the tank to measured the flowrates of the water flowing inside the tank. There are Coriolos Flowmeter, Vortex Flowmeter and Orifiice Flowmeter. Besides that, the opening of the **hand valve** located before the control valve also effect the level of water inside the tank. Other disturbance to the level is **atmosphere pressure** inside the tank. Other disturbance is **another path of** pipe before the control valve.

4.2 Proportional-Integral (PI) Mode for Single Loop Testing

There are several methods to obtain which mode of controller gives the best performance. The testing is start by finding the suitable value for PB (Proportional Band). This is the gain needed for *Proportional Mode (P-Mode)*. Then for *Proportional-Integral Mode (PI-Mode)* by finding the coefficient for Proportional Band and Integral Time (Ti). Then, the performance between these two modes is compared and PI mode seems to give better performance than P mode.

4.2.1 Proportional Mode

In proportional mode, only value of Proportional Band is required. By using trial and error method, value for PB that makes the PV near enough to the SV is 40mm H_20. In P Mode, the PV does not equal to the SP value. The error in this mode is proportional to the value of PB. In order to obtain the closest value of PV to SP, the controller gain, PB been varied by using try and error method. The controller's gain is proportional to the error towards the performance of the system. Up until the 8th trial, the final value of the system still does not equal to the set point of the system. This is one of the characteristic of P-controller. There is a large error for this controller, so this is not the best controller for this system.

Table 6: Trial and Error for P Controller

Trial	PB	Ti	Td	Comment
1	100	9999	0	Not stable
2	60	9999	0	Not stable
3	50	9999	0	Not stable
4	45	9999	0	Not stable
5	35	9999	0	Stable
6	30	9999	0	Stable
7	25	9999	0	Stable
8	20	9999	0	Stable

4.2.2 Proportional-Integral Mode

Table 7 shows the percentage opening for each hand valve that attached to the plant. The setting above need to be followed in order to obtain required performance of level control.The coeffient obtained is as shown below.

Table 7: Percentage Opening of Valves

Hand Valve	% Opening
HV 202	40%
HV 112	100%
HV 111	80%
HV 121	80%
Before P101	100%

Table 8: Settings for PI Mode

Proportinal Band (PB)	30%
Integral Time (Ti)	8 seconds
Initial Set Point	10.03 mm H_20
Final Set Point	15.01 mm H_20
Maximum Level	25.00 mm H_20

When the opening of control valve been set to 100%, the maximum level is 25mm H_20 (during Manual mode). Figure 16 shows the response of level control after according to the setting in Table 7.

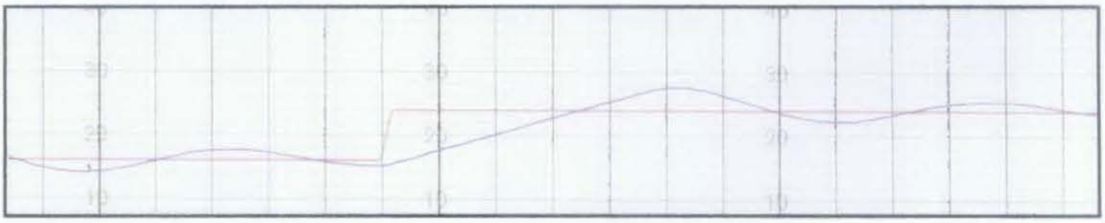


Figure 17: Response between PV and SP with respest to time

Red Line : Set Point (SP)

Blue Line : Process Variable (PV)

Table 9: Trial and Error for PI Controller

Trial	PB	Ti	Comment
1	100	20	Not stable
2	70	20	Not stable
3	60	20	Not stable
4	50	15	Stable
5	30	12	Stable
6	30	10	Stable
7	40	8	Stable
8	30	8	Stable

4.2.3 Analysis of the Graph

Based on the graph obtained, the response is first-order system with **overshoot of 2.22mm H_2O**. The system's **damping ratio is 0.5**. Time taken for the system to settle is 12 seconds. The two constants that obtained from this experiment will be used to operate the system in cascade mode and compare its performance. In the next stage, level controller will be cascaded with flow controller. For level controller, the PI mode controller gives the better performance of first-order system with overshoot of 2.22mm H_20. From observation, all the flowmeters differs in the size of the pipeline and this is one of the factors that make the flowrate into the tank varies and resulting in different value of level.

