

**AN INTERACTIVE LEARNING OF PROCESS CONTROL
THROUGH SIMULATION OF HEAT EXCHANGER USING
MATLAB SIMULINK.**

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by

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**Thesis submitted in partial fulfillment of the requirement
for the degree of Bachelor of Chemical Engineering**

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LIST OF SYMBOLS

	Symbols	Unit
θ	Dead Time	minutes
τ_D	Derivative Gain	minutes
τ_I	Integral Gain	1/minutes
K_p	Steady State Process Gain	-
τ	Time Constant	minutes

LIST OF ABBREVIATIONS

Abbreviations

GUI	Graphical User Interface
PID	Proportional-Integral-Derivative
	Control Algorithm
Sync	Synchronize

PEMBELAJARAN INTERAKTIF KAWALAN PROSES MELALUI SIMULASI PENUKAR HABA MENGGUNAKAN PERISIAN MATLAB SIMULINK.

ABSTRAK

Kerjaya jurutera proses amat penting di hampir setiap industri di seluruh dunia. Hal ini kerana, sistem kawalan memainkan peranan yang besar dalam setiap industri terutamanya dalam kebanyakan industri kejuruteraan. Oleh itu, negara kita memerlukan jurutera proses yang kompeten untuk mengekalkan parameter pada nilai yang dikehendaki dan pada masa yang sama memastikan keselamatan di loji. Walau bagaimanapun, banyak pelajar universiti tidak mempunyai minat dalam pembelajaran kawalan proses. Konsep pengawalan proses tidak berjaya menarik minat para pelajar. Oleh itu, ramai pelajar tidak berminat untuk belajar kawalan proses secara mendalam kerana mereka mempunyai pemikiran bahawa kawalan proses sukar difahami dan membosankan. Dalam karya ini, pendapat para pelajar mengenai subjek kawalan proses telah dikenal pasti melalui kaedah penilaian bercampur. Keputusan yang diperolehi daripada kaji selidik menunjukkan bahawa majoriti pelajar memilih simulasi masa nyata untuk diperkenalkan dalam pengajaran kawalan proses bagi membantu mereka memahami kawalan proses dengan lebih baik. Para pelajar diminta untuk menggunakan program simulasi yang disediakan dan kaji selidik pasca simulasi dibuat untuk mendapatkan maklum balas pelajar mengenai program simulasi. Keputusan dari kaji selidik itu menunjukkan bahawa 4 daripada 9 peserta dengan latar belakang kawalan proses dan 5 dari 8 peserta tanpa latar belakang kawalan proses dapat skor dengan baik dalam kuiz yang disediakan untuk menguji pemahaman mereka mengenai program simulasi ini.

AN INTERACTIVE LEARNING OF PROCESS CONTROL THROUGH SIMULATION OF HEAT EXCHANGER USING MATLAB SIMULINK.

ABSTRACT

Process engineer career is gaining importance in almost every industry worldwide. This is because, control system plays a huge role in every industry especially in many engineering industries. As such, our country requires competent process engineers to maintain the desired production capacity and at the same time ensure safety in a plant. However, many university students have little or no interest in learning process control subject.. As such, many students restrict themselves from learning process control deeper as they have a mindset that process control is difficult to understand and boring. In this work, students' opinions regarding process control subject was identified through a mixed-mode assessment method. The results obtained from the survey are analyzed. It shows that majority of the students prefer real-time simulation to be introduced in the teaching method of process control for them to understand process control better. Hence, a real-time virtual laboratory has been created for the simulation of heat exchanger using MATLAB Simulink. The students were asked to work on the simulation program and a post-simulation survey was created to obtain students' feedback on the simulation program. The results from the survey show that 4 out of 9 participants with process control background and 5 out of 8 participants without process control background are able to score well in the quiz questions which were prepared from to test their understandings on this simulation programme.

CHAPTER ONE : INTRODUCTION

1.0 Introduction

Chapter one introduces the overview of this research and how interactive learning can be implemented in process control course with the formation of virtual laboratory using MATLAB Simulink. In general, this chapter outlines the research background of interactive learning of process control, the problem statement and objectives of this study along with the scope of work.

