Decoupling Level Flow Process Control

by

Masyanti bt Abu Mansor

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

JANUARY 2006

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

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.

MASYANTI BT ABU MANSOR

CERTIFICATION OF APPROVAL

Decoupling Level Flow Process Control

by

Masyanti bt Abu Mansor

A project dissertation submitted to the
Chemical Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CHEMICAL ENGINEERING)

Approved by,

(Ms Chai Siew Wah)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2006

ABSTRACT

This Final Year Research Project (FYRP) which entitled "Decoupling Level Flow Process Control" is purposely done to model level and flow process using step test and several set of experiments. Data extracted from the experiments were used to build process models and were simulated in the MATLAB simulink since it is the most appropriate software that can model the process. In order to achieve the main objectives of the project which is to design the decoupler as well as reducing or eliminating the interactions, some calculation involves in the decoupler design stage.

As a requirement to the project, some modifications have been done on the equipment involved. From the experimental works, transfer function for level process, flow process and interaction between level and flow process could be obtained. In the simulation, the trial is divided into three parts namely open loop process, closed loop with PID process and closed loop with PID plus a decoupler process. All the responses were analyzed to compare the effectiveness of the decoupler.

Based on the result, it is shown that the level will deviate in a great amount if step change is applied in an open loop process. However, the deviation decreases as the conventional PID controller is introduced in the process. As expected, with the presence of decoupler, the result will be better since the decoupler helps the controlled variable to be as close as possible to the desired set point. It is also observed that the performance of the decoupler is better as the flow rate increases as well as at higher gain of the interaction process; in other words, the decoupler works best for strong interaction process.

The objectives specified for this project have been successfully achieved within the time constraint given. Further research could be made to observe the performance of the decoupler in the industries.

ACKNOWLEDGEMENTS

First and foremost, I would like to recite my deepest gratitude towards God the Most Merciful for giving me the chance to complete my Final Year Research Project (FYRP) on "Decoupling Level Flow Process Control". With His blessed, I am able to pen-off my project within the time frame.

I would like to take this opportunity to extend my warmest appreciation to several individuals whom had helped me to complete this project successfully. Special thanks go to Universiti Teknologi PETRONAS and Chemical Engineering Faculty that had given me this opportunity to conduct this project as a partial fulfillment for the requirement of the Bachelor of Engineering (Hons).

My warmest appreciation to Ms Chai Siew Wah, my supervisor and Prof V.R Radhakrishnan whose guidance and support had come in very useful throughout the completion of this project. Their knowledge and experience came in very useful in my times of difficulty. Thanks for spending your precious time to help me.

A bunch of thank you dedicated to FYRP lab technician, Mr Zaaba and all the laboratory personnel at Control Process Laboratory especially to Mr Jamal and Mr Asnizam whom had spent their valuable time in assisting me with the projects assignments. Their cooperation is highly appreciated.

Apart from that, I would like to express gratitude to my beloved parents who have encouraged me and give supports in accomplishing this project successfully. Same goes to my colleagues for the relentless work and commitment in supporting me on this project. Last but not least, I would like to thanks others who have contributed directly and indirectly to the success of this project but have been inadvertently omitted from the list. I am glad to say that all the dedication and kindness of those involved will always be remembered. Thank you.

TABLE OF CONTENT

Certification....i
Abstract....iii
Acknowledgement....iv
List of figures....v
List of tables....vi
List of graphs....vii
Abbreviations and nomenclature....vii

CHAPTER 1: INTRODUCTION

1.1 Background study....1
1.2 Problem statement....2
1.3 Objectives....6
1.4 Scope of study
1.4.1 Relevancy of the project....6
1.4.2 Feasibility of the project within the scope and time frame....7

CHAPTER 2: THEORY AND LITERATURE REVIEW....8

CHAPTER 3: METHODOLOGY

3.1 Methodology....10
3.2 Explanation of the experiment....12
3.3 Tool....13

CHAPTER 4: RESULT AND DISCUSSION

4.1 Experimental result
4.1.1 Level process and flow process....14
4.1.2 Interaction between level and flow process....16
4.2 Calculation for decoupler design....17
4.3 Simulation result....19

4.4 Discussion..22

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion..28

5.2 Recommendations..29

CHAPTER 6: CASE STUDY 30

References..34

Appendices

LIST OF TABLES

Table 1: Controller gain, K_p and time constant, τ_p for level process

Table 2: Controller gain, K_p and time constant, τ_p for flow process

Table 3: Simulation's result for open loop process

Table 4: Simulation's result for open loop process and the percent of deviation from the set point

Table 5: Simulation's result for closed loop process with the introduction of a decoupler and the percent of deviation from set point.

Table 6: Simulation result for higher gain with and without using decoupler

Table 7: Level measurement data for various percentages of valve openings

Table 8: Flow measurement data for various percentages of valve openings

Table 9: Identified parameters for level process

Table 10: Identify parameters for flow process

LIST OF GRAPHS

Graph 1: Characteristic curve of exit globe valve for several MV opening

Graph 2: Level and flow relationship for the best three lines selected from the characteristic curve of exit globe valve

Graph 3: Graph produced for step change 0 % to 20% of valve opening in the open loop test

Graph 4: Graph produced for step change 0 % to 80% of valve opening in the open loop test

Graph 5: Graph produced for step change from 0 m^3/hr to 200 m^3/hr in the closed loop with PID controller

Graph 6: Graph produced for step change from 0 m^3/hr to 600 m^3/hr in the closed loop with PID controller

Graph 7: Graph produced for step change from 0 m^3/hr to 200 m^3/hr in the closed loop with PID controller plus decoupler

Graph 8: Graph produced for step change from 0 m^3/hr to 200 m^3/hr in the closed loop with PID controller plus decoupler

ABBREVIATIONS AND NOMENCLATURE

PID controller	Proportional, Integral and Derivative controller
τ_p	Time constant
K_p	Gain of the controller
MV	Manipulated variable

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND STUDY

Over the last several decades, most industrial systems were run essentially manually or using on-off control. Many operators were needed to keep watch on the many variables in the plant. As a consequence of the expanding scale and volume of production, there could be hundreds or even thousands of variables to be controlled in a plant. The manual effort thus needed in operation is tremendous. With increasing labor and equipment costs, and with eager demand of high precision, quality and efficiency, the idea of employing operators for the control of physical systems rapidly became uneconomical and infeasible. Automatic control thus becomes the solution much sought after. The fundamental component in an automatic control system is the so called controller. The function of the controller is to receive information about the system from a variety of sensors, process it and automatically generate commands for corrective action to bring the variable of interest to its desired value.

A typical system will have several variables to be controlled and is called multivariable systems. These conditions are referred to multiple inputs; multiple outputs (MIMO) control problems. The most important feature with a multivariable system is possible cross couplings or interactions between its variables whereby one input variable may affect all the output variables. it prevent a loop to be designed independently as adjusting controller parameters of one loop affects the performance of another, sometimes to the extent of destabilizing the entire system. Process interactions can occur naturally because of their physical and chemical make up. Other than that, it may also arise as a consequence of process design, for example, the use of recycle streams for heat recovery purposes.

Strong process interactions can cause serious problems if a conventional multi loop feedback control scheme such as PI or PID controllers is employed. The process interactions can produce undesirable control loop interactions where the controllers fight each other. In general, multivariable control is much more difficult than single variable control.

A multivariable system will be simplified to a number of single variable system if it has no cross couplings between variables, and is called decoupled. A design strategy is then to design a multivariable controller which can decouple the process interactions that is the resulting control system has no more couplings between the desired reference variables and the output variables.

1.2 PROBLEM STATEMENT

Decoupling control is one of the strategies for reducing control loop interactions. The addition of additional controllers called decouplers to a conventional multiloop configuration, the design objective of reducing control loop interactions can be realized. In this project, process interactions occur between level and flow. However, only one way interaction is involved in this process in which only flow is affecting the level. When the flow rate increases, the level starts to increase too. Refer to Figure 1 which shows the schematic diagram of the process. It is obvious that when the manipulated variable, which is, the flow rate changes, it affects the controlled variable, in this case, the level.

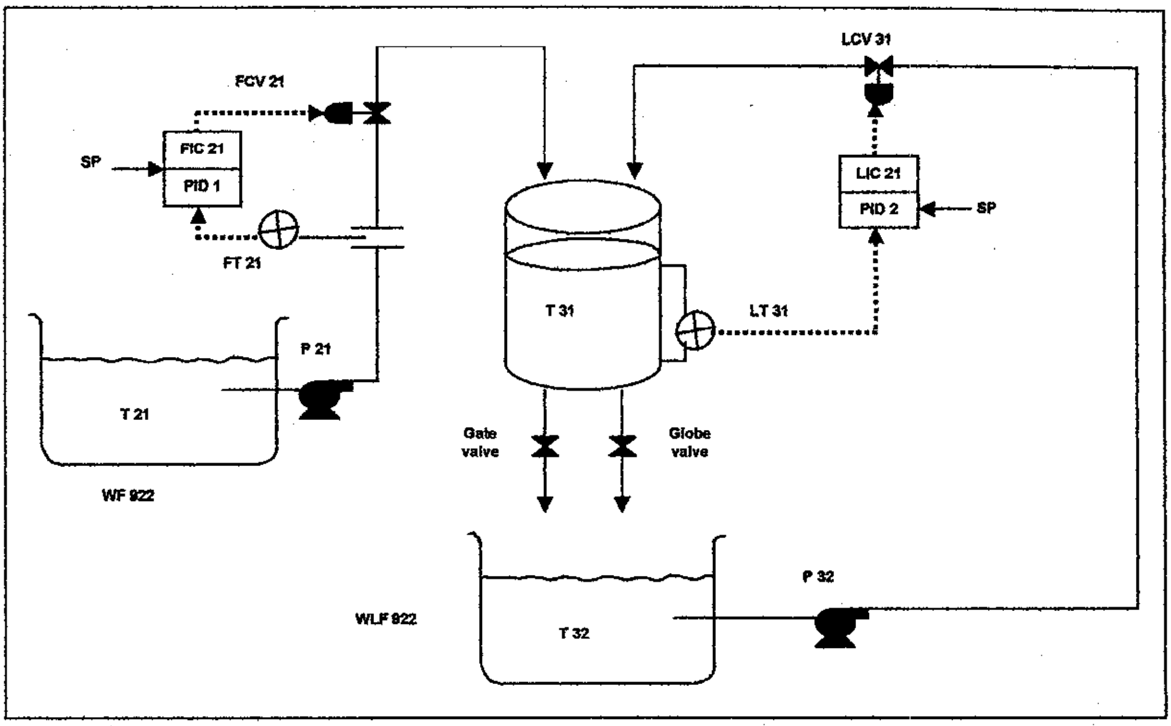


Figure 1: Schematic diagram of level flow process

On the other hand, Figure 2 represents the simplified block diagram of the studied process together with the interactions. G_{c1} and G_{c2} are the conventional feedback controllers while G_{p11}, G_{p21} and G_{p22} are the process transfer function. The block diagram is in a simplified form because the load variables and transfer functions for the final control elements and sensors have been omitted.

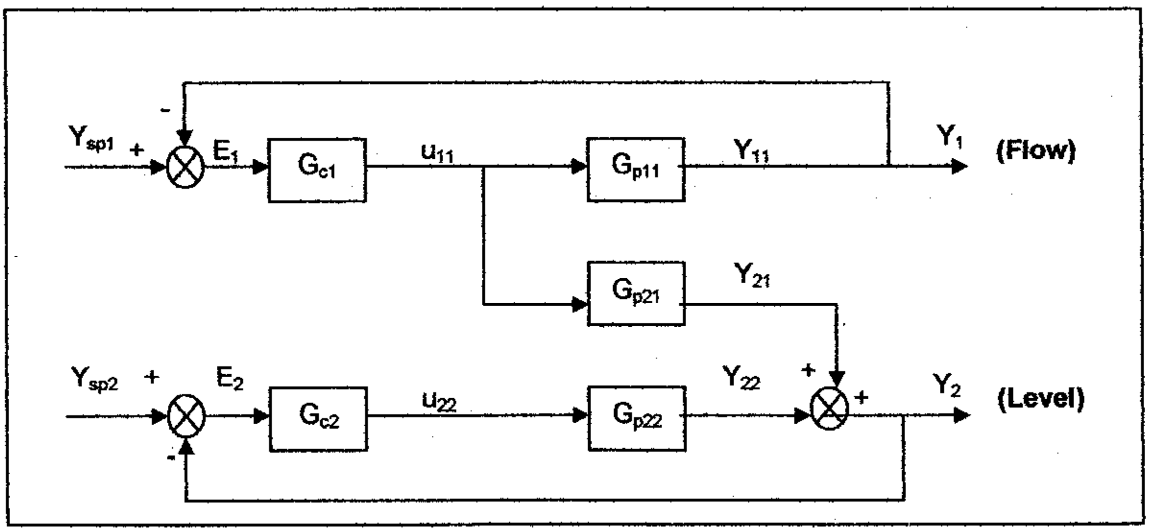


Figure 2: Process interactions between two parameters (level and flow)

In order to have a clearer view on the decoupler, Figure 3 shows a multivariable decoupling control system incorporating an interaction compensator which represent the application of the decoupler in the process.