Proportional Band is the input span for the system. **PB= (100/Kp)**; where Kp is the proportional gain. While performing this experiment, the initial value that been used in order to obtained the correct PB is by equating PB=1. Which means that we set the proportional, **Kp = 100**. The integral time (Ti) is 8 seconds. When this value been increased or decreased, the system will become unstable. That is why 8 seconds is the best integral time in order for the system to be stable.

4.3 Wiring for Cascade Mode

In cascade mode, two controllers are connected together. One controller will be control flow and another is level. The setting for flow controllers need to be set into cascade mode. The setting for it is available in the Yokogawa User Manual. There are few problems that regarding cascade mode. This matter will be discussed more detailed in discussion part. The main problem of the connection of the controller is the Manipulated Variable in Loop 1 does not equal to the Set Point for of Loop 2. Because of this relationship is not satisfied, the process cannot be proceed.

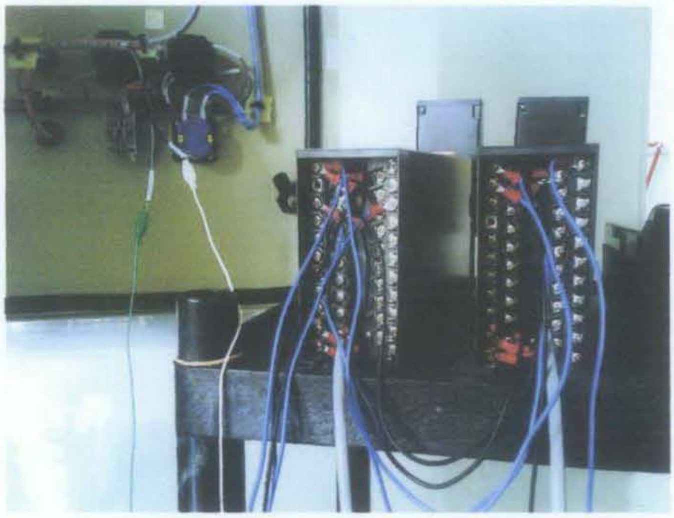


Figure 18: Connection for Cascade Mode (First Trial)