1.1 Process Control

Process control is a key technology for developing and introducing sustainable solutions in the aspect of safety and plant operation in the process industry sector. It is the job of a process engineer to improve a process design and to control the process in a chemical industry. It is an active changing of a process based on the process monitoring results. Usually, the authority responsible for the process makes a change to bring the process back into control, once the process monitoring tools have detected an out-of-control situation. However, nowadays, the improvement of control system technology has made it possible to be done automatically by the control system itself. Almost all unit operations in a chemical industry can be controlled using control system in order to obtain

the desired result. Those unit operations are heat exchanger, reactor, expander, evaporator etc. Other than reactor, heat exchanger is also one of the equipment that is commonly being used in different industrial operations. Its applications also various such as heating, cooling, condensation or evaporation process. Heat exchanger can support wide range of temperature and pressure of a process fluid used in a plant. The main use of a heat exchanger system is to transfer heat from a hot fluid to a cooler fluid. Heat exchanger can be classified into different types, namely, shell and tube heat exchanger, plate heat exchangers, finned tube heat exchanger, adiabatic wheel heat exchanger etc. Shell and tube heat exchanger is one of the important types of heat exchanger among the various types of heat exchangers. This is because it is widely used in power generation, refineries and petrochemical industries, medical applications, refrigeration and heating and air conditioning. As a result, the students have higher chance to encounter or work with a heat exchanger in the future if they employed as a process engineer in a manufacturing plant. Other than that, the working principle of a heat exchanger is quite simple to understand even for participants without prior knowledge on process control. Therefore, in order to get an accurate result solely on the efficiency of this simulation programme in contributing as a successful interactive learning tool, a simple unit operation, such as the heat exchanger is chosen as the main subject of this simulation programme.

1.2 Importance of Process Control

It is vital for process engineers to be aware that modern plants have become much more difficult to operate as most of the processes are highly integrated. It is challenging to hinder disturbances from propagating from one unit operation to another in those complex plants. However, with the aid of process control engineering, the solutions for most problems can be found, including the one stated above. The processes can be monitored and influenced as they take place. This is made possible by the measurement and control of variables such as flow rate, pressure, temperature, and concentration. As a result, the knowledge of process control is very important for an engineering student, especially for those related to the process engineering sector. With the proper knowledge on process control subject, they will be able to ensure an efficient plant operation and at the same time improve the safety factors of a plant.

The similar concept applies to heat exchanger also as process control is one of the important elements in the performance of a heat exchanger. The main use of a heat exchanger system is to transfer heat from a hot fluid to a cooler fluid. Hence, the temperature control of the outlet fluid is very important in a heat exchanger. In order to control the outlet temperature of the fluid, a controller should be used. Generally, a PID controller, Fuzzy Logic controller or Neural Network Controller is used in chemical industries for this purpose. Therefore, the basic knowledge on the concept of process control design plays a vital role here as it deals with important techniques that can optimize the heat transfer process in a heat exchanger to ensure a desired outlet temperature of the

process fluid is obtained. Thus, it is beneficial for chemical engineers to be able to develop mathematical models using software tools for process control simulation as it can be a great help for better understanding of the basic concept of process control in real life industry.

1.3 Problem Statement

A typical challenge for students to learn process control is the difficulty in understanding the application of control theories to real scenarios. The amount of energy and efforts they use up in the process of learning control system bears no relation to the understanding they achieve at the end of each learning session. This leads to loss in interest and reinforcement of the learning of process control among students. As a result, they cannot perform well as a competent process engineer later during their working life.

In addition to that, the available process control based physical laboratories are still suffering from poor accessibility as not all students can access it at a same time. The access restrictions in terms of the available number of equipment and building access limited to normal working hours affect students' comforts and enthusiasm especially for experiments with slow dynamics.

Moreover, physical laboratories will often be expensive and may require significant ongoing support and expertise from staff to maintain and guide the students throughout the period of lab sessions. They need to thoroughly assist the students to avoid any unnecessary damage or problems on the costly equipment which may be caused by students during their trial and error process of learning. This will be time, labor and cost consuming, especially if the equipment involved is expensive and have limited availability.

Therefore, it is utmost important to step into this problem and think of a solution before the nation get deprived of quality and competent process engineers. A survey is to be carried out on engineering students from a local university and a process control simulation programme is to be developed for learning purpose using MATLAB Simulink software to help students to grasp this critical course.

1.4 Research Objectives

The objectives of this work are as follow:

- i) To build a Simulator (simulation programme) using Heat Exchanger mathematical model through MATLAB Simulink software.
- ii) To introduce a real-time simulation in the simulator.
- iii) To obtain pre-simulation and post-simulation feedback from students on their perspective and understanding on process control/control system.

1.5 Scope of Work

In this research, survey plays a huge role to analyze and obtain students' opinions and perspectives on process control subject. The survey carried out was a mixed-mode, consisting of both qualitative and quantitative analysis as both methods have their own plus-points and drawbacks (Leydens et al., 2004). The subject of this study is the heat transfer in a heat exchanger which has most direct relevance to chemical engineering discipline. However, the study conducted does not restrict to chemical engineering students only. Students from other engineering background are welcomed as well to involve in the survey and research, as heat exchanger is a common system in chemical engineering and indeed in most engineering field as well (Rossiter, 2017). Engineering students from a local university, Universiti Sains Malaysia (USM), could participate in this study. This limitation is done to improve the effectiveness of this survey results as different universities may have different methods of teaching process control. The targeted numbers of participants are around 20 students and the participation of this survey is completely voluntary as the main purpose of this survey is to obtain a quality result on students' opinion on process control and not to obtain high quantity results. Social media were used as a medium for publishing this survey.

