Designing a Virtual Laboratory of the Heat Exchanger Experiment by Artificial Neural Network (ANN)

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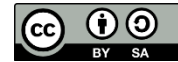
Abstract

A great number of universities worldwide are having their education interrupted, partially or fully, by the spread of the corona virus (COVID-19). Consequently, an increasing number of universities have taken the steps necessary to transform their teaching, including laboratory and workshops into an online or blended mode of delivery. Irrespective of the measures taken, universities must continue to maintain their high academic standards and provide a high-quality student experience as required for delivery of learning outcomes associated with each degree program. This has created a challenge across the higher education landscape, where academics had to switch to remote teaching and different approaches to achieving laboratory delivery. As a result, students have not been receiving face-to-face teaching, and access to laboratory facilities has been limited or nearly impossible. In this paper we are seeking to develop the heat exchanger laboratory and make it remotely by using the Matlab and Simulink tool using the artificial neural network (ANN) method instead of using the conventional way of modelling and simulating the system.

Keywords: Virtual Laboratory, Heat Exchanger, Artificial Neural Network, Matlab, Simulink Tool

Nomenclatures

ANN	Artificial Neural Networks
AI	Artificial Intelligence
C	Heat capacity
Cp	Specific heat capacity of water at constant
HEX	Heat Exchanger
LMTD	Logarithmic Mean Temperature Difference
ρ	Density of water
ŋ	Overall Efficiency

Q	Heat energy transferred for a unit mass
Q	Heat energy transferred for a unit time
Q_a	Heat energy (power) absorbed
Q_e	Heat energy (power) emitted
T	Temperature
ΔT	Change in temperature
U	Heat transfer coefficient
VH and VC	Volumetric flow rate (Hot and Cold circuit)

1. Introduction

The work helped to conduct experiments on heat exchangers available in university laboratories mainly in understanding this system, and knowing finding and calculating temperature differences at the inlet and outlet, whether in terms of hot inlet or cold inlet, and calculating its efficiency and other calculations. Related to it. Due to the spread of Corona virus (Covid 19) around the world, it has led to closures in all sectors. Among these vital sectors are universities and schools. The study was faraway, and this is reason enough to stop doing practical experiments in the labs, and switch to the theoretical side.

Therefore, it was our duty as students to find ways to complete these experiments even were distant, by creating programs that would find what was needed from each experiment by entering data as if we were in the laboratory.

In the field of education, virtual laboratories constitute a special category of simulations and are based on models of physical laboratories and the experimental processes taking place therein (Rossiter 2016). Technology enhanced simulation offers educators the ability to form an attractive and interactive learning environment so that learners become active participants in the educational process (Cook et al. 2013). There are virtual laboratories, which can be used by educators in order to create experiments for students in a variety of educational institutions, including high schools and universities. [1]

Nowadays, online virtual laboratories are considered a vital information and communication technology tool for teaching practical skills related to real laboratory experiments. [2]

Virtual laboratories (VL) are not tools that have emerged as a consequence of the pandemic; they have been an essential component of the e-learning process. UNESCO defines virtual laboratories as "an electronic workspace designed for remote collaboration and experimentation, or carry out other creative activities, and disseminate results using information and communication technologies". VL makes it possible to compensate for the lack of face-to-face experimentation. It is low cost, flexible, and advantageous to access as many times as the students require. [3]

Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other. Heat exchangers are commonly used in practice in a wide range of applications, from heating and air-conditioning systems in a household, to chemical processing and power production in large plants.

Heat exchangers differ from mixing chambers in that they do not allow the two fluids involved to mix. In a car radiator, for example, heat is transferred from the hot water flowing through the radiator tubes to the air flowing through the closely spaced thin plates outside attached to the tubes. Heat transfer in a heat exchanger usually involves convection in each fluid and conduction through the wall separating the two fluids. In the analysis of heat exchangers, it is convenient to work with an overall heat transfer coefficient U that accounts for the contribution of all these effects on heat transfer. The rate of heat transfer between the two fluids at a location in a heat exchanger depends on the magnitude of the temperature difference at that location, which varies along the heat exchanger. In the analysis of heat exchangers, it is usually convenient to work with the logarithmic mean temperature difference LMTD, which is an equivalent mean temperature difference between the two fluids for the entire heat exchanger [4].

2. The Proposed System Design

This project is a model that simulate two types of heat exchanger with the two types of water flow inside the parallel flow and counter flow. The simulation is done based on a practical experiment that we have carried out about the relation between the temperature of the water that flow through the hot inlet from the heater and the flow rate of it and the flow rate of the cold water that flow through the cold inlet. The model has been built and designed using the artificial neural network "ANN model" in Mat lab and Simulink.

2.1. ANN Model for Heat Exchangers

We have built and design the model using the Mat lab and Simulink tool using the artificial neural network ANN method instead of using the conventional way of modeling and simulating the system because by using this method our project will meet the new technology and science by of the Artificial intelligence "AI". The purpose and the objective of this model is to save time and cost while studying two types of heat exchanger (Shell & tube and plate) and the relationship between them, flow type, and flow rate with the water temperatures that flows from the inlet and outlet holes of them. We have built our model based on the data that we have collected form the practical experiment that we have carried out.

2.2. The Design and Modeling Procedures of the ANN Model

In the modeling and designing stage of the Shell and tube/ plate heat exchanger model using an ANN model, we have to identify the following:

First, ANN model can be implemented by to different ways. Which are:

(1) Single layer perceptron feed forward neural network. This type has input nodes and output layer, and it has neurons without feedback. This method is not accurate.

