MODELING AND CONTROL OF HEAT EXCHANGER BY USING BIO-INSPIRED ALGORITHM

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Dedicated to….

My beloved father and mother

Who has so much faith in me

Love you always

Also to my siblings

I could have never done it without you

To all my friends, who have stood by me through thin and thick

I treasure all of you

Thanks for showing me with love, support and encouragement

Life has been wonderfully color by you

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ABSTRACT

Heat exchanger is a heat transfer device that is used for transfer of thermal energy between two or more fluids available at different temperature. Based on the previous study referred, the same data of heat exchanger had been used but different types of model were used to find the structural model of heat exchanger. The main objective of this study is to obtain structural model using ARMAX equation and optimize the value of PID parameters. In this study, data from heat exchanger experiment was used to determine the parameter of ARMAX equation and by using GA and PSO, all the parameters were optimized. Transfer function obtained will be used for plant modelling. Validation test used to validate between normalised data input and error. Validation test used were autocorrelation and cross-correlation. Finally, applying PID controller onto plant modelling to optimize the value of Kp, Ki and Kd. The analysis shows that MSE value produce from GA is 0.0035473 while PSO's MSE value is 0.0043595. ARMAX parameters were obtained by using GA and PSO with 4 inputs (a0, a1, a2, and a3) and 4 outputs (b0, b1, b2 and b3). For GA, the inputs are -0.000214, -0.000728, -0.0020, and -0.000804 while the outputs are -1.0000, -0.1783, -0.1473 and 0.3248. For PSO, the inputs are 0.0104, -0.0122, -0.0067 and 0.0118 while the outputs are -0.4274, -0.1256, -0.1865 and -0.2614. From the validation test, GA produced smoother and effective result compared to PSO with less noise exists. By attaching PID controller, all the parameters value (Kp, Ki, and Kd) was optimized. For GA, the parameters are -0.5567, -54.1127 and 0.0005. For PSO, the parameters are -0.2846, -56.4346 and 0.0010. Even though both algorithms produced different simulation results, both of them succeed to reduce the result before attaching PID controller. As a conclusion, GA produces better result compared to PSO.

ABSTRAK

Penukar haba adalah alat pemindahan haba yang digunakan untuk pemindahan tenaga haba antara dua atau lebih cecair pada suhu yang berbeza. Berdasarkan rujukan kajian sebelum ini, data penukar haba yang sama telah digunakan tetapi berbeza jenis model yang digunakan untuk mencari model struktur. Objektif utama kajian ini adalah untuk mendapatkan model struktur dengan menggunakan persamaan ARMAX dan mengoptimumkan nilai parameter PID. Dalam kajian ini, data dari penukar haba eksperimen telah digunakan untuk menentukan parameter persamaan ARMAX dan dengan menggunakan GA dan PSO, semua parameter telah dioptimumkan. Rangkap pindah yang diterima akan digunakan untuk pemodelan tumbuhan. Ujian validasi digunakan untuk mengesahkan antara input data pulih dan kesilapan. Ujian validasi yang digunakan adalah autokorelasi dan silang korelasi. Akhir sekali, memohon pengawal PID ke pemodelan tumbuhan untuk mengoptimumkan nilai Kp, Ki dan Kd. Analisis menunjukkan bahawa nilai MSE hasil dari GA adalah 0.0035473 manakala nilai MSE PSO adalah 0.0043595. Parameter ARMAX diperolehi dengan menggunakan GA dan PSO adalah 4 input (a0, a1, a2, dan a3) dan 4 output (b0, b1, b2 dan b3). Untuk GA, data masuk adalah -0.000214, -0.000728, -0.0020, -0.000804 manakala data keluar adalah -1.0000, -0.1783, -0.1473, 0.3248. Untuk PSO, data masuk adalah 0.0104, -0.0122, 0.0067, 0.0118 manakala data keluar adalah -0.4274, -0.1256, -0.1865, -0.2614. Daripada ujian pengesahan, GA menghasilkan hasil licin dan berkesan berbanding dengan PSO dengan kurang bunyi. Dengan melampirkan pengawal PID, semua nilai parameter (Kp, Ki, dan Kd) telah dioptimumkan. Untuk GA, parameter -0.5567, -54.1127 and 0.0005. Untuk PSO, parameter -0.2846, -56.4346 and 0.0010. Walaupun kedua-dua algoritma menghasilkan keputusan simulasi yang berbeza, mereka berjaya untuk mengurangkan hasil keputusan. Kesimpulannya, GA menghasilkan keputusan yang lebih baik berbanding dengan PSO.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Heat exchanger is a heat transfer device that is used for transfer of thermal energy between two or more fluids available at different temperature. It is commonly used in industries in almost all process and power plants to generate steam for the main purpose of electricity to generation via steam turbines (Yiu,2007). In most heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or in direct contact. Common examples of heat exchangers are familiar to us in day-to-day use are automobile radiators, condensers, evaporators, air preheaters, and oil coolers (Sha,2003).