After a handful of results obtained, it was then analyzed, and the results were compiled into a chart. Based on that result, it was obvious that students are having quite a difficult time to understand process control and they prefer to study it through any simulation program. Hence, a simulation of heat exchanger was done using Simulink software which mainly focuses on studying the heat transfer. A real-time sync block was added in the Simulink block

diagram to view the results in real time. Once the simulation was done, a controller was added to the process. Some of the important variables such as manipulated and controlled variables and the set point were identified, and adjustable knobs were installed for each of those variables. This is to make the simulation program a user-friendly and easier for participants to understand the effects of changing these parameters on the outlet temperature of the product stream. The students are again, voluntarily invited to work on the simulation program before they were asked to fill up another feedback survey. This survey is to identify the effectiveness of the simulation program in improving students' understanding on the working principle of a heat exchanger and on process control subject. Unlike previous works done by other researches, this paper focuses on real-time simulation of the heat exchanger for the students to get a clear picture on how heat is being transferred rather than normal simulation which just emphasize on the result obtained.

CHAPTER TWO : LITERATURE REVIEW

2.0 Introduction

This chapter introduces the key terms used in this study and compares the studies done by other researchers previously. Studies on Interactive Learning (IL), mathematical model formation and different types of assessment methods and virtual laboratory can be found in this chapter.

2.1 Interactive Learning (IL)

Interactive learning (IL) is a learning process that can engage the students in wrestling with the study materials. The boundaries between lecturers and student become vague as they become partners in the journey of knowledge acquisition. The concept of flipped-classroom, one of the approach of IL, able to boost students' engagement and enthusiasm by placing the student, not the lecturer at the centre of learning process. This approach is aimed to encourage students to prepare earlier for a much richer learning experience.

There are many papers reported successful studies of integrating IL into undergraduate educations. Throughout the years, IL has been exploited in many ways. Interactive video lectures were prepared by embedding Interactive Learning Activities (ILAs) in between video clips. It provided learner-content interaction to the students and improves their learning

comprehension and retention ability (Hung et al., 2018). Apart from utilising video lecturers, IL has been introduced with simulations using software and physical laboratories to provide the students with real-life experience. According to Feisel & Rosa (2005), digital simulators can expand undergraduate digital design education without burdening the students in terms of work load.

The use of software as a part of interactive learning is in line with the latest Education Blue Print of Malaysia (2013-2025). The Ministry of Education of Malaysia has emphasised the importance of integrating technology-based teaching-learning environment in the education system. Besides preparing students to the current era, technology such as software is also able to induce proactive and dynamic thinking among students. Lim (2017), presented a study on using a design software, known as Technology Enhanced Learning (TEL) intervention to solve problems related to Fluid-Solid system subject. The software able to generate solutions for many typical engineering design problems with a detailed calculation steps for these problems. The students were given few mini-projects which involved the use of the software for them to involve in repeated practice of using the software. There are also successful researches conducted in the past by integrating the fuzzy logic model for diagnosing on-line defects (Charpentier, 2002) and neural network model (Lee and Park, 2000) in process control courses.

Integrating mathematical simulation software (MATLAB Simulink) has been introduced in chemical process control course for upper-division undergraduates in Villanova University (Li and Huang, 2017). The user-friendly interface of MATLAB Simulink enables easier simulations of mathematical models into a palette of Simulink block diagrams. Thus, IL

using MATLAB Simulink is proven to enhance students' understanding of process control concepts as they gradually adapted to flip-classroom approach.

Campbell et al. (2002) presented the use of Electronic Laboratory Simulator (ELS) to the junior year students of electrical engineering. He studied the efficacy of integrating software simulations of electronic circuit laboratories in education curricula of electrical engineering. Students who work on a combination of both simulated and physical labs performed significantly better on their test compared to those work completely on physical labs.

2.2 Simulations of the Process

The mathematical models to simulate the heat exchanger have been carried out in different ways. Padhee et al. (2011) presented the development of an internal model based PID controller for shell and tube heat exchanger system. A controller functions to control the temperature of the outlet fluid of the heat exchanger in the shortest possible time. The main purpose of this research is to overcome the high overshoot problem that will be normally exhibited by a classical PID controller. Besides that, internal model controller has only a single tuning parameter which is the closed loop time constant. This makes the tuning of the internal model controller to be much easier than the conventional one. As a starting point, few assumptions have been considered in this research. Those assumptions are as listed below:

- 1) The inflow and the outflow rate of fluid are same.
- 2) The heat storage capacity of the insulating wall is negligible.