(2) Multi-layer perceptron feed forward neural network, which has input nodes, output layers, and one or more hidden layer of hidden neurons without feedback.

We have used the second way to implement our ANN model since it is more accurate due the feedback used in it.

2.3. ANN Model Training and Learning Method

ANN can be trained by three methods, which they are supervised learning, Unsupervised learning, or by error correction method. In our model, we have used the error correction method to train our model by using the data of the practical experiment that we did. By using this method, the model will compare its output with the desired output that we have obtain from the experiment. Then the difference between them will be computed. At each iteration of the ANN, this process is continued until the difference is zero.

2.4. Design and Modeling Process

After we set the previous point, we start the modeling and designing process for the heat exchanger plate and shell & tube in parallel and counter flow type. The first step is to set up the data we collected from the practical experiment on an excel sheet. Figure below

Table 1: Data of the Practical Experiments

HEX Type	Flow Type	Heater Temp, oC	Hot water inlet flow rate, L/min	Cold water inlet flow rate, L/min	Th1, oC	Th2, oC	Tc1, oC	Tc2, oC
1	1	40	3	1	40.7	39	18	23.2
1	1	40	3	1.5	40.6	38.6	17.9	21.9
1	1	40	3	2	40.6	38.4	17.9	21.2
1	1	40	3	2.5	40.9	38.5	17.9	20.8
1	1	40	3	3	40.6	38	17.9	20.5
1	1	40	3	3.5	40.5	37.8	17.9	20.2
1	1	40	3	4	40.4	37.6	17.9	20
1	1	50	3	1	51.3	48.5	18.6	27
1	1	50	3	1.5	50.5	47.4	18.6	25
1	1	50	3	2	51.2	47.3	18.6	24.1
1	1	50	3	2.5	51.3	47.4	18.7	23.4
1	1	50	3	3	51.2	47.1	18.8	22.8
1	1	50	3	3.5	50.7	46.5	18.8	22.4
1	1	50	3	4	51	45.6	18.9	22.1
1	1	60	3	1	60	56.1	18.6	30.3
1	1	60	3	1.5	60.3	55.8	18.5	27.6
1	1	60	3	2	60	55	18.4	25.9
1	1	60	3	2.5	60.1	54.8	18.4	25.3
1	1	60	3	3	60.2	54.5	18.4	24.1
1	1	60	3	3.5	60.1	54.3	18.5	23.4
1	1	60	3	4	60	54	18.5	22.9

HEX Type	Flow Type	Heater Temp, oC	Hot water inlet flow rate, L/min	Cold water inlet flow rate, L/min	Th1, oC	Th2, oC	Tc1, oC	Tc2, oC
1	1	40	1	3	41.2	36.6	18	19.5
1	1	40	1.5	3	40.4	36.9	18	19.7
1	1	40	2	3	40.6	37.6	18	20
1	1	40	2.5	3	40.8	38.1	18.1	20.3
1	1	40	3	3	40.6	38.1	18.1	20.6
1	1	40	3.5	3	40.4	38.1	18.1	20.8
1	1	40	4	3	40.3	38.2	18.1	21
1	1	50	1	3	51	44.1	18.9	21.1
1	1	50	1.5	3	49.5	44.4	18.9	21.4
1	1	50	2	3	49.6	45.2	18.9	21.7
1	1	50	2.5	3	50.7	46.4	18.7	22.2
1	1	50	3	3	50.7	46.8	18.7	22.5
1	1	50	3.5	3	50.3	46.9	18.6	22.8
1	1	50	4	3	50.9	47.3	18.6	23.1
1	1	60	1	3	59.9	50.6	18.6	21.6
1	1	60	1.5	3	58.1	51	18.6	22.1
1	1	60	2	3	57.5	51.3	18.7	22.7
1	1	60	2.5	3	58.8	52.8	18.7	23.5
1	1	60	3	3	60.5	54.8	18.8	24.3
1	1	60	3.5	3	60	54.8	18.8	24.6
1	1	60	4	3	60.7	55.8	18.8	25.2
1	2	40	3	1	40	37.9	14.5	20.7
1	2	40	3	1.5	40.2	37.7	14.5	19.3
1	2	40	3	2	40.1	37.5	14.6	18.4
1	2	40	3	2.5	40	37.3	14.7	18
1	2	40	3	3	40.1	37.2	14.9	17.9
1	2	40	3	3.5	40.1	37.1	15	17.5
1	2	40	3	4	40.2	37.1	15.1	17.4
1	2	50	3	1	50.3	47.6	17.5	25.8
1	2	50	3	1.5	50.4	47.3	17.5	23.9
1	2	50	3	2	50.2	46.7	17.5	22.7
1	2	50	3	2.5	50.4	46.7	17.6	22