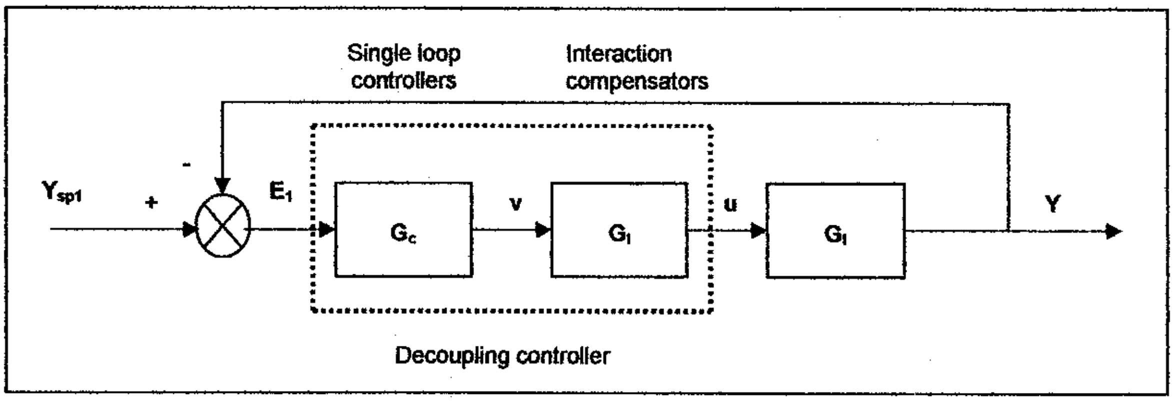


Figure 3: A multivariable decoupling control system incorporating an interaction compensator.

The decouplers are designed to compensate for the undesirable process interactions. For example, in Figure 4, decoupler T_{21} can be designed to cancel Y_{21}, which arises from the undesirable process interaction between U_{11} and Y_2. The output signals from the feedback controller serve as input signals to the decoupler, T_{21}. In fact, decoupling can be interpreted as a type of feed forward control rather than a measured load variable.

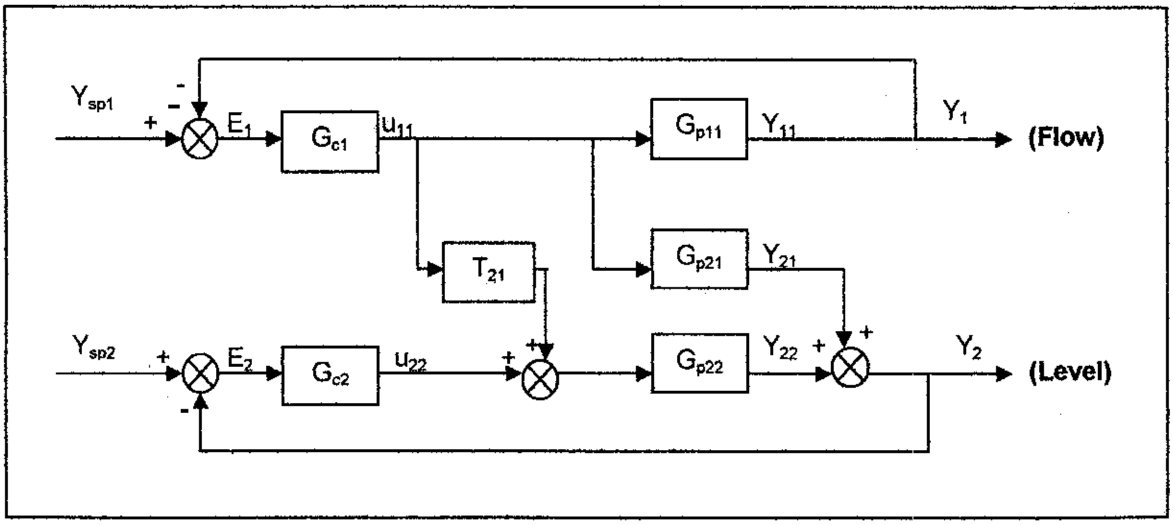


Figure 4: A decoupling control system

If a conventional multiloop control strategy performs poorly due to control loop interactions, a number of solutions are available:

1. Detune one or more of the control loops
2. Choose different controlled or manipulated variables (or pairings)
3. Use a decoupling control system

For the purpose of this project, the third technique will be applied where it is needed to determine the controller actions so that each of the output errors is driven to zero in an acceptable way. The task is to design the controller such that the interaction effects are eliminated or at least significantly reduced.

As a consequence, a transfer function which represents the decoupler will be developed in order to eliminate or minimize the undesirable process interactions. There are several advantages of transfer function which explain the reason why it was chosen. The transfer function representation makes it easy to compare the effects of different inputs. A second advantage of the transfer function is that the dynamic behavior of a given process can be generalized easily. Once the response of the process is analyzed to an input change, the response of any process described by the same generic transfer function is then known. For a general first order transfer function with output Y(s) and input U(s),

$$Y(s) = \frac{K_p}{\tau_p s + 1} U(s)$$

A general time domain solution can be found once the nature of the input change is specified by using step or impulse change. Another benefit of transfer function form is that it is not necessary to re-solve the ODE (Ordinary Differential Equation) when K_p, τ_p, or U(s) changes. Thus, to achieve that target, several sets of experiments need to be run to determine the transfer function of the process.

1.3 OBJECTIVES

In completing this final year research project, several objectives have been identified to ensure that it can be completed within the time limit and the scope given. Those objectives are listed as below:

- To model the Level Flow process using step tests and experiments
- To simulate the process in MATLAB simulink
- To design a decoupler system necessary to eliminate the interaction between level and flow.

1.4 SCOPE OF STUDY

Several experiments should be conducted to figure out the transfer function that represents the process studied. It could be achieved by applying step test to the manipulated variables and study some characteristics of the valves in order to model the Level Flow process. Parameters such as the controller gain and its time constant are determined through some calculation based on the data gathered from experiments. Those data are needed to be simulated in the MATLAB since simulink is the software that being used in this project. Through some correlations and calculations, then only the decoupler that suits to the process could be obtained. However, the scope of study is not limited on developing the decoupler itself but also its relation with alternative techniques as well as its application in the industry.

1.4.1 Relevancy of the project

This final year research project is relevant to the current situation since the decoupler is one of the important elements in the latest technology. Its function of reducing or eliminating process interactions which usually occur in most of the industry provides an alternative strategy for multivariable controls.

1.4.2 Feasibility of the project within the scope and time frame

It is expected that the project's objectives which are as outlined before, should be achieved during one semester or within 13 weeks. Thus, all experimental works and simulation results shall be completed within that time frame. However, due to time constraint, the simulation will be focused to design a decoupler that is suitable for the studied process only which based on the several sets of experiments.

CHAPTER 2

THEORY AND LITERATURE REVIEW

Decoupling control system provides an alternative approach for reducing control loop interactions. The basic idea is to use additional controllers called decouplers to compensate for undesirable process interactions. In fact, decoupling can be interpreted as a type of feed forward control where the input signal is output of a feedback controller rather than a measured load variable.

As quoted from Babatunde A. Ogunnaike (1994), in decoupling, additional transfer function blocks are introduced between the single loop controllers and the process, functioning as links between the otherwise independent controllers (p. 777). The actual control action experienced by the process will therefore now contain information from all the other controllers. This is because, according to M.T Tham (July 1999), loop interactions without decoupler can cause system instability unless proper precautions are taken in terms of control system design (p. 2).

Decoupling control is popular not mainly because it can simplify multivariable control system design but rather because it is a desired feature in many practical applications. Decoupling is required for ease of system operations. This is because of technicians operating a multivariable control system can hardly decide the values of multiple set points to meet their target. Other than that, poor decoupling could be the principal common control problem in industry. Dale E. Seborg (2004) points out that decoupling control can provide two important benefits (p. 498). First, the control loops are eliminated. Consequently, the stability of the closed loop system is determined solely by the stability characteristics of the individual feedback control loops. Another benefit is that, a set point change for one controlled variable has no effect on the other controlled variables.

Based on Robert H. Perry (1997), there are several types of decoupling control configurations have been employed (p.8-22). *Complete decoupling* is a situation where the number of decouplers introduced is same with the number of interactions. For example, two decouplers are installed to eliminate two interactions that exist.

Partial or one-way decoupling refers to only one of the two decouplers is used where the other decoupler is set equal to zero. It is an attractive approach for control problems where one of the controlled variables is more important than the other or one of the process interactions is weak or absent. The advantage of partial decoupling is that, even for highly interacting processes, it tends to be less sensitive to modeling errors than complete decoupling. Other than that, partial decoupling can also provide better control than complete decoupling.

Static decouplers can be used reduce the steady state interactions between control loops. The advantage of static decoupling is that less process information is required where only steady state gain is needed. *Non-linear decouplers* can be used when the process behavior is non linear.

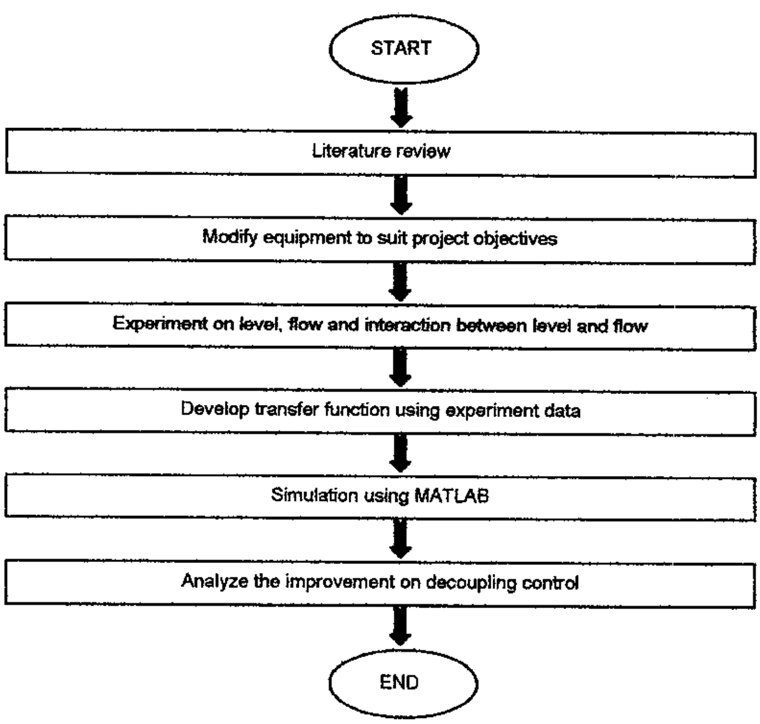
In principle, according to Don W. Green (1997), ideal decoupling eliminates control loop interactions and allows the closed loop system to behave as a set of independent control loops (p.8-23). But in practice, this ideal behavior is not attained for a variety of reasons, including imperfect process models and the presence of saturation constraints on controller outputs and manipulated variables. Other than that, a major reason is that this design approach neglects the system's internal state, with the result that system controllability can be lost due to pole zero cancellation in the decoupling compensator. Furthermore, the ideal decoupler design equations may not be physically realizable and thus would have to be approximated.