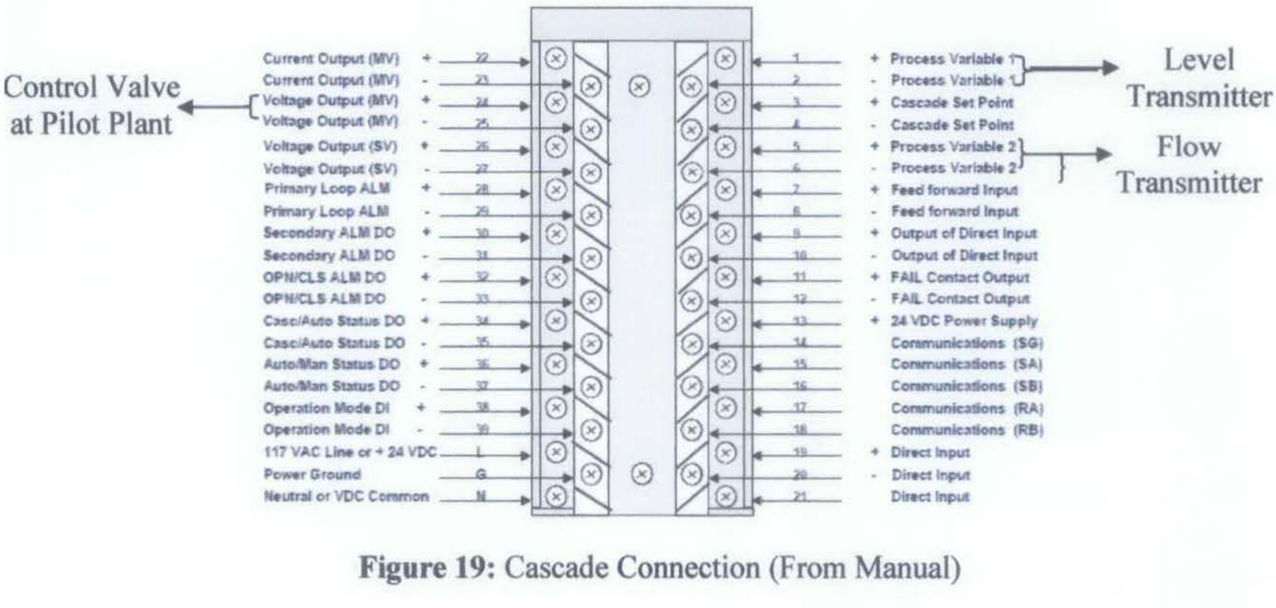


Figure 19: Cascade Connection (From Manual)

Table 10: Configuration inside YS150

Configuration	Display	Selection
Configuration Panel 1	SET	ENBL
	CTL	CAS
Configuration Panel 2	CMOD1	CAS
Configuration Panel 3	DI1F	E-PMV,E-STC, E-O/C
	CSR1	ON
	CSW1	ON

4.4 Recorder

The recorder of flatbed type had been affix to the controller in order for the output to be displayed simultaneously when the plant is running. The chart recorder is an instrument used to record various process and electrical signals. This recorder records data on paper. The paper is passed under a pen and the pen is deflected in proportion to the signal. It has two channels; one is connected to Process Variable (PV) and another is connected to Set Point (SP) of the system. The time base also can be manipulated according to the desired performance.

Figure 20: Flatbed Recorder

4.5 Alarm Implementation for Level Control

Alarm for level control has been implemented for the mobile pilot plant for safety cautions. When the liquid in the calibration tank reaches at certain level, an indication of alarm at the controller will be activated. This alarm indication will alert people around that the tank had reached the maximum or minimum level.

For this mobile flowmeter calibration trainer, the maximum level for the liquid in the calibration tank the calibration tank is 28.76 mm H_2O. The alarm will create High Alarm at 85% and Low Alarm at 15% of the maximum water level.

Table 11: High and Low Alarm Values

PH1	0.85 x 29.09 = **24.73 mm H_2O**
LH1	.0.15 x 29.09 = **4.364 mm H_2O**

Based on table above, the engineering unit PH1 (*High-limit-alarm-set-point for process variable 1*) and PL1 (*Low-limit-alarm-set-point for process variable 1*) are being set accordingly to the limit that has been computed for the alarm to operate.

4.6 Controller Tuning

The open-loop test had been carried out instead of closed-loop tuning method upon considering several problems encountered throughout the experiment. The major problem is the Mobile Pilot Plant which is purposely provided to regulate only the flow. So, there are some difficulties in controlling and measuring the level. Additionally, the liquid volume of the tank is quite immense for the controller to trace the changes in the level while it is increasing or decreasing. Moreover, it is difficult to find the right and suitable hand valve setting for the level to maintain and to observe for its alteration when Manipulated Variable is being changed.

Table 13: Simulation for PID Controller

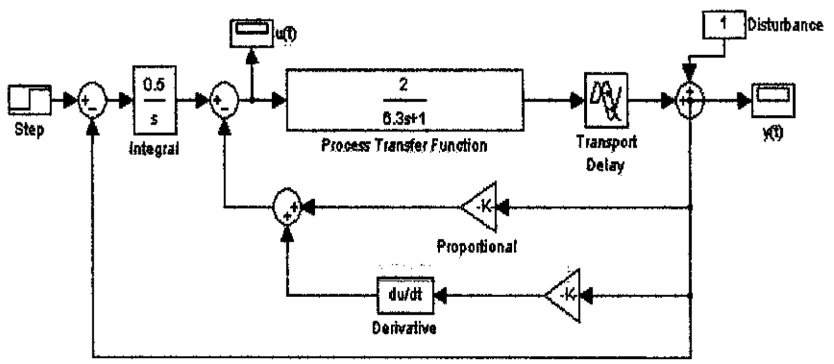
<table>
<tr><th>PID Control</th></tr>
<tr><td>