HEX Type	Flow Type	Heater Temp, oC	Hot water inlet flow rate, L/min	Cold water inlet flow rate, L/min	Th1, oC	Th2, oC	Tc1, oC	Tc2, oC
1	2	50	3	3	50.6	46.6	17.7	21.6
1	2	50	3	3.5	50.5	46.3	17.7	21.1
1	2	50	3	4	50.4	46	17.7	20.8
1	2	60	3	1	60	55.9	17.9	30
1	2	60	3	1.5	59.9	55.3	17.9	27.3
1	2	60	3	2	60.1	55	17.9	25.4
1	2	60	3	2.5	60.3	54.9	17.9	24.3
1	2	60	3	3	60.3	54.6	17.9	23.5
1	2	60	3	3.5	60.3	54.4	17.9	22.8
1	2	60	3	4	60.2	54.1	17.9	22.3
1	2	40	1	3	40.1	35.4	16.3	17.8
1	2	40	1.5	3	39.5	35.9	16.5	18.1
1	2	40	2	3	39.9	36.8	16.6	18.6
1	2	40	2.5	3	40.3	37.5	16.8	19
1	2	40	3	3	40.5	37.9	17.3	19.8
1	2	40	3.5	3	40.6	38.2	17.4	20.1
1	2	40	4	3	40.5	38.3	17.5	20.4
1	2	50	1	3	49.6	43.2	18.5	20.6
1	2	50	1.5	3	49.7	44.5	18.5	21
1	2	50	2	3	49.8	45.2	18.4	21.2
1	2	50	2.5	3	50.9	46.5	18.3	21.8
1	2	50	3	3	50.5	46.5	18.2	22.1
1	2	50	3.5	3	50.4	46.7	18.2	22.4
1	2	50	4	3	50.3	46.9	18.2	22.6
1	2	60	1	3	57.4	48.7	17.7	20.5
1	2	60	1.5	3	57.2	50.3	17.5	20.7
1	2	60	2	3	58.1	51.7	17.2	21.2
1	2	60	2.5	3	59	52.9	17.3	22.1
1	2	60	3	3	60.1	54.3	17.5	23
1	2	60	3.5	3	59.9	54.6	17.7	23.7
1	2	60	4	3	60	55.2	17.9	24.3
2	1	40	3	1	40.6	39.5	16.2	19.2

HEX Type	Flow Type	Heater Temp, oC	Hot water inlet flow rate, L/min	Cold water inlet flow rate, L/min	Th1, oC	Th2, oC	Tc1, oC	Tc2, oC
2	1	40	3	1.5	41	39.7	16.5	18.9
2	1	40	3	2	40.6	39.3	16.6	18.5
2	1	40	3	2.5	40.2	38.9	16.7	18.2
2	1	40	3	3	40.3	38.9	16.8	18
2	1	40	3	3.5	40.4	39	16.9	18
2	1	40	3	4	40.5	38.9	17.1	18.2
2	1	50	3	1	50.8	49.4	17.7	22.1
2	1	50	3	1.5	51	49.4	17.6	21
2	1	50	3	2	50.9	49.2	17.7	20.4
2	1	50	3	2.5	50.7	49.1	17.8	20
2	1	50	3	3	50.7	48.8	18.1	20
2	1	50	3	3.5	50.7	48.7	18.2	19.9
2	1	50	3	4	50.7	48.6	18.3	19.8
2	1	60	3	1	60.9	59	18.3	23.9
2	1	60	3	1.5	60.9	58.8	18.3	22.6
2	1	60	3	2	60.9	58.7	18.3	21.9
2	1	60	3	2.5	61	58.6	18.3	21.3
2	1	60	3	3	61.3	58.7	18.4	20.9
2	1	60	3	3.5	61.2	58.3	18.4	20.6
2	1	60	3	4	61	58.1	18.4	20.4
2	1	40	1	3	41.4	38.6	17.2	18.1
2	1	40	1.5	3	40.9	38.8	17.2	18.1
2	1	40	2	3	41.2	39.4	17.2	18.3
2	1	40	2.5	3	40.6	39	17.6	18.8
2	1	40	3	3	40.5	39.3	17.7	19
2	1	40	3.5	3	40.6	39.4	17.8	19.1
2	1	40	4	3	40.5	39.4	17.8	19.3
2	1	50	1	3	51.3	47.6	18.4	19.5
2	1	50	1.5	3	50.7	47.9	18.4	19.4
2	1	50	2	3	51.3	48.8	18.3	19.9
2	1	50	2.5	3	51	48.9	18.1	19.8
2	1	50	3	3	50.9	49.1	18.1	20

HEX Type	Flow Type	Heater Temp, oC	Hot water inlet flow rate, L/min	Cold water inlet flow rate, L/min	Th1, oC	Th2, oC	Tc1, oC	Tc2, oC
2	1	50	3.5	3	50.7	48.9	18.1	20.1
2	1	50	4	3	50.5	49	18.2	20.3
2	1	60	1	3	60.8	56.1	18.5	19.9
2	1	60	1.5	3	59.9	56.2	18.5	20.2
2	1	60	2	3	60.4	57.2	18.5	20.4
2	1	60	2.5	3	61.4	58.5	18.5	20.7
2	1	60	3	3	61.2	58.6	18.5	21
2	1	60	3.5	3	61	58.5	18.6	21.2
2	1	60	4	3	60.9	58.6	18.5	21.4
2	2	40	3	1	41.2	40.2	18.2	21
2	2	40	3	1.5	40.8	39.7	18.2	20
2	2	40	3	2	40.9	39.7	18.2	20
2	2	40	3	2.5	40.7	39.6	18.2	19.7
2	2	40	3	3	40.8	39.5	18.1	19.5
2	2	40	3	3.5	40.8	39.4	18.1	19.3
2	2	40	3	4	40.8	39.4	18.1	19.2
2	2	50	3	1	51	49.6	18.3	22.3
2	2	50	3	1.5	50.1	48.6	18.3	21.3
2	2	50	3	2	51	49.3	18.3	20.8
2	2	50	3	2.5	50.7	48.9	18.4	20.5
2	2	50	3	3	50.7	48.8	18.7	20.6
2	2	50	3	3.5	50.7	48.8	18.8	20.4
2	2	50	3	4	50.7	48.5	18.8	20.4
2	2	60	3	1	60.4	58.4	18.5	24.5
2	2	60	3	1.5	61	58.8	18.5	23.1
2	2	60	3	2	61	58.6	18.5	22.1
2	2	60	3	2.5	60.6	58.1	18.5	21.5
2	2	60	3	3	60.6	58	18.7	21.3
2	2	60	3	3.5	61	58.3	18.7	21.1
2	2	60	3	4	60.6	58.6	18.7	20.9
2	2	40	1	3	41.7	39.1	18.2	19
2	2	40	1.5	3	41.7	39.7	18.3	19.3