CHAPTER 3
METHODOLOGY

3.1 METHODOLOGY

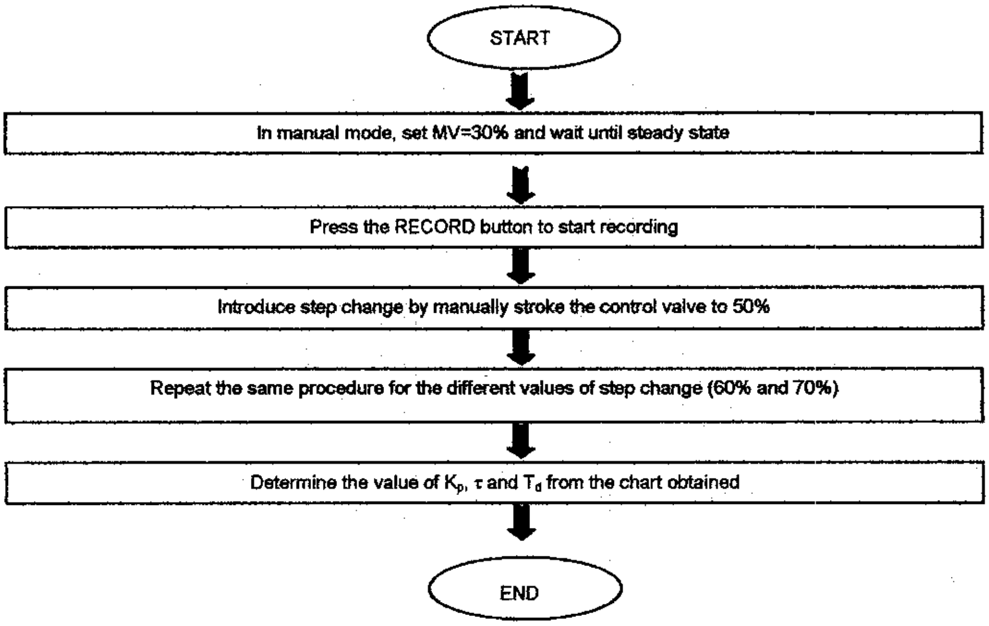
Since the project is a semi empirical modeling which involves a process knowledge and experiment, the methodology is divided into two parts where the first part represent the overall methodology of the project and then followed by the experimental procedures for a different set of experiments.

i) Overall methodology of the project.

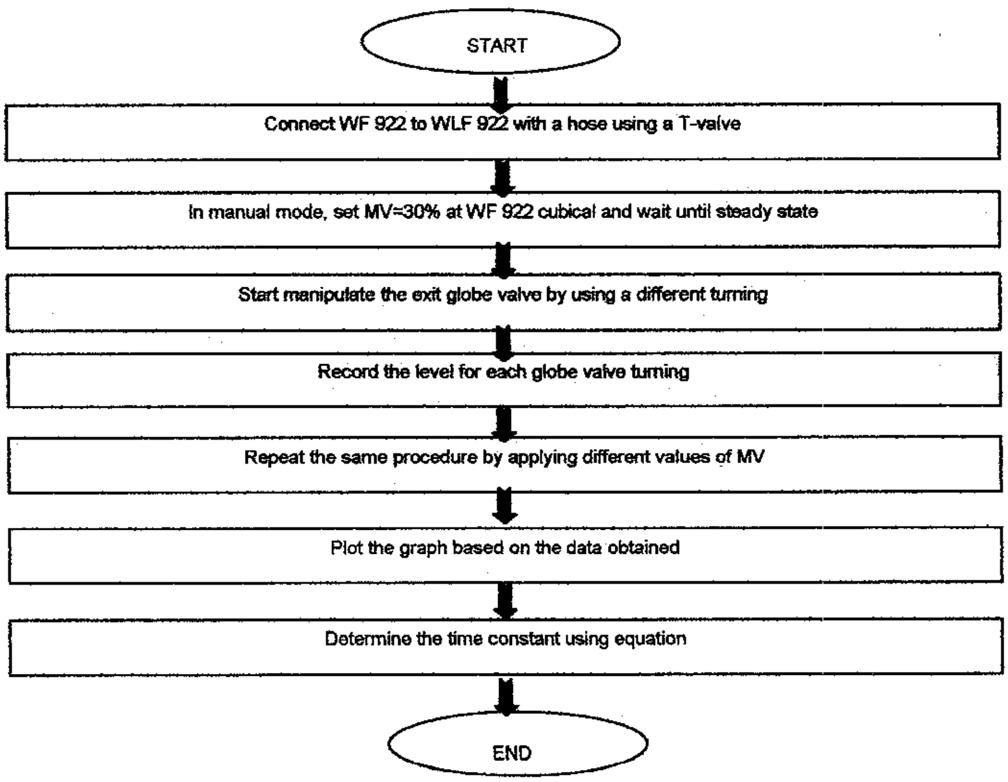


ii) Experimental data for several sets of experiments

a) Level measurement and flow measurement



b) Level-flow measurement



3.2 EXPLANATION OF THE EXPERIMENT

The process plant consists of two steel tanks, three centrifugal pumps and the associated piping, valves and fittings. Water is used as a medium in this experiment to simulate a liquid phase level and flow process. It is pumped by P32 from tank T32 to tank T31 as its inflow. The outflow from T31 returns to T32 by the gravity flow, in which case the level process in T31 is a self regulating process. Two outflow gravity pipes are provided each with its own manual valve. Gate valve is used a draining purposes and will be fully shut when the experiment is running. However, the globe valve could be used in case if there is a need to study the valve characteristics.

The project requires two models to model the level and flow process. Thus, a model of WLF 922 is implemented to study the level process while a model of WF 922 is needed to study the flow process. However, in order to achieve the stated objectives, some modification should be done to the equipment to study the interaction between those two processes. As a result, both models were combined using a hose, so that water could be supplied from WF 922 to the tank T31 of WLF 922. From here, the interactions between level and flow can be observed. Increasing or decreasing the flow rate by manipulating the valve opening (manipulated variable) of WF 922 will give effect to the level in the tank. The outflow water will flows through the globe valve which is situated at the bottom of the tank.

For the purpose of this experiment, self regulating tank is applied for the level. Self regulating is a condition where the tank outflow is by gravity instead of being pumped out. Such a level process is unlikely to overflow or run dry because the higher the inflow and therefore the level, the higher the outflow. In contrast, the slower the inflow and therefore the level rise, the slower the gravity outflow. Such a level process behaves as if it has its own self-controlling mechanism. When there is a step disturbance, the level will raise or fall initially at an almost constant rate but it will soon slow down exponentially to a constant equilibrium level or steady state or in other words, it will seek a new level following a step change in the manipulated input.

For level and flow process, the experiments were done based on manual and data was recorded by the chart recorder. In this condition, the process was done in a manual mode where the manipulated variables are changed based on the desired step change. These data could be obtained directly since the equipment is made for the purpose of studying level and flow respectively. However, in a case of studying the interaction between level and flow, it is not as direct as previous study. This is due to the difficulty of stabilizing level in the tank. Thus, the valve characteristics were identified to achieve the objective of experiment. It can be done by turning the globe valve to a certain degree and reading was taken for each turning. From the data collected, a graph was plotted. The graph was about the characteristic curve of exit globe valve and from there, three best lines were identified. Then, the second graph was plotted by manipulating those three lines which results on the interaction between level and flow. Both graphs show almost a linear relationship. Refer to Appendices for the two graphs obtained.

3.3 TOOL

The appropriate tool for this project is MATLAB simulink. This software is used to simulate the process where transfer function for each process is represented in a block diagram. Comparison of the result in term of a deviation from set point is determined when the transfer function for a decoupler is introduced compared to when there is no decoupler at all. It can be observe that is has quite obvious difference when a transfer function for a decoupler which has a function of reducing or eliminating the interactions is applied.

CHAPTER 4
RESULT AND DISCUSSION

As stated in the methodology section, transfer function should be obtained first through experimental works before simulation for it could be done. After several set of experiments done, important parameters are determined from the chart obtained such as gain of the controller, K_p and also time constant, τ_p. However, for the interaction process, those parameters are obtained through the graph produced. As the experimental works completed, then only simulation could be started. Several trial and errors were done to determine the appropriate PID values. Next, result was observed for each introduction of flow rate step changes. All the result from the experiments and also the simulation are summarized as below:

4.1 EXPERIMENTAL RESULT

4.1.1 Level process and flow process

The results shown below are only the summary for each process. However, the overall result including the chart obtained from the chart recorder and also calculation done in order to determine all those parameters are not represented here. Refer to Appendices for further details.

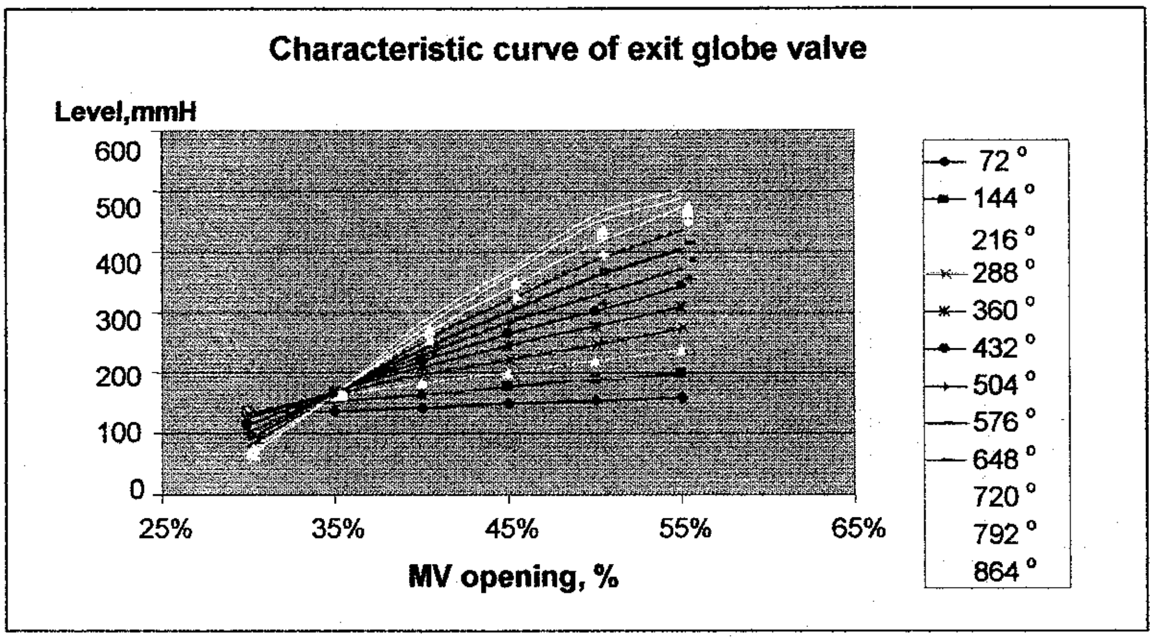
Table 1: Process gain, K_p and process time constant, τ_p for level process

MV Step Change	**K_p**	**τ_p**
30% 50%	5.95 mmH_2O / %	0.84 min
30% 60%	11.77 mmH_2O / %	2.76 min
30% 70%	16.13 mmH_2O / %	3.12 min