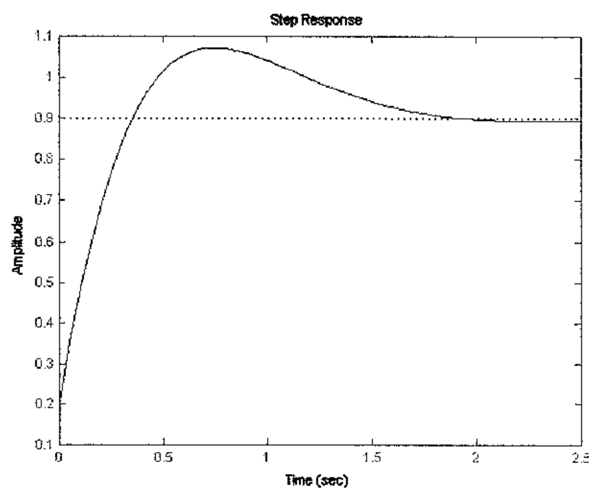
Figure 23: Simulink Block Diagram of PID Control</td></tr>
<tr><td>

Figure 24: PID Control Loop Response</td></tr>
</table>

4.6.2 Discussion on Tuning Result (Trial and Error Method)

The results for PI and PID controller in the Matlab simulations are using the parameters value from trial and error method. The value of P, I and D are the values that optimize this design.

For Proportional + Integral term been applied to the plant, the performance appears better than P term only. This controller provides zero-steady-state offset for an impulse disturbance. The dynamic system is stable; the process variable (PV) settling time is short and the overshoot of the PV past the set point. Nevertheless, after fine-tuning practice, the system managed to achieve quarter decay ratio.

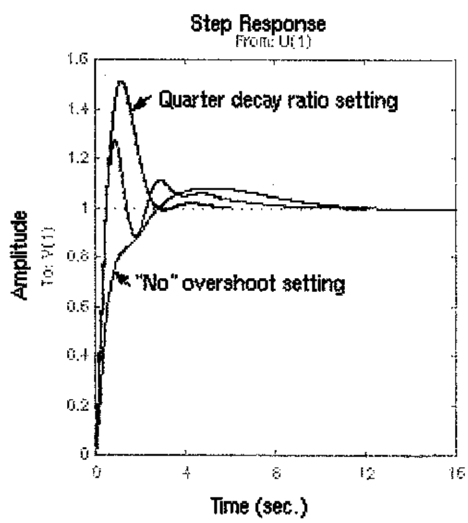


Figure25: Decay Ratio Graph for PI Controller

Theoretically, the contribution from the integral term is proportional to both the magnitude of the error and the duration of error. Summing the instantaneous error over time (integrating the error) gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output. The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain, Ti [1]

The integral term (when added to the proportional term) accelerates the movement of the process towards setpoint and eliminates the residual steady state error that occurs with a proportional controller. However, since the integral term is responding to accumulate errors from the past, it can cause the present value to overshoot the set point value (cross over the setpoint and then create a deviation in the other direction) [1]

From the experiment, the Proportional + Integral + Derivative controller's performance appears bad as the dynamic system is not stable and the process variable (PV) does not achieve zero steady-state offset. In spite of that, it does not show large overshoot since the volume of the liquid in the open tank is quite huge for the response to be more responsive.

Theoretically, the rate of change of the process error is calculated by determining the slope of the error over time (its first derivative with respect to time) and multiplying this rate of change by the derivative gain, Td. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, Td [1]

The derivative term slows the rate of change of the controller output and this effect is most noticeable and makes the final value close to the controller setpoint. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. However, differentiation of a signal amplifies noise in the signal and thus this term in the controller is highly sensitive to the noise in the error term and can cause a process to become unstable if the noise and the derivative gain are sufficiently large.