HEX Type	Flow Type	Heater Temp, oC	Hot water inlet flow rate, L/min	Cold water inlet flow rate, L/min	Th1, oC	Th2, oC	Tc1, oC	Tc2, oC
2	2	40	2	3	41.2	39.6	18.3	19.5
2	2	40	2.5	3	40.9	39.4	18.4	19.6
2	2	40	3	3	40.8	39.5	18.4	19.7
2	2	40	3.5	3	40.6	39.5	18.4	19.8
2	2	40	4	3	40.7	39.6	18.4	19.9
2	2	50	1	3	51.4	47.8	18.8	19.9
2	2	50	1.5	3	50.9	48.1	18.7	20
2	2	50	2	3	50.8	48.5	18.7	20.2
2	2	50	2.5	3	51.1	49	18.7	20.3
2	2	50	3	3	50.9	48.9	18.6	20.5
2	2	50	3.5	3	50.6	48.9	18.8	20.7
2	2	50	4	3	50.6	49	18.6	20.8
2	2	60	1	3	61.1	56.3	18.8	20.3
2	2	60	1.5	3	60	56.2	18.7	20.5
2	2	60	2	3	60.3	57.2	18.6	20.6
2	2	60	2.5	3	60.9	58	18.6	20.9
2	2	60	3	3	60.8	58.1	18.5	21.1
2	2	60	3.5	3	60.8	58.3	18.5	21.2
2	2	60	4	3	60.7	58.5	18.5	21.4

In the excel sheet, we have split the data based on the type of the heat exchanger and the flow type that need to be selected to simulate the system as the following:

- We numbered all the data that related to the shell and tube type as one.
- We numbered all the data that related to the plate type two.
- We numbered all the data that related to the parallel flow as one.
- We numbered all the data that related to the counter flow as two.

After that, we have started to implement our ANN model using the GUI tool from MATLAB. From the command window, we wrote the following syntax "neural network tool" in order to open the GUI tool. This tool helps us to import and select the input and output data from the excel sheet and chose the parameters that needed to train the ANN model. We selected the following parameters:

(1) TRainLM for as the training function.
(2) Error correction method as adaption learning function.
(3) Based on the relationship between the input and output data, we have selected two hidden layers as we mentioned before. The first hidden layer with a symmetric sigmoid transfer function named as "TANSIG" and the second hidden layer with a linear transfer function named as "PURELIN".

The following figure shows our ANN model that we implement by using the GUI tool with two hidden layers.
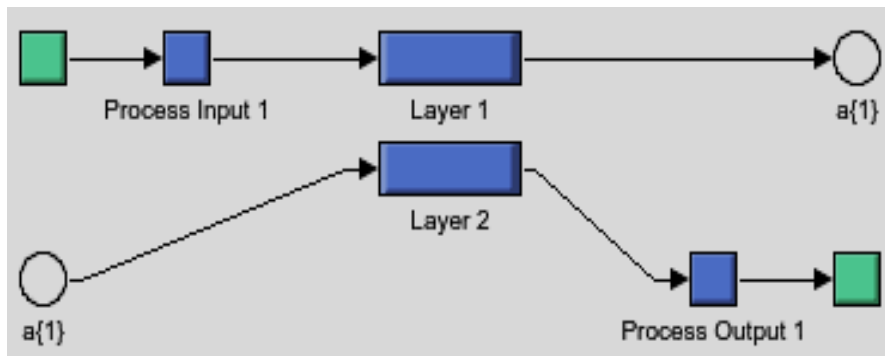

Figure 1: The ANN models

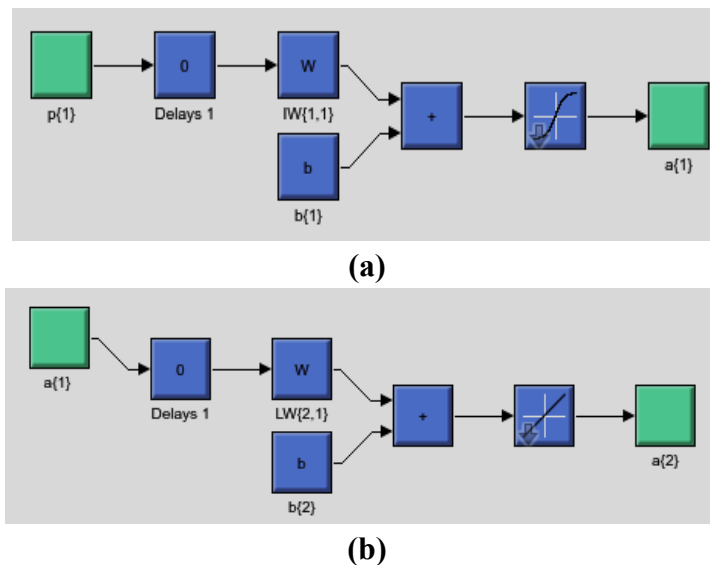The two hidden layers of the ANN model are shown in the following figures:

(a)

(b)

Figure 2: (a) The first hidden layer, (b) the second hidden layer

After we have implemented out ANN model for the system, we train and test the validation of the output data of the ANN model with the actual data that we have. The test result shown in the figure here.