The most commonly used types of heat exchanger in industries are shell and tube heat exchanger. It consists of a bundle of tubes and a shell. One fluid that needs to be heated or cooled will flows through the tubes and the second fluid runs over the tubes that provides the heat or absorbs the heat required (Sha,2003). Heat transfer for both fluids are depends on its flow velocity. The primary heating medium commonly used for heat exchanger is water vapor because it is inexpensive and readily available. Many plants that carry out the process of heat transfer have a boiler to produce water vapor and the cooling medium that usually used is also water.

During the process, the heating medium will flow through the inlet tube shell of heat exchanger while the cooling medium will flow through the outer shell which surrounds the tube of heat exchanger. As mentioned before, both heating and cooling medium will not mix together. It is mean that there are two tubes and vessels inside the heat exchanger where the heating medium will flow using the inside tube while the cooling medium flow using the outside tube of heat exchanger.

The hot fluid transfers its heat to a conductive surface between it and cold chamber; subsequently the partition transfers the heat to the cold fluid. This follows the second law of thermodynamics which states that the heat always flows from a higher to a lower temperature. The real system of heat exchanger that will be used in this project is a shell and tube type of heat exchanger. The detail flow process of heat exchanger will be deeply discussed in Chapter 2.

1.2 Problem Statement

From previous research, in order to identify a model structure of heat exchanger, a lot of methods had been used such as ARMAX method, RELS method, AR method and polynomial method to derive the relationship between input and output obtained. It uses the same data but different types of model.

In this project, method that will be used in order to find the structural model for heat exchanger is ARMAX model. Genetic Algorithm (GA) and Particle

Swarm Optimization (PSO) will be used to optimize the values of each parameter involves. Both structural models will be compared to see its validation using autocorrelation and cross-correlation. If both structural fit perfectly, the project will then be continue with applying the PID controller.

1.3 Objective

In order to accomplish this project, there are a few objectives that have to be achieved. The objectives include;

1. To obtain a mathematical model of heat exchanger by using ARMAX equation.
2. To validate input and output data value from heat exchanger.
3. To obtained the value of Kp, Ki and Kd of PID controller in order to control the system.

1.4 Scope of study

The scopes of this study include;

1. Implement ARMAX model in heat exchanger
2. Optimize parameters using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO).
3. Validate the model with autocorrelation and cross-correlation test.
4. Using MATLAB PID tuner to obtained the value of Kp, Ki and Kd.

1.5 Expected Outcome

The expected result of this project is to design the experiment and obtain the data of Heat Exchanger through experimental design. The data obtained is used to find the transfer function of plant. Another approach that will be used to find transfer function is using ARMAX model. During the process, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) will be used to optimize the parameters value of ARMAX model. Therefore, we could obtain the parameter values and hence the transfer function between plant and ARMAX model can be compared.

1.6 Organisation of Dissertation

The content of this dissertation are organized into three chapters for this Master Project 1 and each chapter is written to be largely self-contained and complete.