Few disturbances were also identified in this process, which are the flow variation of input fluid and the temperature variation of the fluid. By using an available experimental data, a single input-single output model of the heat exchanger has been built. A process reaction curve was plotted, and significant values were obtained from the curve. Using all the values obtained, the PID controller parameter values were solved using Ziegler-Nicholas frequency response tuning criteria. The internal model controller was then developed using Simulink block diagram. The diagram is shown in Figure 2.1.

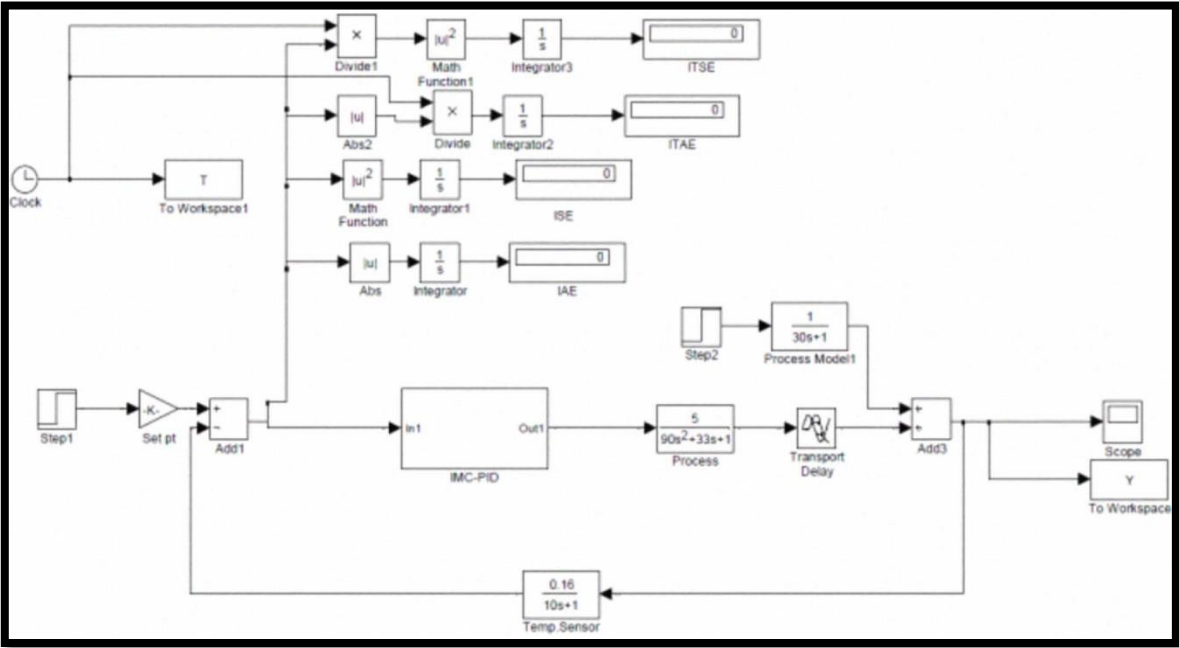


Figure 2.1: The Simulink Model of Internal Model based PID Controller (Padhee et al., 2011)

Other than using transfer functions, Ordinary Differential Equation (ODE) of heat exchanger also have been used to build the model of heat exchanger (Ch'ng K., 2015) studied

about modeling, simulation and control of heat exchanger using ODE equations of a heat exchanger. Similar to the previous journal, few assumptions were made before carrying out the simulation.

Those assumptions are listed below:

- 1) Assume heat capacity and density is constant.
- 2) Assume heat transfer coefficient is constant.
- 3) Assume the temperature of fluid in the heat exchanger is equal to the temperature of fluid in the outlet of heat exchanger.

Then, the ODE equations were developed, and the Simulink block diagram was created. The simulations were allowed to run, and the results obtained were analyzed.

Zeeshan et al. (2014) also have studied about the development of a control system for Shell and Tube Heat Exchanger in MATLAB Simulink. The main objective of this article is to analyze the effect of changing flow rate to the desired outlet temperature of fluid. Mathematical equations were modeled in MATLAB Simulink and Model Predictive Controller (MPC) was used to control the system. In this study, hot gas was used as heating fluid while cold water was used as heating fluid. Both have similar specific heat capacity but varying mass flow rate. The cold fluid enters the system at 32 °C while the hot fluid enters at 58 °C. The detailed parameters values are attached in the appendix. Number of transfer Units (NTU) effectiveness method was used to calculate the desired outlet temperature of fluid and the value obtained was verified using MATLAB Simulink. Cold fluid with a mass flow rate of 0.1 kg/s was able to achieve an outlet temperature of 33.04 °C with an error of 8 % from the experimental result.