From this figure, we can see that the results that are produced by training and testing our ANN model of the heat exchangers are accurate outputs, and they are near to the target data which is the practical experiment's data.
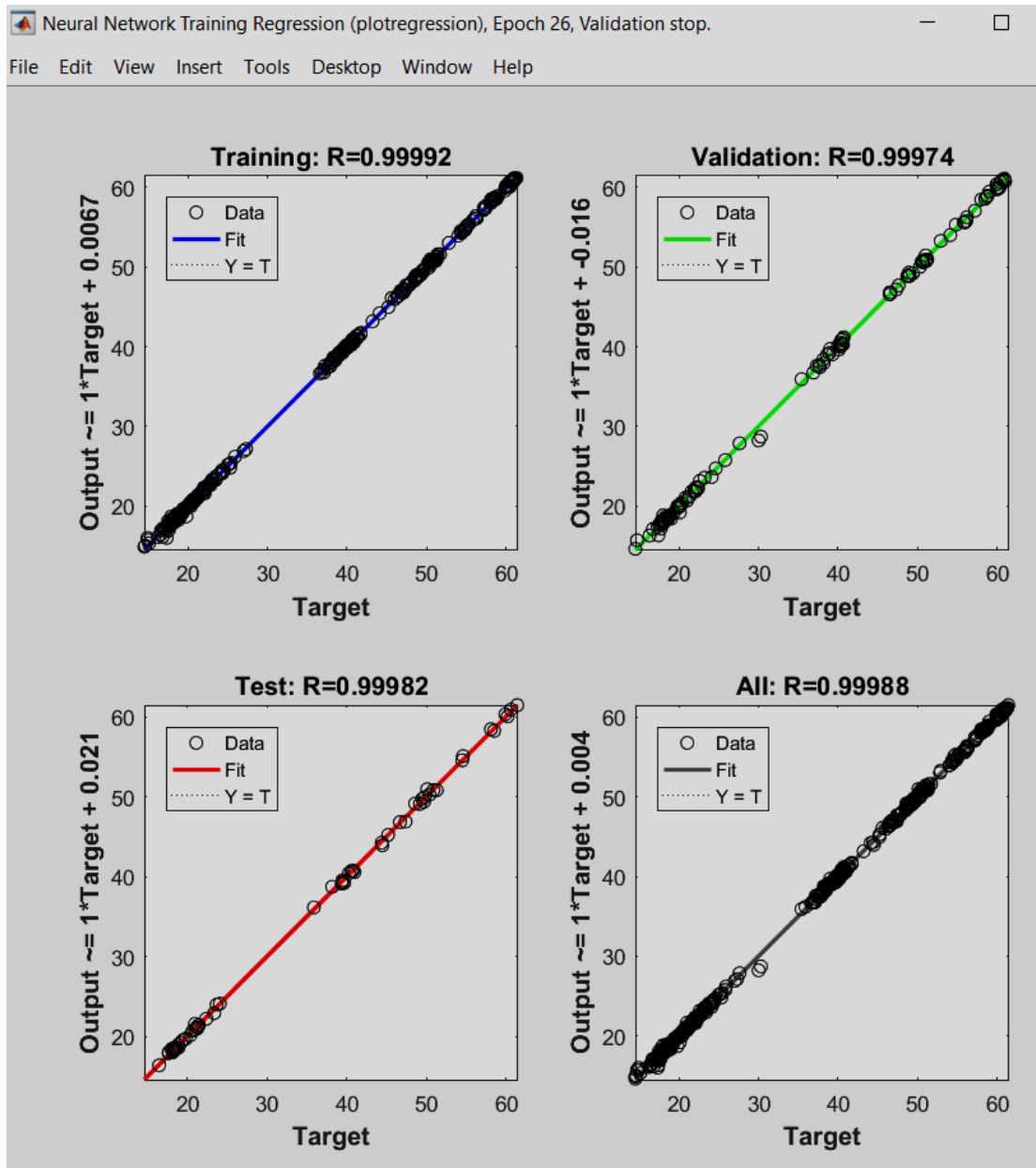
Figure 3: Training and testing for our ANN model of heat exchangers

After implementing the ANN, we make a mask for it to produce the following block shown in the figure below.
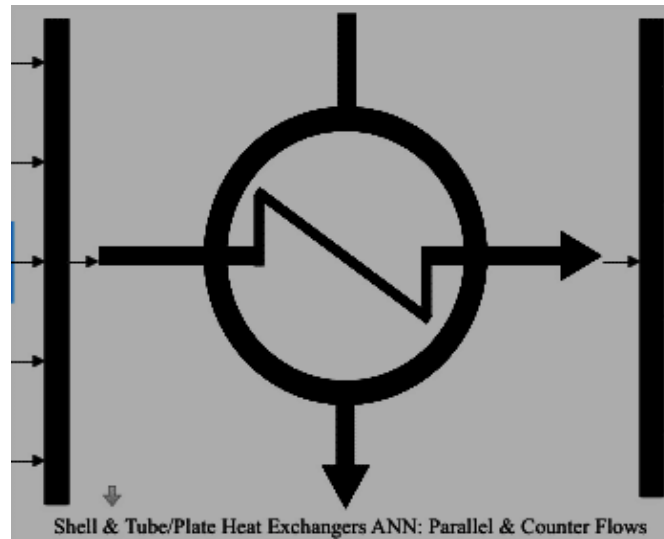
Figure 4: The Block for the ANN Model of the Two Types of Heat Exchanger

From the figure, we can notice that, this block of the ANN model has five inputs and four outputs. The input data of the model are which can be assigned and input by the user are:
(1) Heat exchanger type (Shell and tube or plate).
(2) Flow type (parallel or counter).
(3) The temperature of the water that flows out from heater in C°.
(4) Flow rate of the hot water that flow from the heater to the hot inlet in L. min - 1.
(5) Flow rate of the cold water that flow from the cold inlet in L. min - 1.