4.7 Discussion

4.7.1 Problem Encounter

There are some problems that been encountered while completing this project. After experiment on single-loop mode had been done, the construction of cascade mode been done. At first, all the setting stated inside the user manual of the controller had been done including the wiring behind the controllers. There are two controller been used at first, one for flow control and another one is for level control. The connections are as stated below:

Table 14: Cascade Setting I

Flow Controller	Level Controller	Field	Note
Point 3 and 4	Point 22 and 23	-	MV1=SP2
-	Point 1 and 2	Point 15 and 16	PV1
Point 5 and 6		Point 8 and 9	PV2
	Point 22 and 23	Point 1 and 2	Control Valve

After the wiring and setting inside the controller had been done, there are some problems encountered. The Manipulated Variable in Loop 1 equal to Manipulated Variable in Loop 2. Suppose only Manipulated Variable in Loop 2 will response towards the control valve. Besides that, the PV value also cannot be set and the alarm in Loop 1 was triggered. After these wiring does not yields the correct response, some modifications had been done throughout this project. In the first trial, there are two controllers are used to perform this cascade mode.

According to the manual [3], one controller also can perform cascade mode because there are internal connection inside the controller. Then, this project continues with one controller and the wiring for one controller is as shown below:

Table 15: Cascade Settings II

Controller	Field	Note
Point 22 and 23	Internal connection	MV1=SP2
Point 1 and 2	Point 15 and 16	PV1
Point 5 and 6	Point 8 and 9	PV2
Point 24and 25	Point 1 and 2	Control Valve

Various setup of wiring had been done, but the relationship between Manipulated Variable in Loop 1 with the Set Point in Loop 2 still not there. There are some failure occurred inside the controller and make the controller cannot perform in cascade mode. The hardware problem occurred towards the end of the project session and make the result obtained from the controller is not valid.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The level inside the plant cannot be controlled because the plant is meant to control the flow rate of the fluid. External level controller will be attached to the plant for controlling the level of fluid inside the tank. For Mobile Pilot Plant, the level measurement is zero-level type. The position of the transmitter and the tank is at equal zero level. The position of the transmitter affects in the calculation which takes pressure into consideration. At the pilot plant, there is no existed level controller, but it the level of the fluid inside the tank can be known from the level indicator from the control panel.

The performance of single-loop system been tested. The best controller for single-loop mode is proportional-integral controller (*PI-controller*) which gives the best performance compared to Proportional (*P-Controller*), Proportional-Integral-Derivative (PID-Controller) The performance from single loop will be compared with the system's performance in cascade mode. The purpose of this project is to implement level controller inside the plant and improve the efficiency of level control for two tank system by using another technique besides PID Controller. Throughout this project, cascade mode will result in improving the efficiency of the level control system.

The configurations of cascade mode are been tested but there are some problems occurred to the hardware and make the cascade mode not operate properly. This project will be carried out by the next student by applying the technique that had been mentioned earlier.

5.2 Recommendations

At the early stage of the project, it involves single-loop mode, and in this mode, the plant only allows one operation to be operated at one time; either flow control or level control. To change from level control to flow control can easily done by installing a selector switch to the plant. But, there are too many wires around the plant and controller. It is recommended to make a proper wiring for the selector switch to the plant and also short wiring from the plant to the controller. This can reduce the error or transmitting the signals and also can make the work become tidier.

The installation of cascade mode does not complete because of hardware failure. The main problem that occurred is the setting and wiring of the controller. It is recommended to spend more time on finding the correct setting for cascade mode. This project can be carry out by next student in the future. The main concern now is to obtain the correct connection for cascade mode. Try again to contact the supplier and ask for more details on this controller. (UTP asked the supplier for more details.) Try to proceed with controller from other vendor besides Yokogawa. The efficiency of this plant measurement can be improved by install other output storage other that flatbed recorder.

Distributed Control System (DCS) can be implemented in this plant in order to enhance control system of this plant. One central computer can be connected to the plant in order to control overall process of this plant.

REFERENCE

[1] Marlin. 2000, *"Designing Process and Control System for Dynamic Performance"* 2nd Edition.