Besides that, Schulz, (2004) has carried out simulation of heat exchanger using MATLAB/Simulink operator interface. The cold side fluid is at a temperature of 20°C while the side fluid consists of hot air at a temperature of 100°C. Both the cold and hot fluid enters at a flow rate of 1.4 kg/s. The configuration of the heat exchanger in Simulink is shown in Figure 2.2.

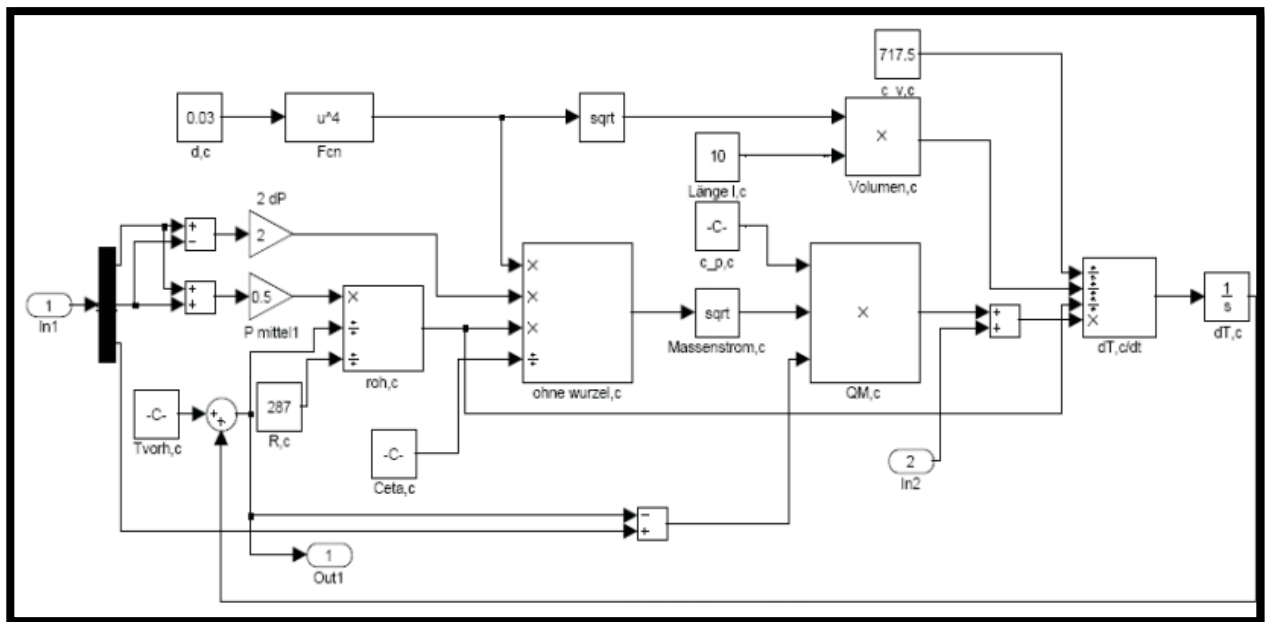


Figure 2.2: Configuration of Heat Exchanger in MATLAB/Simulink.

2.3 Assessment Methods

There are numerous data collection strategies and assessment methods that can be implemented in a research. These evaluation methods have an utmost importance to improve the outcome of a research study. It is also having the ability to determine the success or failure of an experiment. The basic types of assessment are qualitative and quantitative approaches, which would be usually used by engineering educators as a tool to improve their classrooms,

programs and institutions. Quantitative assessment method will result in numerical data while qualitative assessment enables the researches to better understand people’s opinions and their problems. The decision to use any of these approaches should depend entirely on the purpose of the investigation, not the comfort level of the researcher (Leydens et al., 2004). This article underscores several significant differences between qualitative and quantitative methods. Those differences are tabulated in Table 2.1.

Table 2-1: Differences between Qualitative and Quantitative Assessments (Leydens et al., 2004).

Quantitative Methods	Qualitative Methods
<ul style="list-style-type: none"> • Provide numerical descriptions in lieu of detailed accounts • Support generalisations about the phenomenon under study • Involves few variables and many cases • Break the phenomenon into analysable parts. • Suitable for large group of samples. 	<ul style="list-style-type: none"> • Provide detailed descriptions in lieu of numerical data • Elaborate human perceptions and motivations • Involves many variables and few cases • Study the whole phenomenon as it occurs. • Suitable for small sample sizes

From the observation done on the differences of both the methods, it can be concluded that both qualitative and quantitative methods have their own plus-points and drawbacks. Therefore, it is justifiable that some researchers prefer to use a mixed-mode approaches in their research. According to Leydens et al. (2004), there are several qualitative data collection

strategies such as observation, interviews and focus groups and documents like open-ended questionnaires while quantitative assessment normally involve close-ended questions. However, it is often mixed-mode research method will be used in the assessment of engineering education, as it is important to obtain detailed information from a subset of sample and generalized it across the related population.