Look on the following figure to see the inputs variables of the model:
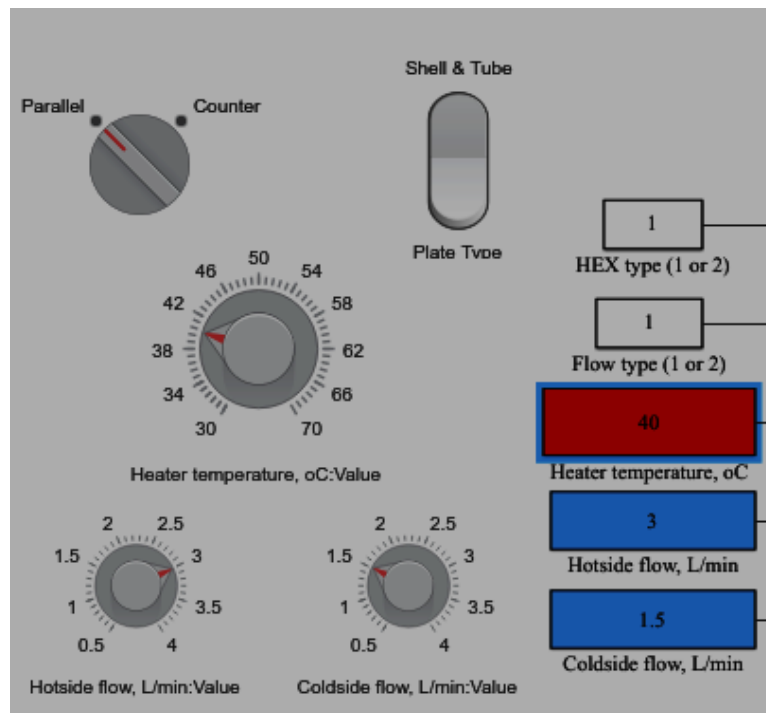
Figure 5: The Input Blocks of the Model

The output that are calculated by the model are the following variables:

(1) Inlet hot water temperature (T_{h1}) in C°.
(2) Outlet hot water temperature (T_{h2}) in C°.
(3) Inlet cold-water temperature (T_{C1}) in C°.
(4) Outlet cold-water temperature (T_{C2}) in C°.
(5) Effectiveness of the selected heat exchanger type with the selected flow type.
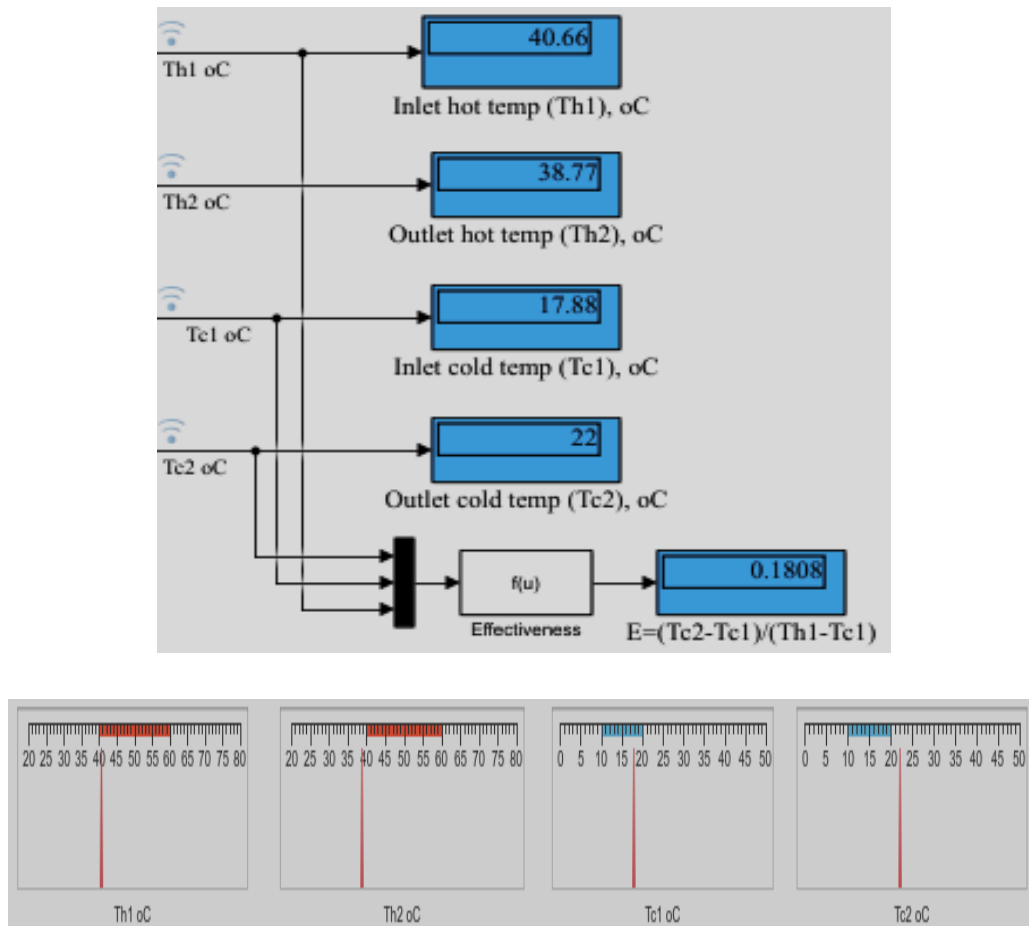
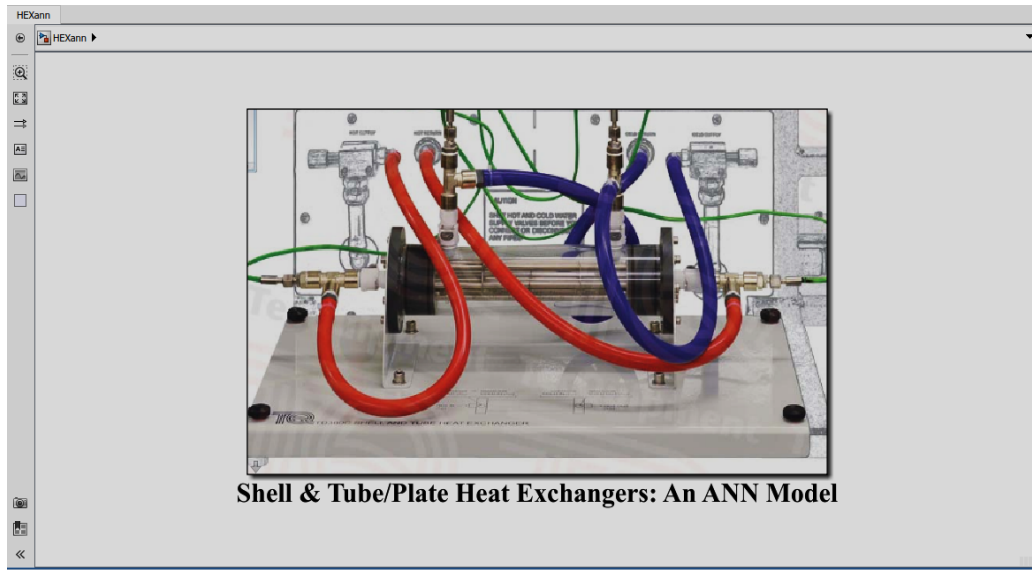Figure 6: Display Blocks for the Output