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[3] Yokogawa M&C Corporation, "Instruction Manual YS 100 Series" 7th Edition

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[6] http://en.wikipedia.org/wiki/PID_controller

[7] http://www.ecircuitcenter.com/Circuits/pid1/pid1.htm

[8] http://www.control.com/thread/1026243937

[9] http://www.control.com/thread/1026188392

[10] http://www.newportus.com/products/techncal/techncal.htm

[11] http://www.expertune.com/artCE87.html

APPENDIX A

Yokogawa Controller YS 170-Single/Dual Loop Programmable Controller

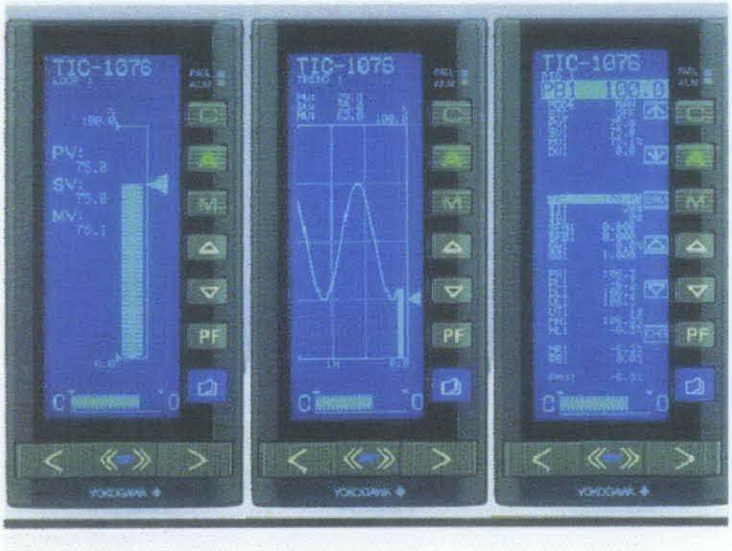

Figure 26: The Yokogawa YS-170

- Remote Set Point (CSV)
- Local Set Point (SV) & Automatic
- Manual Operation of Output
- Increase Set Point
- Decrease Set Point
- Programmable Function Key
- PAGE Key
- Manual Output Keys