Chapter 1 will go through the introduction about heat exchanger basic process. The idea is to be able to understand how the heat exchanger works. Hence, the process of obtaining data from the machine is much easier. Furthermore, the problem statement of this project also discussed as a guideline how the project will carry out to overcome the problem. Next, the research objectives and the research scopes are defined.

Before performing the detail of project process, detail explanation about the heat exchanger process will be discussed in Chapter 2. Furthermore, important elements that involved in this project also will be explained. For examples, the identification system involved, the optimization system used and the validation test upon the result produced. The important parts are the previous works done by other researchers are explored.

For Chapter 3, it describes the methodology involves in conducting the project in order to achieve the objectives of the project. The detail about plant description and experiment design will be discussed in this chapter. Furthermore, summary of genetic algorithm (GA) and particle swarm optimization (PSO) process also will be include to show the process during optimization of parameter involves.

For Chapter 4, it described the result obtained and discussed the cause of it. The detail about analysis of result will also be discussed in this chapter. The important part is, we can compared the result obtain for GA and PSO. Furthermore, we can also compare the plant results with and without PID controller. Parameters of ARMAX model and PID controller also could be optimized.

For Chapter 5, it described the conclusion and recommendations of this project. The conclusion is important to conclude all the result obtained. The recommendation is to give an idea for further research and improving the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The needs for energy and materials savings, as well as economic incentives, have prompted the need to develop more efficient heat exchangers. A preferred approach to the problem of increasing heat exchanger efficiency, while maintaining minimum heat exchanger size and operational cost, is to increase heat exchanger rate.

The heat exchanger is a device built for efficient heat transfer from one fluid to another, whether the fluids are separated by a solid surface or the fluids are directly contacted. One of the heat exchanger types that are commonly used in the process is shell and tube exchanger. For this project, the real system of heat exchanger that will be used is the shell and tube exchanger type.

These types of heat exchanger are widely used in process industrial applications. It is the most versatile and used in conventional and nuclear power stations as condensers, steam generators in pressurized water reactor power plants, and feed water heaters. They offer great flexibility to meet almost any service requirement. It can also be designed for high pressures relative to the environment and high pressure differences between the fluid streams. However, they are a lot of heat exchanger types offer in the industry. The other types of heat exchanger will be explained in the next subtopic.

2.2 Heat Exchanger Description

A heat exchanger is a device that is used for transfer of thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at differing temperatures and in thermal contact (Ogata, 1998). The fluids may be single compounds or mixtures. Typical applications involve heating or cooling of a fluid stream, evaporation or condensation of a single or multicomponent fluid stream, and heat recovery or heat rejection from a system (Chong,2000).

A heat exchanger consists of heat exchanging elements such as a core or a matrix containing the heat transfer surface, and fluid distribution elements such as headers, manifolds, tanks, inlet and outlet nozzles or pipes, or seals. Usually there are no moving parts in a heat exchanger; however, there are exceptions such as a rotary regenerator (in which the matrix is mechanically driven to rotate at some design speed), a scraped surface heat exchanger, agitated vessels, and stirred tank reactors (Kakac,2012).

In most heat exchangers, the fluids are separated by a heat exchanger surface, and ideally they do not mix. Although heat flows from hot fluid to cold fluid by thermal conduction through the separating wall, heat exchangers are basically heat convection equipment. Convection within a heat exchanger is always forced, and may be with or without phase change of one or both fluids. The basic designs for heat exchangers are the shell-and-tube heat exchanger and the plate heat exchanger, although many other configurations have been developed. According to flow layout, heat exchangers are grouped in (Thulukkanam,2000):

a) Shell-and-tube heat exchanger (STHE), where one flow goes along a bunch of tubes and the other within an outer shell, parallel to the tubes, or in cross flow. Figure 2.1a shows a typical example of STHE.

b) Plate heat exchanger (PHE), where corrugated plates are held in contact and the two fluids flow separately along adjacent channels in the configuration. Figure 2.1b shows details of the interior of a PHE.