3. Model Specifications, Capabilities, and Features

This section can be used as a used manual for the model. User will see the following block when he opens the model.

Figure 7: Main Block of the Model

Then he can open this block from the arrow on the left corner in the bottom of the block. He will see the model like in the following figure:
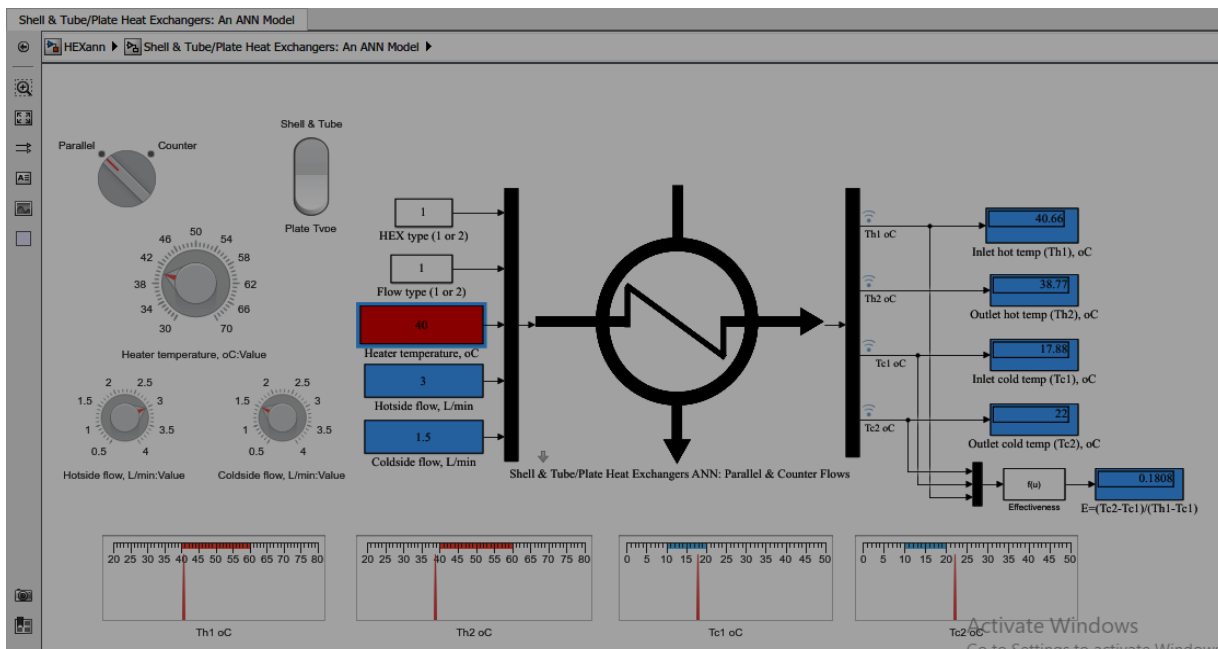

Figure 8: The User Interface of the Model

The model that we have designed is a model that simulate the Shell & tube heat exchanger and plate heat exchanger in the two types of flow for each type. We make the model has a friendly interface for the user which will help any user to use this model as simple as possible. The user can select the desired type of the heat exchanger, the flow type and assign the input variables easily.

As we can see from Figure 8, we can note that:

- User can switch and select the desired type of heat exchanger easily by press the rocker switch to select shell and tube or plate. If he selects shell and tube, the constant named as "HEX type" will be one. While choosing plate type, the constant named as "HEX type" will be two.