Figure 27: Display of FIC-1076

Operation Displays

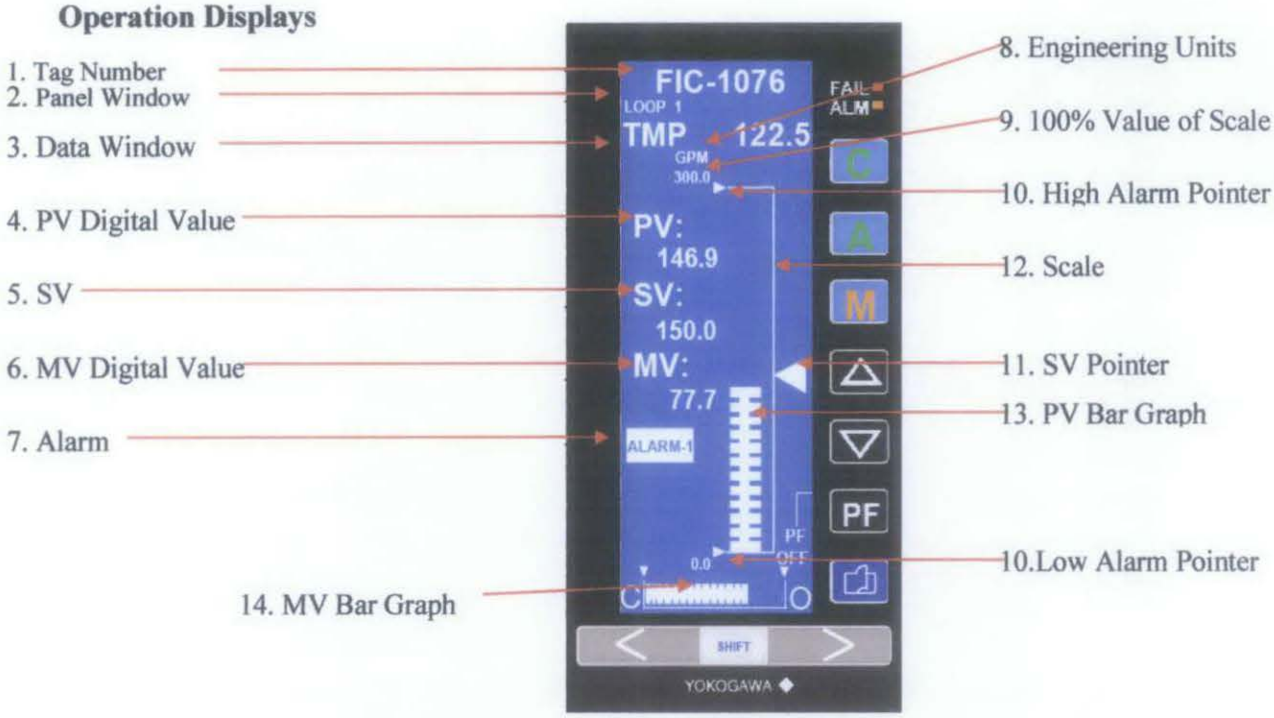

Figure 28: Interface for FIC-1076

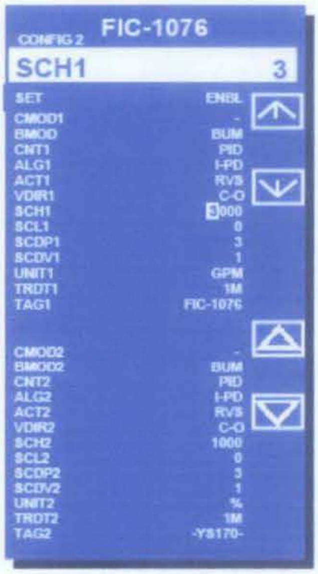

Figure 29: CONFIG-2

The CONFIG 2 displays is used to set the function on the LOOP/TREND/DUAL displays, allow cascaded (remote set point) operation and select the control algorithm.

Explanation:

1. Tag Name: Consists of up to eight digits of alphanumeric characters and symbols. The tag name (TAG) can be set in the Configuration 2 (CONFIG 2) panel.

2. Panel Name: Displays the name of the panel presently viewed.

3. Data Window for YS 170: Allow parameter or analog input to be viewed digitally on the upper right corner of the display. Up to four digits can be shown with a decimal point and polarity sign.

4. PV Digital Value: Four digit display of engineering units for process variable.

5. SV Digital Value: Four digit display of engineering units for set point value.

6. MV Digital Display: Four digit display in percentage of the manipulated variable.

7. Alarm: If a process alarm has been activated, ALARM 1 or ALARM 2 is shown in reverse video on screen. ALARM 1 shown for a LOOP 1 alarm while ALARM 2 is for LOOP 2 (only if LOOP 2 is used)

8. Engineering Units: Up to six alphanumeric characters displaying the engineering units can be shown. The units are selected in the CONFIG 2 display.

9. 0%/100% Value of Scale: The 0% and 100% values of the vertical PV scale are displayed in four digit engineering units. The 0% value (SCL) and 100% value (SCH) are set in the CONFIG 2display.

10. High and Low Alarm Pointer: The PH value (process variable high alarm set point) and PL value (process variable low alarm set point) are displayed with triangular pointers. The PH and PL values are set in the PID Displays.

11. SV Pointer: The set point value (SV) is displayed with a triangular pointer that moves up and down the scale with a resolution of 0.5% units.

12. Scale: Vertical range scale that represents process variable range in engineering units.

13. PV Bar Graph: A vertical bar where the process variable (PV) is displayed in an analog format. The bar consists of 200 elements divided into 50 segments with incremental changes of1 element unit (0.5%)

14. MV Bar Graph: A horizontal bar showing the manipulated variable (MV) or control output value in an analog format. The bar consists of 80 elements divided into 20 segments with incremental changes of 1 element unit (1.25%).