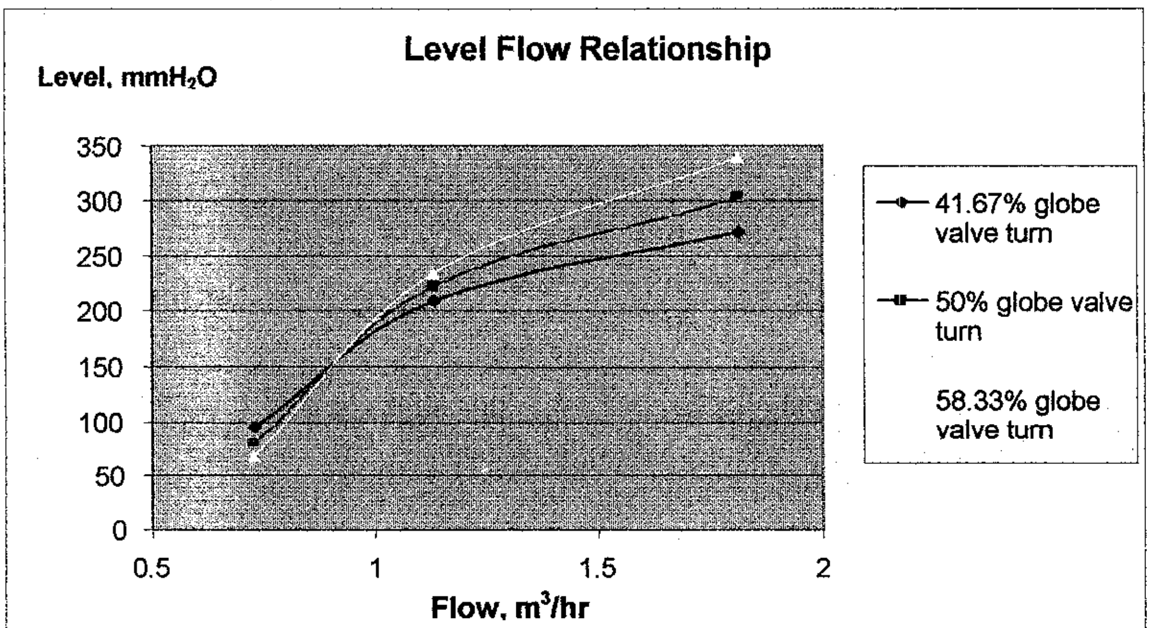
Table 2: Process gain, K_p and process time constant, τ_p for flow process

MV Step Change	**K_p**	**τ_p**
30% 50%	0.053 m^3 / h	0.24 min
30% 60%	0.068 m^3 / h	0.60 min
30% 70%	0.073 m^3 / h	1.2 min

4.1.2 Interaction between level and flow process



Graph 1: Characteristic curve of exit globe valve for several MV opening



Graph 2: Level and flow relationship for the best three lines selected from the characteristic curve of exit globe valve

4.2 CALCULATION FOR DECOUPLER DESIGN

After all the required data are gathered for the modeling part which on the experimental values, the next step is to design the decoupler that suits to the process in order to eliminate the interactions. For further understandings, the transfer function for both level and flow and also the interactions are illustrated as in the figure below.

Three controllers are used in this case where two conventional feedback controllers, G_{c1} and G_{c2} plus one decoupler, T_{21} (refer to Figure 5). Only one decoupler is introduced into the control system since only one-way interaction occurred. Only level will be affected when the flow is manipulated but on the other hand, nothing will occur when level is manipulated. The input signal to the decoupler is the output signal from a feedback controller. Referring to Figure 5, decoupler T_{21} can be designed so as to cancel Y_{21}, which arises from the undesirable process interaction between U_{11} and Y_2.

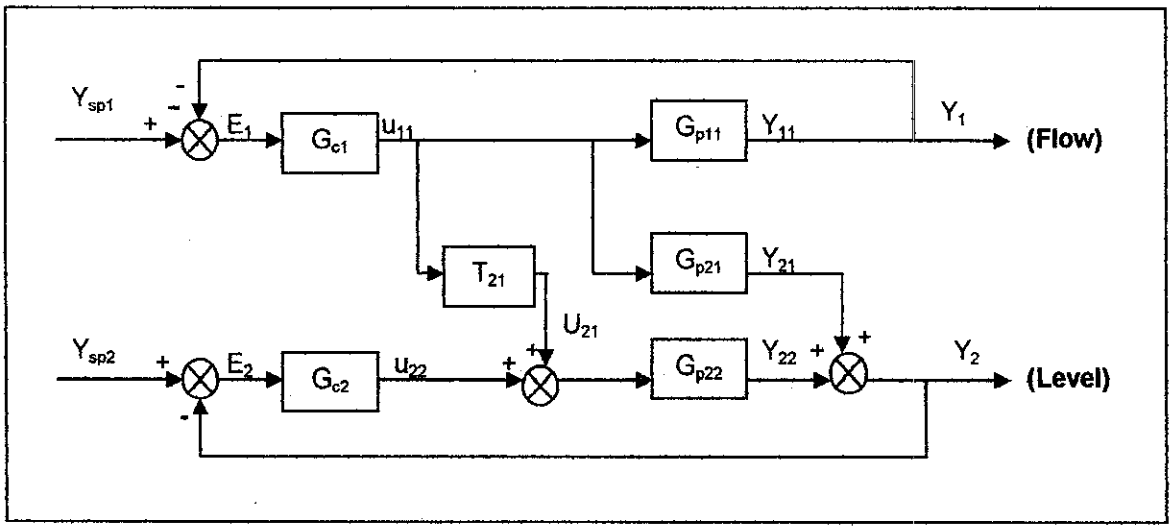


Figure 5: A decoupling control system that need to be designed.

This cancellation will occur at the Y_2 summer if the decoupler output U_{21} satisfies

$$G_{p21}U_{11} + G_{p22}U_{21} = 0$$

Substituting for $U_{21} = T_{21}U_{11}$ gives

$$G_{p21}U_{11} + G_{p22}(T_{21}U_{11}) = 0$$

$$(G_{p21} + G_{p22}T_{21})U_{11} = 0$$

Note that $U_{11}(s)$ is not equal to 0 because U_{11} is a controller output that is time dependent. Thus, to satisfy the equation,

$$(G_{p21} + G_{p22}T_{21}) = 0$$

$$G_{p22}T_{21} = -G_{p21}$$

$$T_{21} = -\frac{G_{p21}}{G_{p22}}$$

In this project, after running the experiment, the transfer functions obtained are as below:

$$G_{p11} = \frac{0.047}{0.24s + 1}$$

$$G_{p21} = \frac{0.3}{0.633s + 1}$$

$$G_{p22} = \frac{1.9162}{0.972s + 1}$$

Thus, substituting the value gives

$$T_{21} = \frac{-G_{p21}}{G_{p22}}$$

$$= -\frac{\frac{0.3}{(0.633s + 1)}}{\frac{1.9162}{(0.972s + 1)}}$$

$$= -\frac{(0.1522s + 0.1566)}{0.633s + 1}$$

$$= \frac{(-0.1522s - 0.1566)}{0.633s + 1}$$

Decoupler is a type of feed forward controller with an input signal that is manipulated variable rather than a disturbance variable. However, it should be bear in mind that the ideal feed forward or here the decoupler is not physically realizable. This is because the design approach generally neglects the system's internal state thus resulting poor control. Other than that, if apply in the industry, the dynamics plant will cause the controller to be unstable.

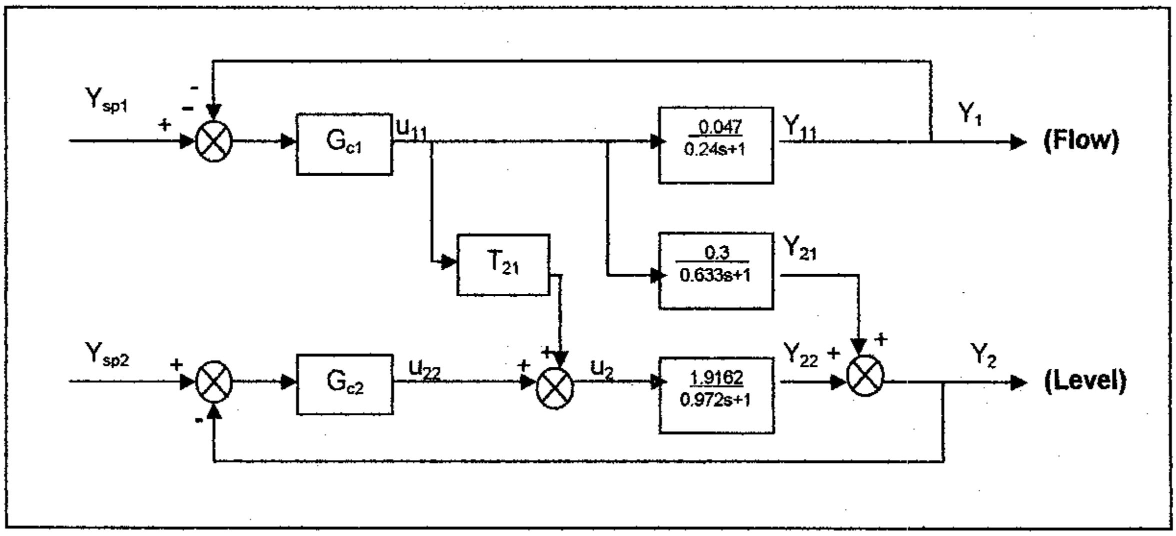


Figure 6: A decoupling control system with transfer function

4.3 SIMULATION RESULT

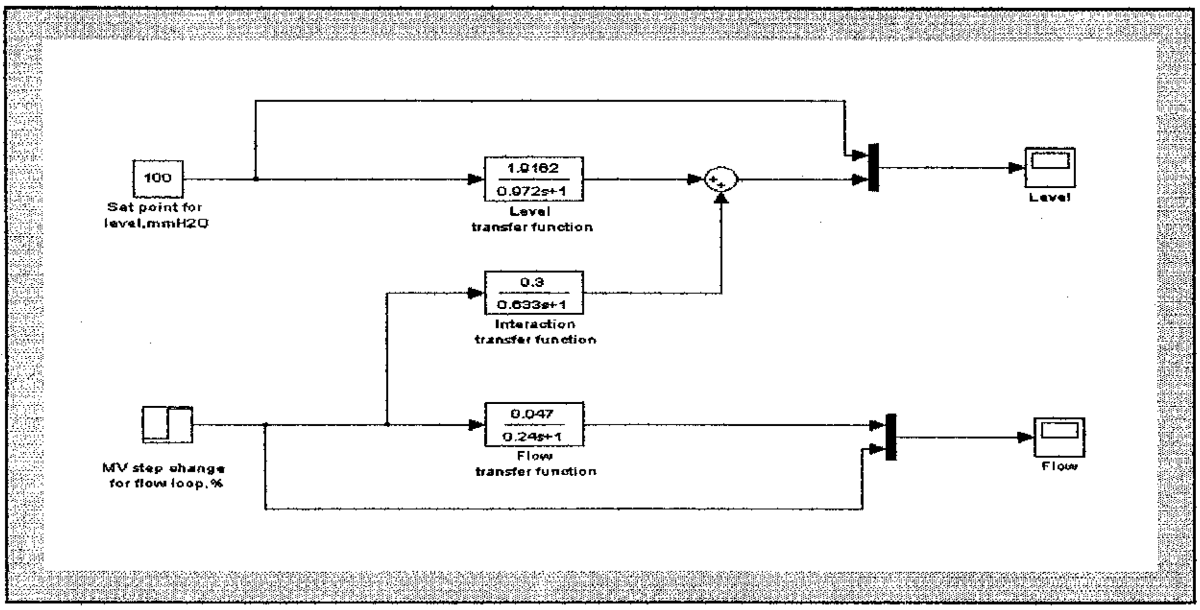


Figure 7: The simulation for open loop process

Table 3: Simulation result for open loop process

Step change for flow, MV	Level, mmH_2O
0	191.613
0% → 20%	197.613
0% → 40%	203.613
0% → 60%	209.613
0% → 80%	215.613
0% → 100%	221.613