c) Open-flow heat exchanger, where one of the flows is not confined within the equipment. They originate from air-cooled tube-banks, and are mainly used for final heat release from a liquid to ambient air, as in car radiator, but also used in vaporizers and condensers in air-conditioning and refrigeration applications, and in directly fired home water heaters. Figure 2.1c shows the example of open-flow heat exchanger.

d) Contact heat exchanger, where the two fluids enter into direct contact. Furthermore, the contact can be continuous such as when the two fluids mix together and then separate by gravity forces, as in a cooling tower, or the contact can be alternatively with a third medium, usually solid, as in regenerative heat exchangers, like the rotating wheel. Figure 2.1d shows the hot gas heats the wheel whereas the cold gas retrieves that energy.

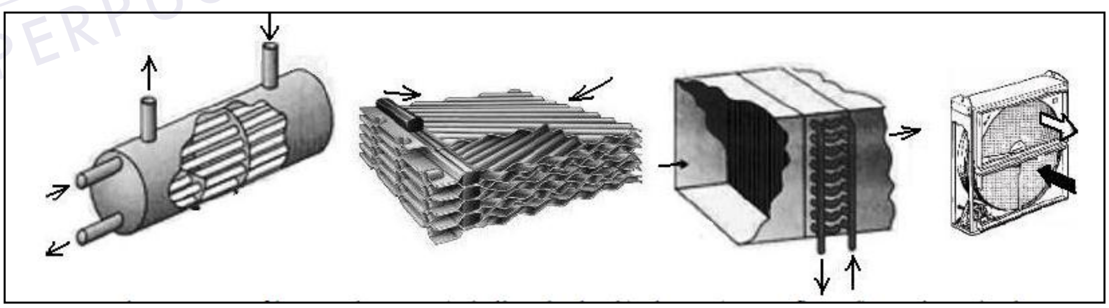

Figure 2.1: Types of heat exchanges: a) shell-and-tube, b) plates, c) open-flow, d) rotating-wheel (Thulukkanam,2000).

For this project, we are focusing on shell-and-tube exchanger types. This exchanger, shown in Figure 2.2, is generally built of a bundle of round tubes mounted in a cylindrical shell with the tube axis parallel to that of the shell. One fluid flows inside the tubes, the other flows across and along the tubes. The major components of this exchanger are tubes (or tube bundle), shell, front-end head, rear-end head, baffles, and tube sheets.

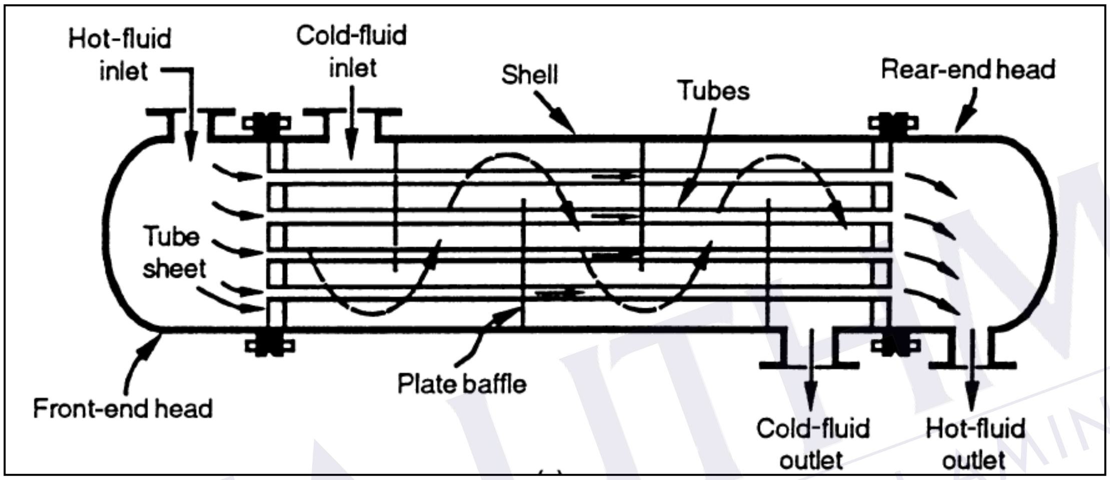

Figure 2.2: Shell-and-tube exchanger (Thulukkanam,2000).