APPENDIX B
INSTRUMENT DEVICES

Figure 30: Coriolis Flowmeter

Figure 31: Orifice Flowmeter

Figure 32: Vortex Flowmeter

Figure 33: Control Valve

Figure 34: Overall Mobile Pilot Plant

APPENDIX C

DIFFERENT TYPES OF SINGLE-STATION CONTROLLER

Table 16: The comparison of three different single-station controllers

TYPE/BRAND	SPECIFICATIONS
Yokogawa Single-Loop Multi Function Controller YS170   **Figure 35:** Yokogawa Brand	The single-station controller was implemented and had been attached at the mobile plant in order for tank level to be measured and controlled. The YS170 single-loop controllers is able to carry out flexible control and arithmetic operations which are required for process control and have the following features: • Display, setting and operation of I/O values, various constants and built-in control functions can be controlled easily from the full-dot LCD and key switches on the front panel. • Trend display of process variable (PV) is possible. • The built-in EEPROM can store parameters and user programs. • The self-tuning function automatically obtains optimum values of PID parameters.

762C Series SINGLE STATION MICRO@Controller (Foxboro)	• A multipurpose station with the ability to accomplish one or two independent control strategies concurrently. • Its control functions are on the job 24 hours a day. It can be turned on or off at the keypad or by configuring logic functions, allowing these controllers to function as advanced PID controllers. • It provides many enhanced functions including Foxboro's patented EXACT tuning algorithm, user-configurable control functions, auto selector control, etc.
Eurotherm T630 Process Data Controller  **Figure 36:** Eurotherm Brand	• T630 is designed to fit into existing panel cutouts as well as new panels requiring traditional loop integrity with the benefit of industry-standard communication for integration into a supervisory control communications for integration into a supervisory control environment. • With a choice of dual-loop cascade as well as single loop or ratio control algorithms, the T630 will actually save panel space in retrofit situations output bar graph by replacing two or even three existing units. • The expansion I/O card allows full handshaking and bumpless transfer when separate units are connected in cascade or in master-slave configuration.

APPENDIX D

TRIALS FOR CASCADE MODE

1. **Two Controllers (YS-150):**

   Follow connection provided in the manual.

2. **One Controller (YS-150):**

   Make direct connection from Point 22 & 23 to Point 26 & 27

3. **One Controller (YS-150):**

   Change connection from Point 3&4 to Point 22&23.

4. **One Controller (YS-170):**

   Connection from Point 3&4 to Point 22&23

5. **One Controller (YS-170):**

   Make the Control Valve connected to Point 24&25

   - Use resistor 250 ohms at Point 24&25
   - Change jumper setting for Point 24 & 25

Figure 37: Controller in cascade mode (Connection 1)

Figure 38: Connection 2

Figure 39: Connection 3

Figure 40: Connection 4

Figure 41: Connection 5

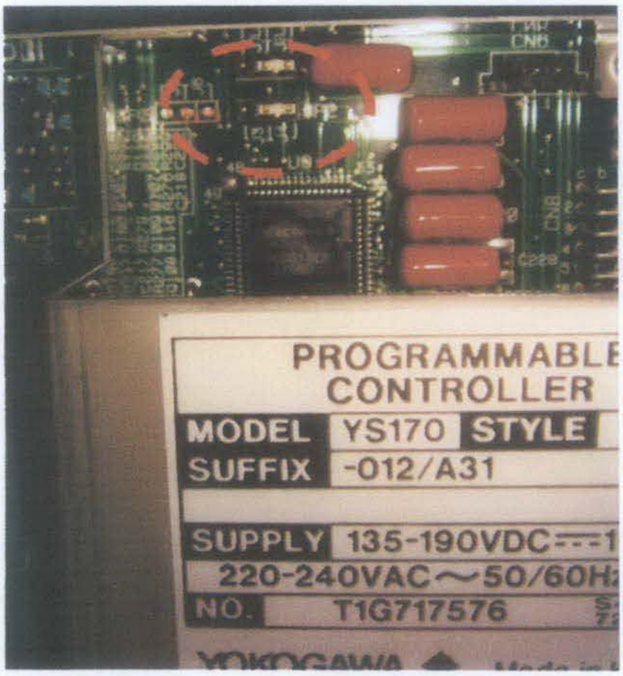

Figure 42: Jumper Setting

APPENDIX E

PILOT PLANT WIRING DIAGRAM