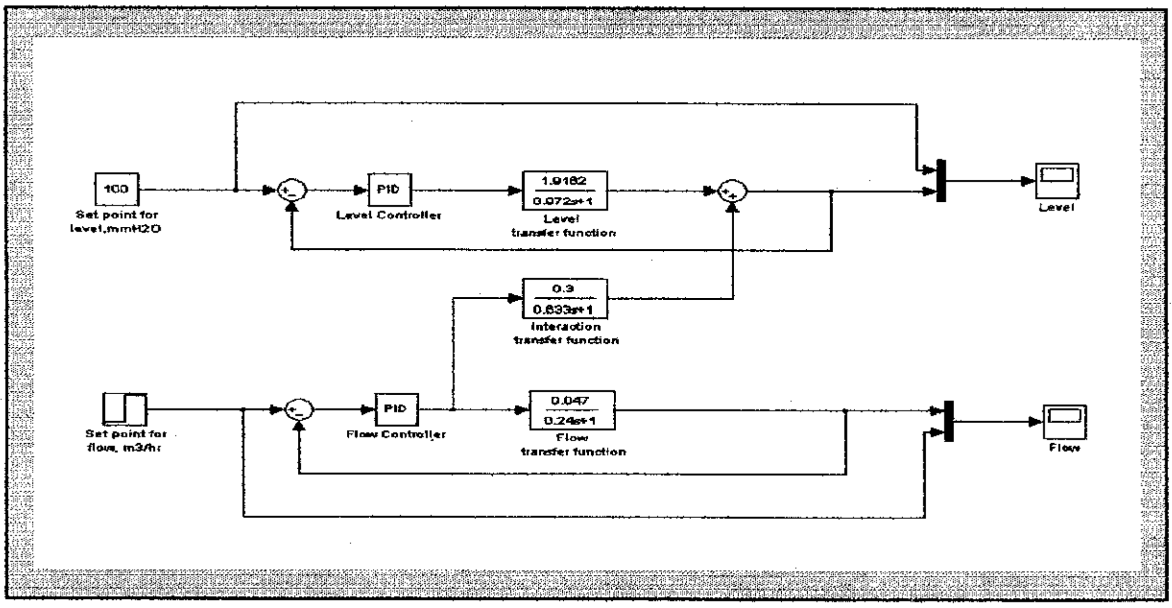


Figure 8: Simulation for closed loop with PID controller

Table 4: Simulation result for open loop process and the percent of deviation from the set point

Step change of set point, m^3/hr	Level, mmH_2O	Deviation from set point, %
0	99.969	0.031
0 → 200	100.340	0.340
0 → 400	100.706	0.706
0 → 600	101.074	1.074
0 → 800	101.442	1.442
0 → 1000	101.809	1.809

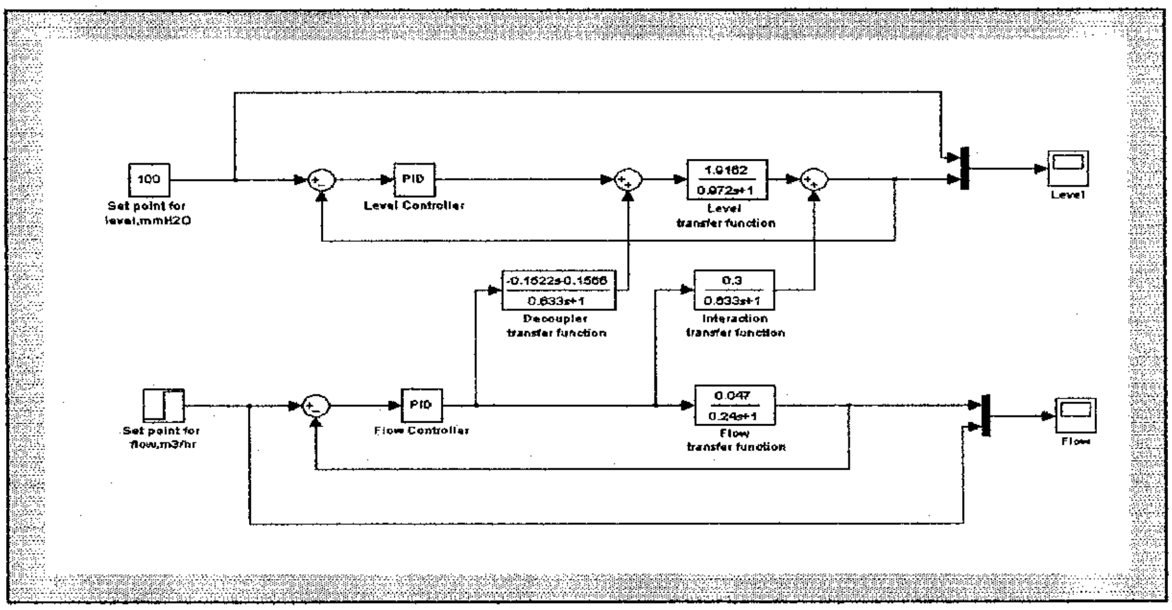


Figure 9: Simulation for closed loop with PID controller plus a decoupler

Table 5: Simulation result for closed loop process with the introduction of a decoupler and the percent of deviation from set point.

Step change of set point, m^3/hr	Level without decoupler, mmH_2O	Deviation from set point, %	Level with decoupler, mmH_2O	Deviation from set point, %
0	99.969	0.031	99.969	0.031
0 → 200	100.340	0.340	99.661	0.339
0 → 400	100.706	0.706	99.424	0.576
0 → 600	101.074	1.074	99.424	0.576
0 → 800	101.442	1.442	99.424	0.576
0 → 1000	101.809	1.809	99.424	0.576

4.4 DISCUSSION

The word *output* generally refers to a controlled variable in a process, a process variable to be maintained at a desired value (set point). In this project, the output refers to the level changes. On the other hand, the word *input* refers to any variable that influences the process output where in this case, the flow rate of the stream flowing into the tank. The characteristic feature of all inputs whether they are disturbance variables or manipulated variables, is that they influence the output variables that wish to be controlled.

Block diagram and transfer function are the most important element for representing the process. A block diagram provides a convenient representation of the flow of information around a control loop and quantitative information can be included by showing the transfer function for each block. The transfer function is an algebraic expression for the dynamic relation between a selected input and output of the process model. Since level and flow follows a first order differential equation model, thus the general transfer function is stated as below:

$$\frac{Y(s)}{U(s)} = \frac{K_p}{\tau_p s + 1}$$

where K_p is the process gain and τ_p is the time constant, U(s) is the input, and Y(s) is a deriving expressions. Process gains relate steady state changes in the process output resulting from step changes in input while time constant is an indicative of the speed of the response of the process. Large values of τ_p mean a slow process response and vice versa. Other than that, some process consists of time delay, T_d. Time delay is however present and popular in process and chemical industries and causes a serious obstacle to good process operation and control. It prevents high gain of a conventional controller from being used, leading to offset and sluggish system response. In this case, since the value obtained is an experimental value, thus the time delay is too small and it can be neglected.

The step change has been applied to know how the process outputs will respond to changes in the process inputs. One reason this input type was chosen because one characteristic of industrial processes is that they can be subjected to sudden and sustained input changes. The chief advantage of the step change method is that only a single experimental test is necessary. But the method does have four disadvantages:

1. The experimental test is performed under open-loop conditions. Thus, if a significant disturbance occurs during the test, no corrective action is taken. Consequently, the process can be upset and the test results may be misleading.
2. For a nonlinear process, the test results can be sensitive to the magnitude and direction of the step change. If the magnitude of the step change is too large, process nonlinearities can influence the result. But if the step magnitude is too small, the step response may be difficult to distinguish from the usual

fluctuations due to noise and disturbances. The direction of the step changes whether positive or negative should be chosen so that the controlled variable will not violate a constraint.

3. The method is not applicable to open-loop unstable processes.
4. For analog controllers, the method tends to be sensitive to calibration errors

Based on the chart obtained from the chart recorder, it is proved that level follows the first order differential equation model. Level process is a single capacity and is a slow process which indicated by lower gain compared to flow process which have a higher gain. The larger the time constant or known as capacity lag, the slower the process and the lower the process gain. Noise usually presents in a level process because the liquid surface is randomly "oscillating" due to inflow/outflow disturbances or in the other case liquid boiling or vapor condensation. However, in the experiment, all those disturbances are neglected. Transfer function to represent the process could be obtained from the chart and is needed in the simulation step. Refer to Appendices for the chart obtained from the experiment and the calculation involved in driving to the transfer function.

Flow control loops are widely used in the process industries. Flow is characterized by fast responses with essentially no time delay. Disturbances in flow control system tend to be frequent but generally small. Most of the disturbances are high frequency noise (periodic or random) due to upstream turbulence, valve changes and pump vibration. It was observed from the chart that the flow process follow the criteria as explained above. Same as level process, the transfer function for flow process is obtained through the chart. The chart recorded in the experiment for flow measurement and the calculation to develop the transfer function is attached in the Appendices.

In the case of interaction between level and flow, the result could not be obtained directly from the chart recorder. As a consequence, the existing procedure is revised and modified. The experiment was done by opening the globe valve at the bottom of tank T31 with a small turn starting from fully shut until it become fully open. Each turn is about 72 degrees and the level for every turning was recorded. At the same time the flow was recorded too to identify their relationship. The purpose of doing that steps are to study the characteristic of the exit globe valve and as a result, the characteristic curve of the exit globe valve was obtained. It is observed that the level increases almost linearly with the increment of control valve opening. From the graph, the three best lines were chosen and it was plotted together with the flow rate in the second graph to observe the relationship between level-flow processes. It is assumed that the normal operating condition was situated in the selected range. The graph shows that the normal operating range for the level-flow process is in a range of 41.67% to 58.33% of the globe valve turn. The same trend produced shows that the level is linearly proportional to the flow and proves that flow has an interaction with the level. The interaction will be a major concern in this project since the interaction should be eliminated or at least minimized by introducing a decoupler.

MATLAB is the responsible software that used to model the transfer function for the process. It is a general purpose software package for mathematical computations, analysis and visualization. Simulink, a companion package to MATLAB, is an excellent interactive environment for simulation and analysis of control systems. Simulink enables the rapid creation of block diagrams based on transfer function, followed by simulation for a given input signal.

For the first part of this project, simulation on open loop process was observed. This condition exists without the presence of controller in controlling the flow rate. Step changes were done for several trials by manually increasing the control valve opening.
For example, it is assumed that the set point for level is 100 mmH_2O for the open loop process (refer to Figure 7). Step change for flow is done by increasing the manipulated variable which is the valve opening. Based on the result obtained in Table 3, it is obvious that the level deviates from a set point in such a great amount. Thus, this type of control mechanism is not suitable for controlling any process where accuracy is important.

On the other hand, in the second part, the response of closed loop with PID controller is observed. However, a suitable setting for Proportional (P) controller, Integral (I) controller and Derivative controller should be chosen to control level and flow process. The controller gain for Proportional controller can be adjusted to make the controller output changes as sensitive as desired to deviations between set point and controlled variable. This is because the application of Proportional only will produces off set after a set point change. This problem could be solved with the help of Integral controller which eliminates the off set. One disadvantage of using Integral action is that it tends to produce oscillatory responses of the controlled variable and as a result reduces the stability of the feedback control system. In other case, Derivative control anticipates the future behavior of the error signal by considering its rate of change. By providing the anticipatory control action, the derivative mode tends to stabilize the controlled process.

As stated, flow is a fast response thus the appropriate controller will be PI controller since the limited amount of oscillation can usually be tolerated. In contrast, for level process, since it is a slow response, PID controller will satisfy the process control. Proper tuning of those controllers will optimize their performance. Based on the result, the deviation from the set point is keep increasing as the flow rate increases but this time, the deviation is smaller compared to the open loop process. A similar procedure was done to the closed loop with PID by introducing a step change. The set point for the level is still assumed to be 100 mmH_2O for comparison purposes (refer to Figure 8). Step increase was done for a several trial and the result was recorded as in Table 4

For the last part, the decoupler is introduced in the closed loop which the main purpose is to reduce the interaction between level and flow. As a result, the level obtained will be closer to the desired set point as the level is not affected by the flow anymore. This is proved by the value listed in Table 5. It can be seen that, the decoupler helps the level to be as close to the set point even though the flow rate is keep increasing. Other than that, it is proved that the performance of the decoupler is more efficient as it applied to a higher flow rate. The configuration of the transfer function for the decoupler could be seen in Figure 9. The sample graphs foe each part are shown in the Appendices.

Thus, the introduction of the decoupler brings the level which is the controlled variable as close as possible to the set point, thus verified that the interactions between the level and flow are minimized.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The concept of decoupling is to reduce control loop interactions by adding additional controllers called decouplers to a conventional multi loop configuration. In principle, decoupling control schemes can provide several important benefits where the interactions between control loops are eliminated or at least reduced. As a consequence, the stability of the closed loop system is determined solely by the stability characteristics of the individual feedback control loops. Other than that, a set point change for one controlled variables has no effect on the other control variables.