Meanwhile, Diefes-Dux et al. (2004) introduced Kirkpatrick's level 1 evaluation method to assess the effectiveness of a computer simulation tool (FOODS-LIB) to perform an engineering design of an ice cream manufacturing process. Kirkpatrick's level method has a main aim of identifying learner's reactions towards their instructional materials prepared. There are several steps involved that an instructor may follow to make use of this evaluation method. Firstly, the instructor need to identify the purpose of his evaluation such as measuring students' perceptions to the instructional material. Then, he needs to design an evaluation form, which should simulate the students to give written comments, honest and immediate suggestions. It is important for the instructor to get to know the satisfaction and understanding level of his learner through the evaluation form. The results from this evaluation used to improve the instructional materials in the future. In order to triangulate this formative evaluation, quantitative and qualitative approaches were used together with Kirkpatrick's level 1 evaluation method.

A combination of conventional report-based and alternative method of in-class assessment also can be useful evaluation methods to evaluate students' performance and weaknesses in practical laboratory (Lal et al., 2018). In-class assessment used to indicate students' skills in performing laboratory experiment, collecting data and analysing pre-lab questions. These skills are following the Engineers Australia Accreditation guidelines..

Meanwhile, report-based assessment evaluates students' ability to write scientific reports, relate theory with the experiment and interpret data correctly. Second year students of Curtin University assessed through both assessments but at a different time and at the end of several lab sessions. Then a quantitative evaluation approach was used to measure the effectiveness of both assessments, namely report-based and in-class assessment. A survey method, consisting of close-ended questions was used to be answered by the students. The results obtained from the survey shows that students equally preferred both report-based and in-class assessments. Hence, a combination of both assessments can measure most of the technical, professional and personal skills of students in lieu of using each method separately.

2.4 Virtual Laboratory

Laboratory is a place where students will get a chance to get hands-on experience on the theories they have studied in classroom. Many lab-scale equipment that resembling the actual working principle of industrial equipment can be used by students to learn about many important concepts especially how heat transfer takes place from one fluid to another. However, the high purchase and maintenance cost of equipment limits the quantity of equipment that is available for the students at laboratory. As a result, students are not able to completely get benefits from the physical laboratory method as only certain number of students get chance to use particular equipment at a time. In order to prevent these kind of problems, online laboratory is introduced where there are two types of online laboratory namely, virtual laboratory and remote laboratory. Virtual laboratory does not involve the usage of any real equipment while remote laboratory is about conducting experiment remotely using the internet.

Virtual laboratory has more advantages from both remote and physical laboratories. It works based on software to simulate the actual lab environment. The usage of software such as MATLAB Simulink, LabVIEW and others will help to reduce the purchase cost of expensive equipment (Rohrig and Jochheim, 2002). At the same time, experiments that are too dangerous to be carried out by students can be easily done by virtual laboratories without causing any dangers. The students can repeat a similar experiment many times and learn on how changed parameters affect the outcome of the experiment. Most importantly, virtual laboratory is a place where students can do mistakes and learn from them, without causing any real damages.

2.5 Research Gap

Previously, researchers have studied about virtual laboratory by simulating a heat exchanger in their researches. Some of the researchers also have included a controller in order to control the process parameter. At the end of the simulation, feedbacks regarding the simulation programme were obtained through survey methods. However, none of the researches have included real time simulation in their study. Thus, in this study, a real time synchronization block is included to obtain the result of simulation in real time basis.

CHAPTER THREE : MATERIALS AND METHODS

3.0 Introduction

This chapter explains about the overview of research methodology, research methodology flowchart and detailed steps on how the study was conducted. It also includes the survey methods used to assess the students and method used to analyze the results obtained.

3.1 Overview of Research Methodology

In order to achieve the research objectives as mentioned in Chapter One, a simulation programme based on the working principle of heat exchanger was developed using the real-time Simulink software. The Simulink programme created is used to study the effectiveness of interactive learning of process control using MATLAB-Simulink programme.

Firstly, the perspective of USM engineering students on the process control subject is identified. This is done by carrying out a survey which acts as a medium for the students to pour out what they feel about process control and voice out their opinions on how the interactive learning of process control can be done to enable teaching and studying of process control to be more effective. The results of the survey were analyzed, and a real-time Simulation programme is developed with an added user-friendly interface. Finally, the simulation programme is provided to students to work on that and another feedback survey and a set of quiz were prepared to identify the effectiveness of the simulation programme.

3.2 Research Methodology Steps

The methods proposed for this study is constructed in a flowchart for better understanding. The flowchart has a sequence of events in order to ensure a successful project. The summary of methodology steps involved in this research work is shown in Figure 3.1.