Varieties of different internal constructions are used in shell-and-tube exchangers, depending on the desired heat transfer and pressure drop performance and the methods employed to reduce thermal stresses, to prevent leakages, to provide for ease of cleaning, to contain operating pressures and temperatures, to control corrosion, to accommodate highly asymmetric flows, and so on (Chong 2000). They are the most versatile exchangers made from a variety of metal and nonmetal materials (graphite, glass, and Teflon) and in sizes from small ($0.1m^2$, $1ft^2$) to super giant (over $100{,}000m^2$, $10^6 ft^2$) (Thulukkanam,2000). Here are the main advantages of shell-and-tube heat exchanger:

a) Condensation or boiling heat transfer can be accommodated in either the tubes or the shell, and the orientation can be horizontal or vertical.
b) The pressures and pressure drops can be varied over wide range.

c) Thermal stresses can be accommodated inexpensively.
d) The shell and tubes can be made of different materials.
e) Cleaning and repair are relatively straightforward, because the equipment can be dismantled for this purpose.

Therefore, the shell-and-tube heat exchangers are widely used in the industry since it offers a great flexibility to meet almost any service requirement.

2.3 MATLAB Software

The MATLAB® high-performance language for technical computing integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expected in familiar mathematical notation. It is high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. MATLAB is stands for matrix laboratory and is used in a wide range of applications. It is was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects, which together represent the state-of-the-art in software for matrix computation.

It features a family of application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow people to learn and apply specialized technology. Toolboxes are comprehensive collections of functions (M-files) that extend the environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others (Jimenez,2008). The interface is shown in Figure 2.3.

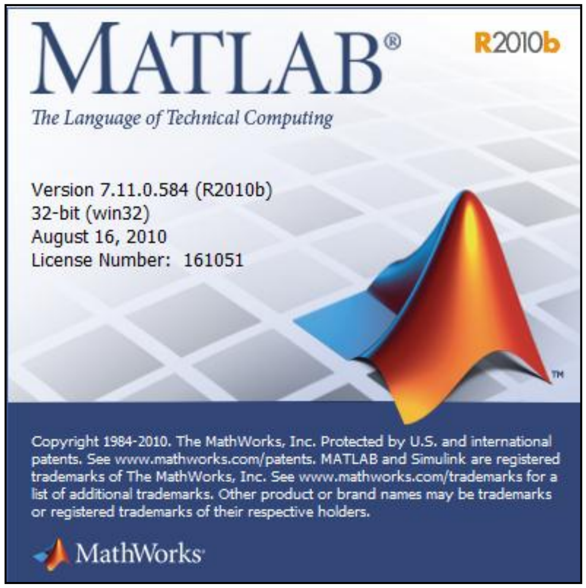

Figure 2.3: MATLAB R2010b Version

2.4 System Identification – ARMAX Model

System identification is the general process of developing a model for some particular system from given input-output data and the process of deriving a mathematical system model from observed data in accordance with some predetermined criterion. To solve this system identification, there are a lot of structures such as ARX (Autoregression with exogenous input) model, ARMAX (Autoregression moving average exogenous input) model, OE (Output Error) model and general polynomial model. In this project, the selected model structure that will be used is ARMAX model and estimation algorithm using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO).

The model for this identification is heat exchanger QAD BDT 921. For model validation, the identified model will be test using autocorrelation test and cross-correlation test. It is to verify that the identified model fulfills the modeling requirement according to subjective and objective criteria of good model approximation. The input-output data are sometimes recorded during a specifically

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