In this project, the model for level process, flow process and interaction process between level and flow were obtained through experimental data using step test. After that, all the required data from the modeling stage were extracted to be simulated in the MATLAB simulink. Finally, the desired decoupler managed to be designed where its existence is very important to eliminate or reduced the loop interactions.

However, for many systems, decoupling multivariable control is generally not as satisfactory as the calculation result would suggest. A major reason is that this design approach neglects the system's internal state, with the result that system controllability can be lost due to pole zero cancellation in the decoupling compensator. Also since the decouplers are more or less fixed by the plant dynamics, these controllers can be unrealizable or even unstable.

Thus, it can be concluded that this project has successfully achieve all the objectives stated at the early stage.

5.2 RECOMMENDATIONS

It is recommended that this project will be extended to a greater scope to further investigate the decoupling principle so that its application can be varied. Other than that, it is suggested that data to be simulated is taken from real process, thus decoupler response would be more realizable. Hopefully this project will become a milestone for the next project which involves the same concept.

CHAPTER 6
CASE STUDY

A case study has been conducted to observe the performance of the decoupler when the gain of the interaction process is higher which means that when it is a strong interaction process. For the purpose of the study, the same process which is level and flow process is made as a reference. In this case, only the gain of the transfer function for the interactions process is assumed to have a certain value which is higher than the experimental result. In other words, the interaction in the experiment is small thus resulting a small gain. This condition is studied because in general, many processes in industries involve strong interactions.

Based on Figure 1, decoupler T_{21} can be designed so as to cancel Y_{21}, which arises from the undesirable process interaction between U_{11} and Y_2. The condition and procedures applied in obtaining the decoupler is still same as the previous calculation.

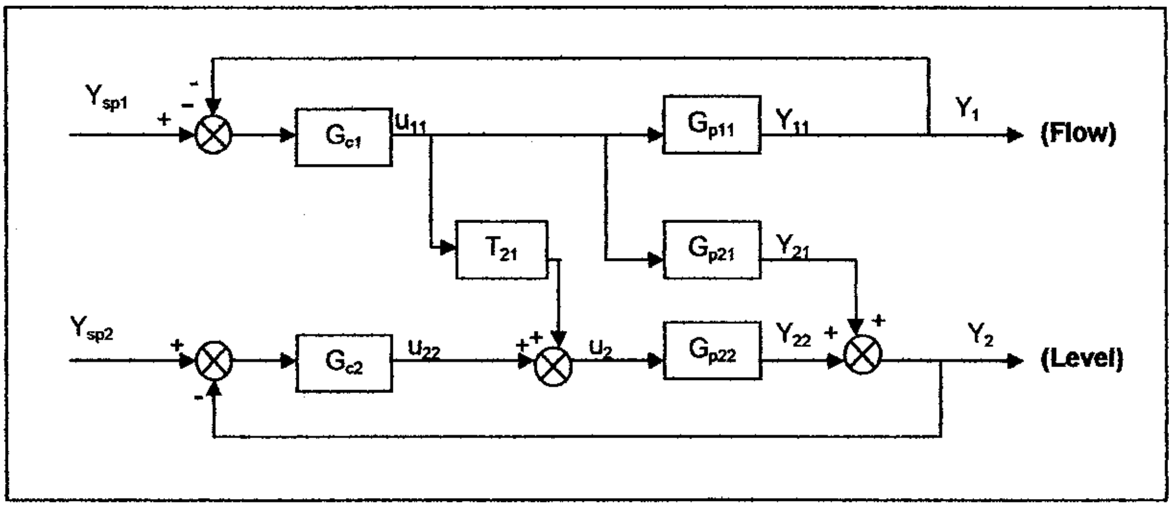


Figure 10: A decoupling control system that need to be designed for the case study

This cancellation will occur at the Y_2 summer if the decoupler output U_{21} satisfies

$$G_{p21}U_{11} + G_{p22}U_{21} = 0$$

Substituting for $U_{21} = T_{21}U_{11}$ gives

$$G_{p21}U_{11} + G_{p22}(T_{21}U_{11}) = 0$$

$$(G_{p21} + G_{p22}T_{21})U_{11} = 0$$

Note that U11(s) is not equal to 0 because U11 is a controller output that is time dependent. Thus, to satisfy the equation,

$$(G_{p21} + G_{p22}T_{21}) = 0$$

$$G_{p22}T_{21} = -G_{p21}$$

$$T_{21} = -\frac{G_{p21}}{G_{p22}}$$

In this case study, let say that the process has a higher gain for process interaction compared to the experimental value which means that the interaction is greater and the result will be as below:

$$G_{p11} = \frac{0.047}{0.24s + 1}$$

$$G_{p21} = \frac{15}{0.633s + 1}$$

$$G_{p22} = \frac{1.9162}{0.972s + 1}$$

Thus, substituting the value gives

$$T_{21} = -\frac{G_{p21}}{G_{p22}}$$

$$= -\frac{\dfrac{15}{(0.633s + 1)}}{\dfrac{1.9162}{(0.972s + 1)}}$$

$$= -\frac{(7.6088s + 7.828)}{0.633s + 1}$$

$$= \frac{(-7.6088s - 7.828)}{0.633s + 1}$$

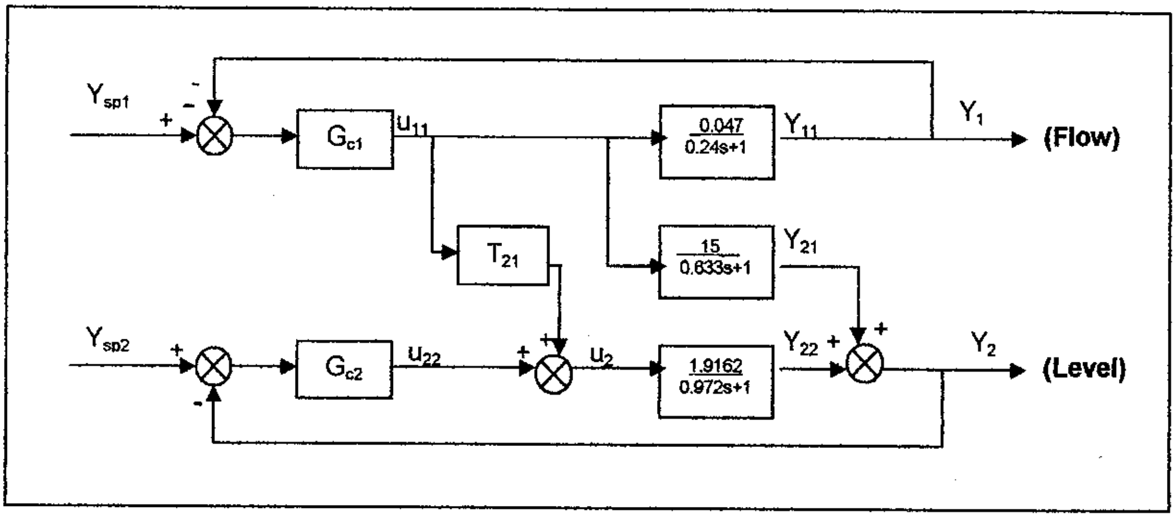


Figure 11: A decoupling control system with transfer function but with higher gain

Simulation in MATLAB was done similar to that using the experimental result; just the gain of the interaction is increased from 0.3 to 15. From the result obtained, the percent of deviation without applying decoupler will result in a bigger deviation as the flow rate increases but with the implementation of the decoupler, the percent of deviation could be reduced. The simulation result is listed as below:

Table 6: Simulation result for higher gain with and without using decoupler

Step change of set point, m^3/hr	Level without decoupler, mmH_2O	Percent of deviation,%	Level with decoupler, mmH_2O	Percent of deviation,%
0	99.97	0.03	99.97	0.03
0 to 150	109.15	9.15	99.42	0.58
0 to 200	118.36	18.36	99.42	0.58
0 to 250	122.95	22.95	99.42	0.58
0 to 300	127.55	27.55	99.42	0.58
0 to 350	132.15	32.15	99.42	0.58
0 to 400	136.74	36.15	99.42	0.58
0 to 450	141.34	41.34	99.42	0.58
0 to 500	146.00	46.00	99.42	0.58

It can be seen that the interaction between level and flow is increases as the flow rate which is the manipulated variables increases. It can be proved by the percent increment of deviation from the set point. It means that, bigger disturbances to the level, the bigger the offset.

In contrast, when the decoupler is introduced in the process, it brings the level as close as possible to the set point compared when the decoupler is not used since the percentage of deviation when using the decoupler is small compared when there is no decoupler in the process interactions.

Thus, it can be conclude that the decoupler will performs better for a strong interactions process. Other than that, the process gain will influence the decoupler performance since higher the gain for the interaction process, the effectiveness of the decoupler will be greater.

REFERENCES

1. Babatunde A. Ogunnaike and W. Harmon Ray, 1994, *Process dynamics, Modelling and Control,* USA, Oxford University Press.

2. Dale E. Sebarg, Thomas F. Edgar and Duncan A. Mellichamp, 2004, *Process Dynamics and Control*, USA, John Wiley and Sons.

3. Eronini Umez Eronini, System Dynamics and Control, United States of America, PWS Publishing.

4. Harold Wade, March 2005, *Advanced Automation of Control Loops*, Wade Associates.

5. Lorenzo Sadun, Applied Linear Algebra- The Decoupling Principle, United States of America, Prentice Hall.

6. M. Tham, 1999, *Multivariable Control: An Introduction to Decoupling Control,* University of Newcastle Upon Tyne.

7. Robert H. Perry and Don W. Green, 1997, *Perry's Chemical Engineers' Handbook,* Seventh Edition, McGraw Hill, United State of America.

8. Qing-Guo Wang, 2003, *Decoupling Control-Lecture Notes in Control and Information Sciences*, New York,Springer.

9. *Level Flow Control lab manual*, 2005, Universiti Teknologi Petronas.