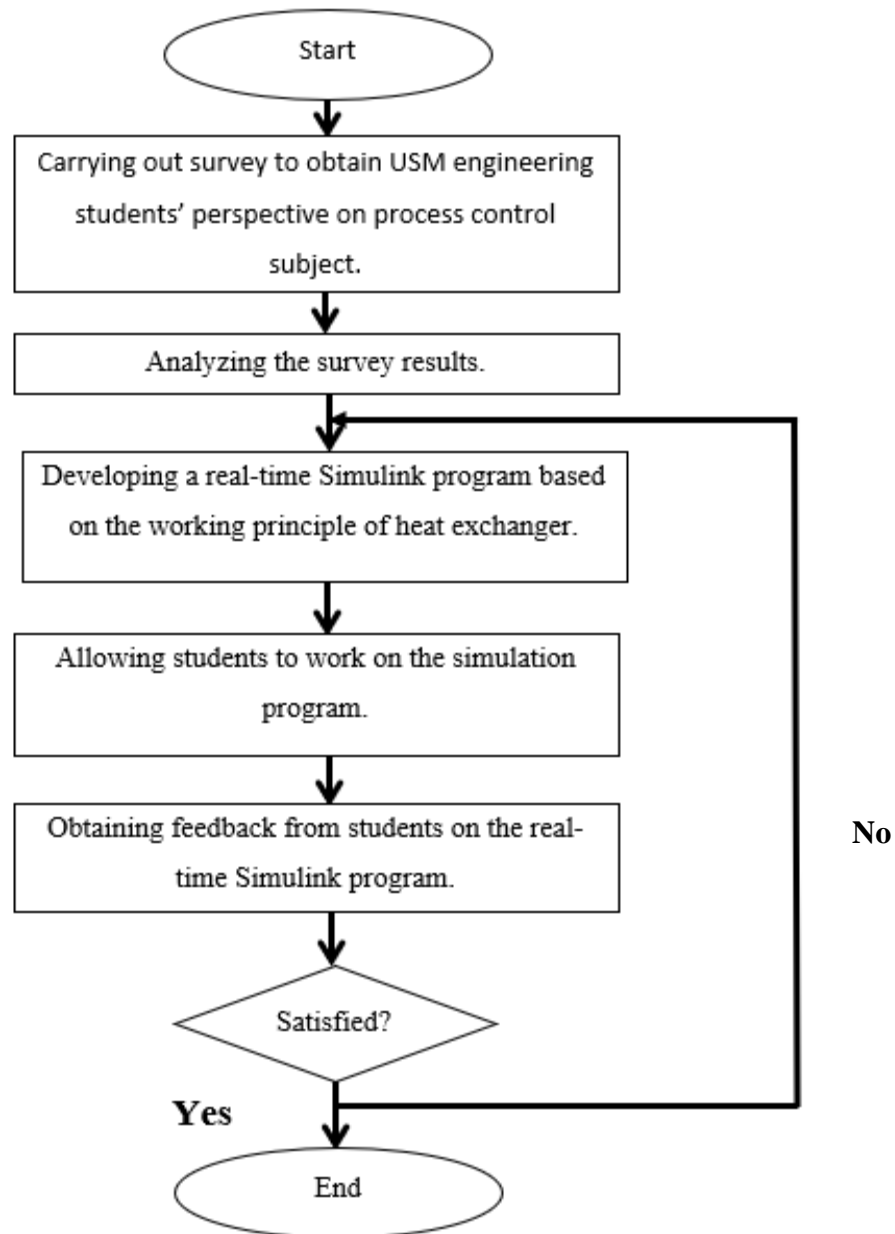


Figure 3.1: Flowchart of Methodology Steps Proposed for this Study.

3.2.1 Obtaining Feedback from USM Student's on their Perspective on Process Control subject.

3.2.1. a) Survey Method

Few methods were used to obtain feedback from USM students to identify their perspective on process control subject. Firstly, a survey was carried out in order to get to know students' enthusiasm level and perspective on process control subject. The targeted group was undergraduate students from Universiti Sains Malaysia(USM). Students from different engineering background are allowed to respond to this survey to obtain a general view on process control subject and not just limited to students from School of Chemical Engineering. The information about the survey is summarised in section **3.2.1.b**.

3.2.1. b) Summary of Pre-Simulation Survey Questions

Question 1: What do you feel about Process Control subject?

- a. Likes it very much
- b. Neutral
- c. No interest at all

Question 2: Do you want to learn Process Control/Control System in the future, if given a chance?

- a. Sure
- b. No

Question 3: Briefly explain, what is the problem you faced in understanding Process Control/Control System?

- a. Difficult to understand the basic concept itself
- b. Difficult to relate theories with real industry example
- c. Difficult in terms of building mathematical model, Laplace transform and simulation part.