10. Honeywell,1 August 2005 <http:// www.manufacturing.net>

APPENDICES

RESULTS OF EXPERIMENT

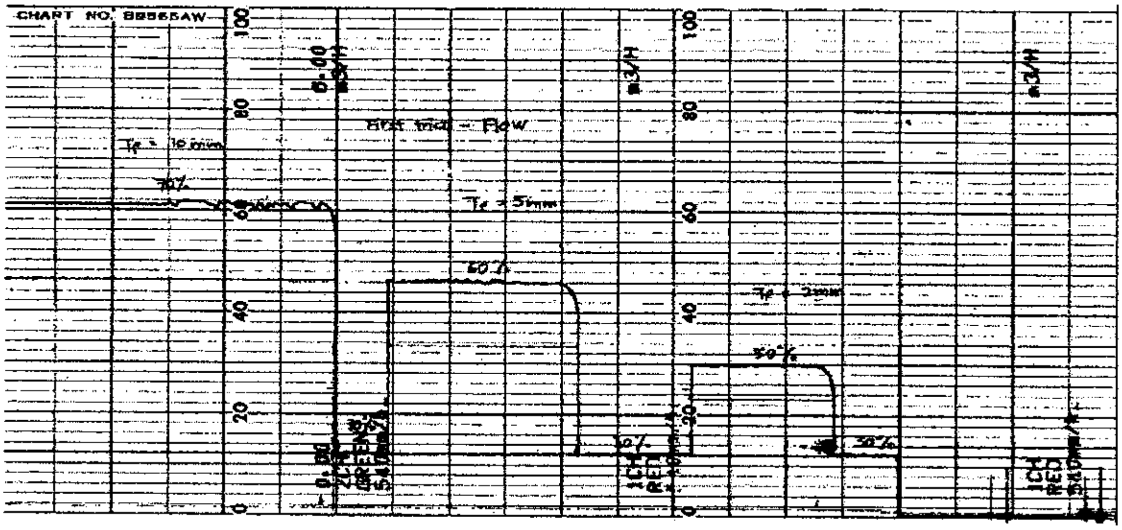


Figure 12: Chart obtained from the experiment of flow process

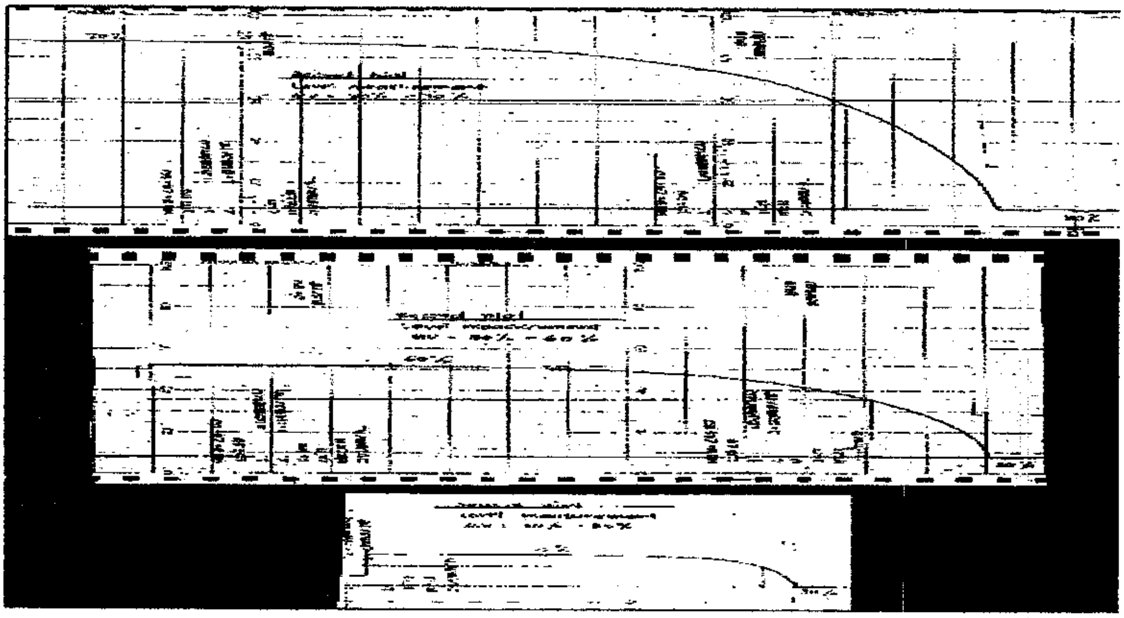


Figure 13: Chart obtained from experiment for level process

Table 7: Level measurement data for various percentages of valve openings

MV (valve opening in %)	PV (level of water, mmH_2O)
30%	58
50%	177
30%	60
60%	421
30%	58
70%	703

Table 8: Flow measurement data for various percentages of valve openings

MV (valve opening in %)	PV (flow of water, m^3/h)
30%	0.70
50%	1.76
30%	0.70
60%	2.74
30%	0.70
70%	3.63

CALCULATION

i) Calculation to determine K_p and τ_p for level process using step tests (first trial)

a) *For step test from 30% to 50%*

$$K_p = \frac{\Delta PV}{\Delta MV} = \frac{(177 - 58)\ mmH_2O}{(50 - 30)\ \%} = 5.95\ mmH_2O / \%$$

$$\tau_p = 58 + 0.632\ (\Delta PV)$$
$$= 58 + 0.632\ (119)$$
$$= 133.21\ mmH_2O$$

From the graph, the value at 133.21 mmH_2O corresponds to 7.0 mm from the starting point. The speed for the chart recorder is 500 mm/h, thus,

$$\tau_p = \frac{7.0 \text{ mm}}{500 \text{ mm/h}} = 0.014 \text{ h} = 0.84 \text{ minutes.}$$

b) For step test from 30% to 60%

$$K_p = \frac{\Delta PV}{\Delta MV} = \frac{(421-60) \text{ mmH}_2\text{O}}{(60-30)\ \%} = 11.77 \text{ mmH}_2\text{O} / \%$$

$$\tau_p = 60 + 0.632\ (\Delta PV)$$

$$= 60 + 0.632\ (361)$$

$$= 288.15 \text{ mmH}_2\text{O}$$

From the graph, the value at 288.15 mmH_2O corresponds to 23 mm from the starting point. The speed for the chart recorder is 500 mm/h, thus,

$$\tau_p = \frac{23 \text{ mm}}{500 \text{ mm/h}} = 0.046 \text{ h} = 2.76 \text{ minutes.}$$

c) For step test from 30% to 70%

$$K_p = \frac{\Delta PV}{\Delta MV} = \frac{(703-58) \text{ mmH}_2\text{O}}{(70\text{-}30)\ \%} = 16.13 \text{ mmH}_2\text{O} / \%$$

$$\tau_p = 58 + 0.632\ (\Delta PV)$$

$$= 58 + 0.632\ (645)$$

$$= 465.64 \text{ mmH}_2\text{O}$$

From the graph, the value at 465.64 mmH_2O corresponds to 26mm from the starting point. The speed for the chart recorder is 500 mm/h, thus,

$$\tau_p = \frac{26.0 \text{ mm}}{500 \text{ mm/h}} = 0.052\text{h} = 3.12 \text{ minutes.}$$

ii) Calculation to determine K_p and τ_p for flow process using step tests (first trial)

a) *For step test from 30% to 50%*

$$K_p = \frac{\Delta PV}{\Delta MV} = \frac{(1.76 - 0.70)\ m_3/h}{(50 - 30)\ \%} = 0.053\ m_3/h.\ \%$$

$$\tau_p = 0.70 + 0.632\ (\Delta PV)$$
$$= 0.70 + 0.632\ (1.06)$$
$$= 1.37\ m_3/h$$

From the graph, the value at 1.37 m_3/h correspond to 2mm from the starting point. The speed for the chart recorder is 500 mm/h, thus,

$$\tau_p = \frac{2\ mm}{500\ mm/h} = 0.004\ h = 0.24\ \text{minutes.}$$

b) *For step test from 30% to 60%*

$$K_p = \frac{\Delta PV}{\Delta MV} = \frac{(2.74 - 0.7)\ m_3/h}{(60 - 30)\ \%} = 0.068\ m_3/h.\ \%$$

$$\tau_p = 0.7 + 0.632\ (\Delta PV)$$
$$= 0.7 + 0.632\ (2.52)$$
$$= 1.99\ m_3/h$$

From the graph, the value at 1.99 m_3/h corresponds to 5mm from the starting point. The speed for the chart recorder is 500 mm/h, thus,

$$\tau_p = \frac{5\ mm}{500\ mm/h} = 0.01\ h = 0.6\ \text{minutes.}$$

c) *For step test from 30% to 70%*

$$K_p = \frac{\Delta PV}{\Delta MV} = \frac{(3.63 - 0.70)\ m_3/h}{(70 - 30)\ \%} = 0.073\ m_3/h.\ \%$$

$$\tau_p = 0.7 + 0.632\ (\Delta PV)$$
$$= 0.7 + 0.632\ (2.99)$$
$$= 2.55\ m_3/h$$

From the graph, the value at 2.55 m_3/h corresponds to 10mm from the starting point. The speed for the chart recorder is 500 mm/h, thus,

$$\tau_p = \frac{10\ \text{mm}}{500\ \text{mm/h}} = 0.02\ \text{h} = 1.2\ \text{minutes.}$$

iii) Summary of the result

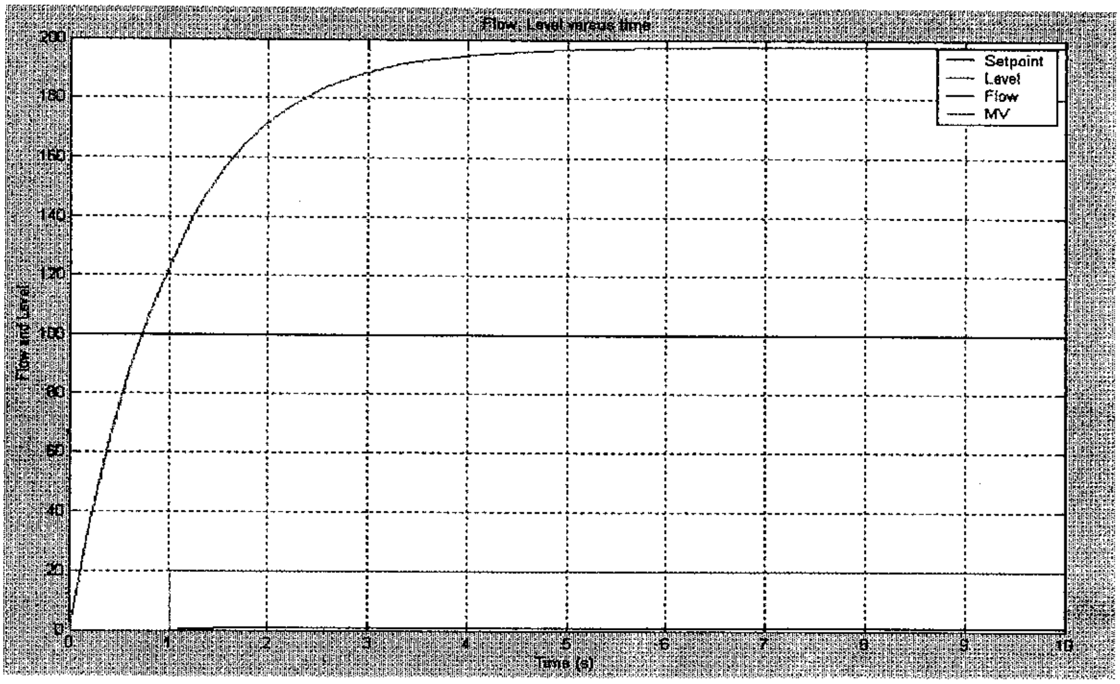
Table 9: Identified parameters for level process

MV Step Change	K_p	τ_p
30% → 50%	5.95 mmH_2O / %	0.84 min
30% → 60%	11.77 mmH_2O / %	2.76 min
30% → 70%	16.13 mmH_2O / %	3.12 min

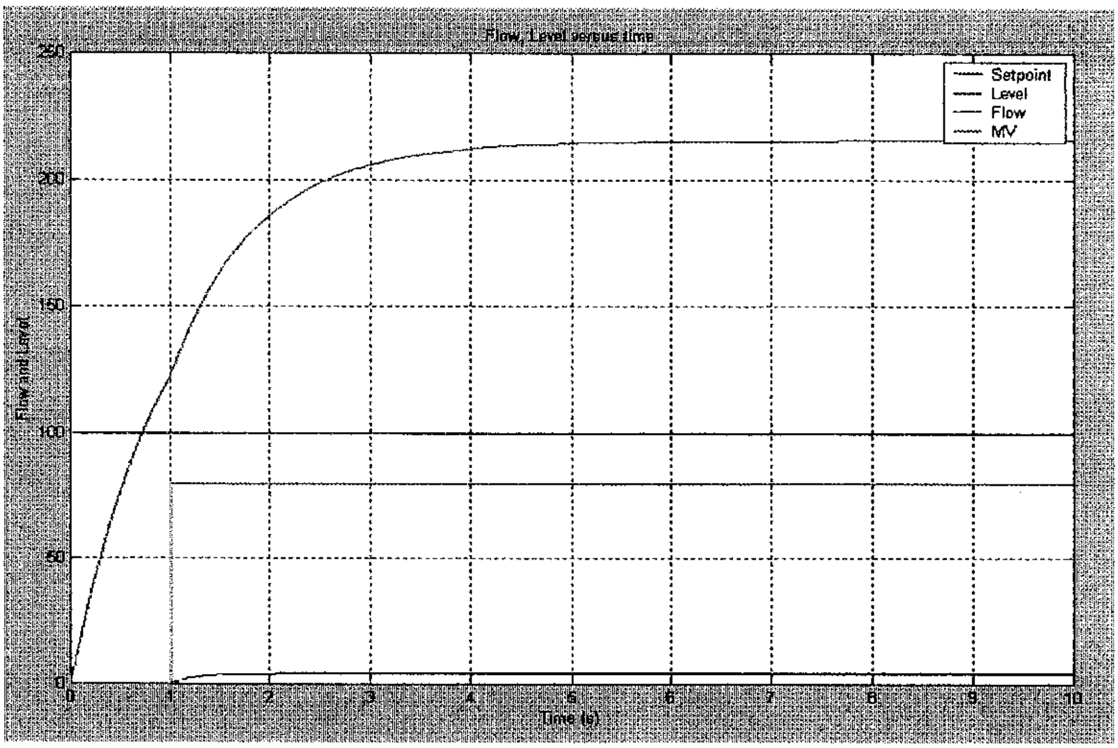
Table 10: Identify parameters for flow process