Question 4: What do you feel about Process Control/Control System teaching in your institution?

- a. My lecturers are too emphasising on theory part of Process Control/Control System.
- b. My lecturers are great in teaching Process Control, I can understand easily.
- c. I am coming to the class just for the sake of attendance.

Question 5: Do you prefer to learn process control/control system in computer instead of learning theory?

- a. I prefer learning theory in class.
- b. Yes, I prefer to learn through computer.
- c. I prefer both

Question 6: In your opinion, how to make learning process control/control system interesting?

- a. Teach process control/control system using visualized and real-time simulation instead of teaching the theories.
- b. Exposing the students with basic concept of process control/control system is important.

3.2.2 Analyzing the Results

The survey was posted in social media such as Facebook and shared in WhatsApp groups which were identified to have potential number of participants. The results were collected after 10 days of time. It was compiled into a proper chart, together with the result of the interview. This is done to easily analyzing the results obtained. The responds obtained are also divided into two parts, which are Chemical Engineering Background and Non-Chemical Engineering Backgrounds. Similar responds for each of the questions and the number of the respondents for each answer options are carefully compiled. Meanwhile, the suggestions provided by the respondents take into consideration as well. The compiled results are shown in Chapter 4.

3.2.3 Developing a Real-Time Simulink Programme

Simulation is the designing the operation of a real-world process over time in a computer-based tool. A simulation of heat exchanger is carried out. This is followed with an addition of a real time synchronization block in the simulation programme to fulfill the third objective. Besides that, Graphical User Interface (GUI) was implemented in the Matlab Simulink programme as an additional work.

The process of simulating a process first requires that a model to be developed. In this research, the working principle of a heat exchanger is being simulated.

Few assumptions were made before carrying out the simulation:

- 1) Heat capacity and density is constant.
- 2) Heat transfer coefficient is constant.

3) The temperature of fluid in the shell side of heat exchanger is equal to the temperature of fluid in the outlet of heat exchanger.

Table 3-1: The Parameters and Values for Modeling, Simulation and Control of Heat Exchanger.

Property		Unit	Values	References
Shell side fluid-hot water	$T_{s,inlet}$	$^{\circ}C$	26.85	<i>Modelling, Simulation and Control of Heat Exchanger by using MATLAB, (Kevin Ch'ng Jun Yan,2015)</i>
	A_s	m^2	0.0254	
	ρ_s	kg/m^3	1000	
	$C_{p,s}$	J/kgK	200	
	F_s	m^3/s	0.1	
	m_s	kg	25.4	
Tube side fluid-cold water	$T_{t,inlet}$	$^{\circ}C$	96.85	
	A_t	m^2	0.0314	
	ρ_t	kg/m^3	1030	
	$C_{p,t}$	J/kgK	102	
	F_t	m^3/s	0.2	
	m_t	kg	32.34	
General Properties	T_{∞}	$^{\circ}C$	30.00	
	Δz	m	1	
	K	W/mK	400000	
	H	W/m^2K	500	

The parameter values for designing a heat exchanger model have tabulated in Table 3.1 while the ordinary differential equations is listed below:

Shell Side:

Rate of accumulation of thermal energy in Shell Side = Rate of energy in – Rate of energy out – Rate of heat transferred to tube-side fluid- Rate of heat loss to the surroundings.

$$\frac{m_s}{\rho_s F_s} \frac{dT_s}{dt} = (T_{s,inlet} - T_s) - \frac{kA_i}{\Delta z \rho_s F_s C_{p,s}} (T_s - T_t) - \frac{hA_d}{\rho_s F_s C_{p,s}} (T_s - T_\infty) \dots\dots\dots eq$$

(1)

Tube Side:

Rate of accumulation of thermal energy in tube-side fluid = Rate of energy in – Rate of energy out – Heat transferred from shell-side.

$$\frac{m_t}{\rho_t} \frac{dT_t}{dt} = F_t (T_{t,inlet} - T_t) + \frac{kA_i}{\Delta z \rho_t C_{p,t}} (T_s - T_t) \dots\dots\dots eq$$

(2)

Where,

- m = mass of the fluid (kg) = $\rho A_{cross\ sectional} \Delta z$
- ρ = density of the fluid (kg/m^3)
- $T_{s/t,inlet}$ = Inlet temperature of fluid (shell side/tube side) (K)
- F = Flow rate of fluid (m^3/s)
- $T_{s/t}$ = Outlet temperature of the fluid (shell side, tube side) (K)
- k = Heat-transfer coefficient between shell and tube
- A_i = Area of heat transfer between shell and tube (m^2)
- $C_{p,s/t}$ = Heat capacity of fluid (J/kgK)
- Δz = Length of tube (m)
- h = heat transfer coefficient between ambient and shell
- T_∞ = Ambient temperature (K)