MV Step Change	K_p	τ_p
30% → 50%	0.053 m^3 / h	0.24 min
30% → 60%	0.068 m^3 / h	0.60 min
30% → 70%	0.073 m^3 / h	1.2 min

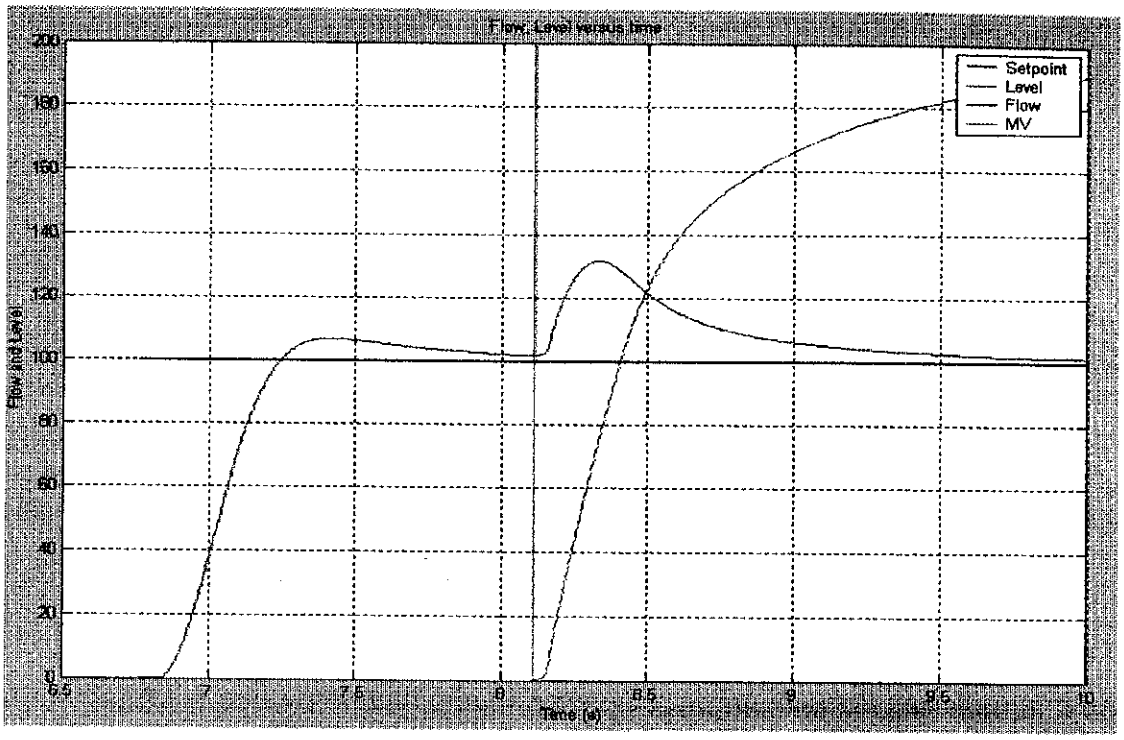
SIMULATION RESULT



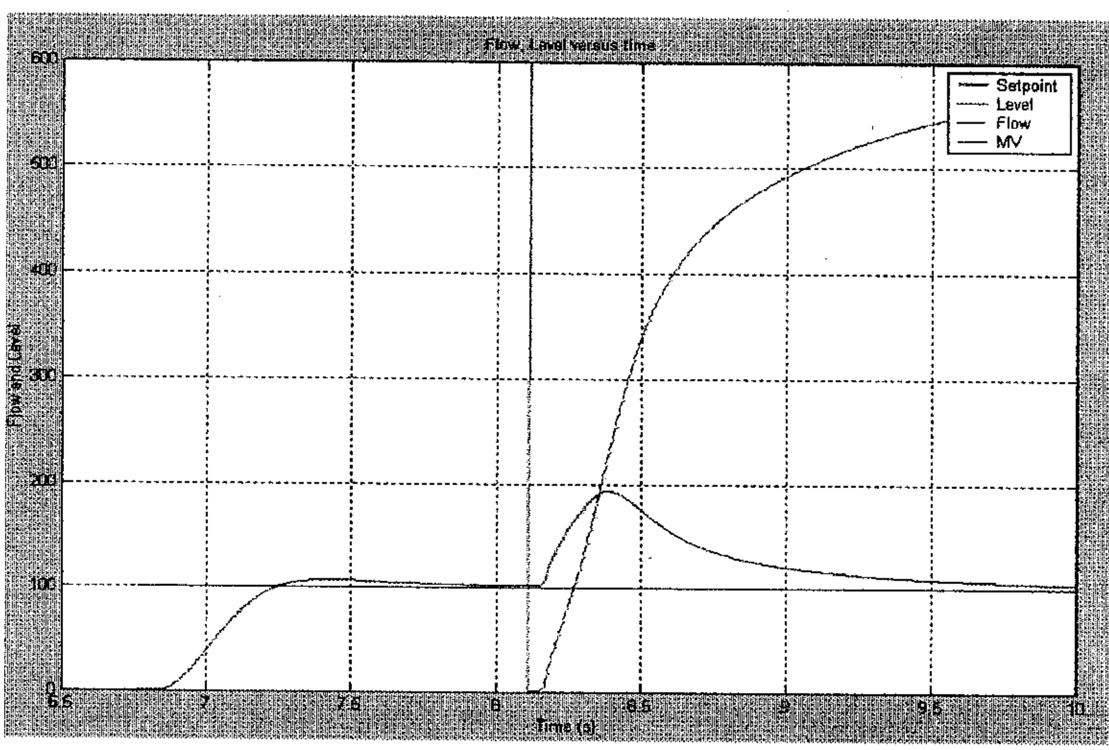
Graph 3: Graph produced for step change 0 % to 20% of valve opening in the open loop test



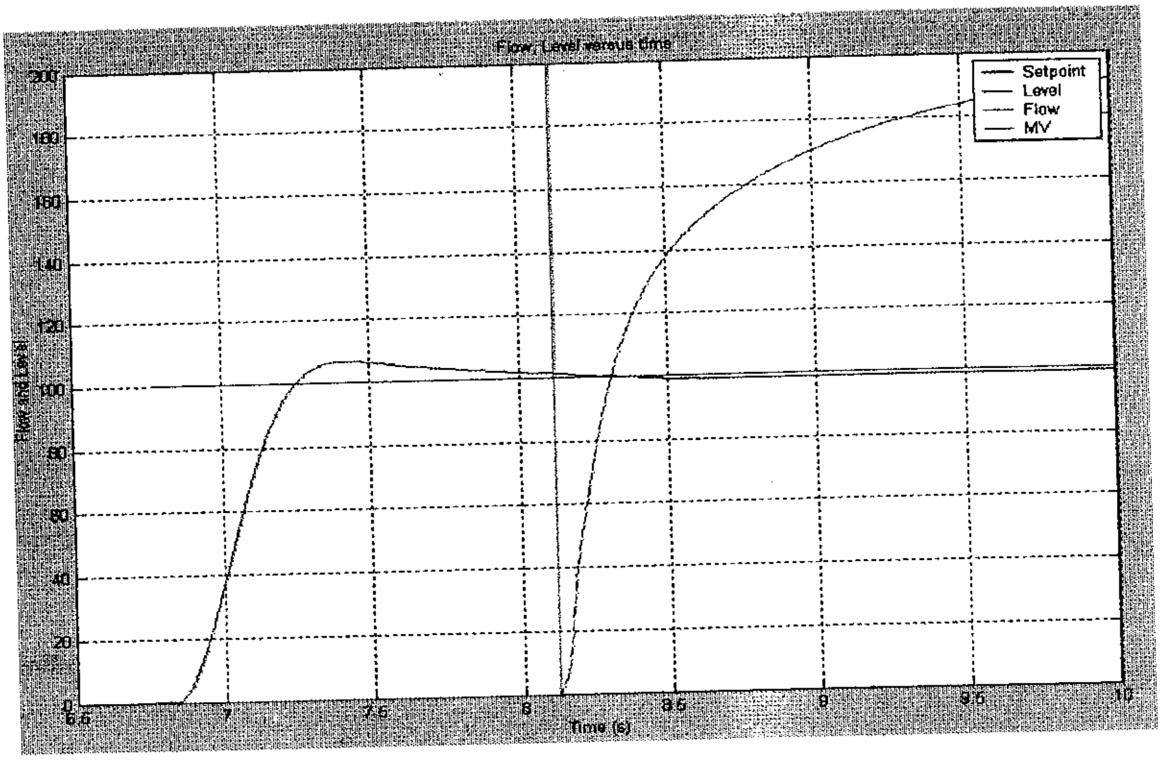
Graph 4: Graph produced for step change 0 % to 80% of valve opening in the open loop test



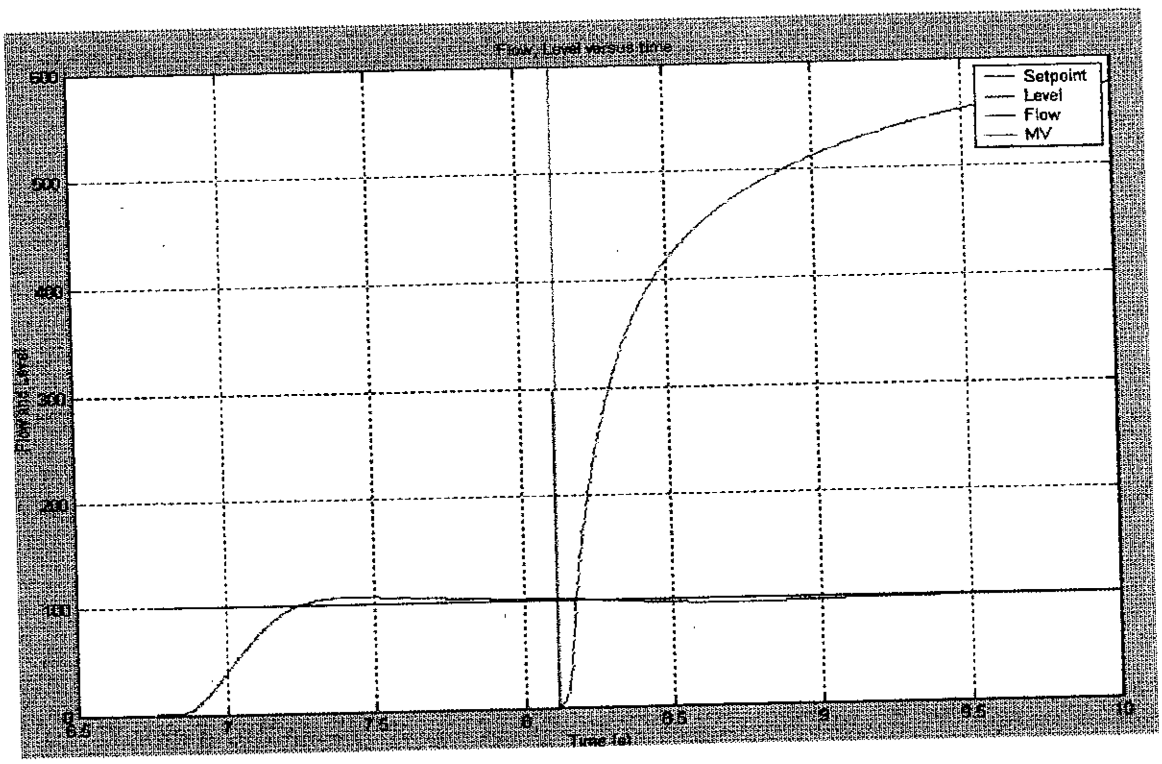
Graph 5: Graph produced for step change from 0 m^3/hr to 200 m^3/hr in the closed loop with PID controller



Graph 6: Graph produced for step change from 0 m^3/hr to 600 m^3/hr in the closed loop with PID controller



Graph 7: Graph produced for step change from 0 m^3/hr to 200 m^3/hr in the closed loop with PID controller plus decoupler



Graph 8: Graph produced for step change from 0 m^3/hr to 200 m^3/hr in the closed loop with PID controller plus decoupler