- User can switch and select the desired type of flow by press the rotary switch to select parallel flow or the counter flow. If he selects parallel flow, the constant named as "flow type" will be one. While choosing counter flow type, the constant named as "flow type" will be two.

- User can assign and input any value between 30 C° up to 70C°, which represent the temperature of the water that flows out from heater into the hot inlet hole of the heat exchanger. He can use the heater temperature's knob to tune the temperature or he can input it directly from the constant named as "heater temperature°".

- User can input any value between 0.5 and 4 for the hot side flow and cold side flow directly from the constant blocks named as "Hot side flow, L/min" and "cold side flow, L/min". On the other hand, he can use the knobs to tune the value of these two variables.

- For the output, the user can see the simulation results after running the simulation from the display blocks on the right labeled as "Inlet hot temperature° (T_{h1}),C°", "Outlet hot temperature° (T_{h2}),C°", "Inlet cold temp. (T_{c1}),C°", "Outlet cold temp. (T_{c2}),C°" or he can see them from the four linear gauge labeled with the output.

- The model also calculates the effectiveness of the selected heat exchanger type and the selected flow type from the last display block.

3.1. Heat Exchanger Service Module

A bench-top base unit for examining and comparing small-scale heat exchangers to help students understand how they work. Requires at least one of the four associated experiments.

Figure 9: Heat exchanger service module

Key Features

- A bench-top service module with optional small-scale demonstration heat exchangers – designed for teaching
- Optional heat exchangers include the most common types used in industry (tubular, plate, shell and tube, and a jacketed vessel with coil and stirrer)
- Simple and safe to use – foolproof fittings allow students to change and connect the optional heat exchangers quickly and easily – needs no tools
- Clear digital displays of all readings – you do not need a computer to work it or take readings
- Can connect to TecQuipment's Versatile Data Acquisition System (VDAS®). [5]

Description

The Service Module (TD360) is the core of the TD360 range. It provides hot and cold water to the heat exchangers and all the instruments needed to measure their performance. All fluid connections to the optional heat exchangers are self-sealing quick connectors – for safety and simplicity. The hot and cold fluid streams have different connectors to reduce errors.

The services module's hot water system includes a tank with a PID controlled electric heater, a pump and tank level indicators. An electrically operated valve opens to let water in to fill the tank. The tank has protection in case of over temperature, low water level and overfilling. The hot water system gives stable flow rates and temperatures.

The services module's cold-water circuit has a flow regulator and connection for an external mains water supply.

Both the cold and hot water system have precision needle valves and turbine flow meters to control and measure the flow rates.

Thermocouples at the connectors measure hot and cold inlet and outlet fluid stream temperatures. Some heat exchangers also have built-in thermocouples for extra temperature measurements. Clear, multiline digital displays show the temperatures and flow rates of the fluid streams.

All optional heat exchangers have the same nominal heat transfer area and wall thickness, so students can compare them directly.

Available Experiment Modules

- Concentric Tube Heat Exchanger (TD360a)
- Plate Heat Exchanger (TD360b)
- Shell and Tube Heat Exchanger (TD360c)
- Jacketed Vessel with Coil and Stirrer (TD360d)

Standard Features

- Supplied with comprehensive user guide
- Five-year warranty

- Made in accordance with the latest European Union directives
- ISO9001 certified manufacturer

Operating Conditions
Operating Environment
> Laboratory

Storage Temperature Range
> –25°C to +55°C (when packed for transport)

Operating Temperature Range
> +5°C to +40°C

Operating Relative Humidity Range
> 80% at temperatures < 31°C decreasing linearly to 50% at 40°C

Essential Services
Bench Space Needed
> 800 mm x 700 mm

Electrical Supply
> Single-phase 220 VAC 50 Hz or two-phase 220 VAC 60 Hz at 13 A

Clean Water Supply and Waste
> 5 L. min – 1 at a minimum 1 bar and maximum 3 bar.

Note: Your water supply must be between 5°C and 20°C. [5]

3.2. Useful Equations and Theory
This section only gives the basic information needed to do the experiments

3.2.1. Average Temperatures in Heat Exchangers
For most heat transfer equations, and calculations of specific heat capacity and density of water, you must find the average temperature for the hot and cold circuits in your heat exchanger. This is the calculated value of the temperature at a mid - point between the inlet and outlet of the circuit.

To find the average temperature of the cold circuit:

$$\overline{T}_C = \frac{T_{C1} + T_{C2}}{2} \tag{1}$$

To find the average temperature of the cold circuit:

$$\overline{T}_H = \frac{T_{H1} + T_{H2}}{2} \tag{2}$$

3.2.2. Specific Heat Capacity at Constant Pressure (c_p)

Specific heat capacity is the amount of heat energy needed to raise the temperature of exactly 1 kg of material by 1 degree (Celsius).

The specific heat capacity of water is 4.2 kJ.kg^{-1}.k^{-1}

Density

As water temperature changes, its density changes slightly. Its maximum density is at approximately 4 degrees Celsius and decreases, as it is your calculations you can use figure (15) to find water density for your water temperature, for a unit m and a constant pressure. Alternatively, Equation 3 shows you how to accurately calculate it (where T is your water temperature in degrees centigrade).

$$\rho = \frac{999.839 + 16.952\,T - 7.990 \times 10^{-6}\,T^3 + 105.846 \times 10^{-9}\,T^4 - 281.030 \times 10^{-12}\,T^5}{\left(1 + 16.887 \times 10^{-3}\,T\right)} \ (3)$$
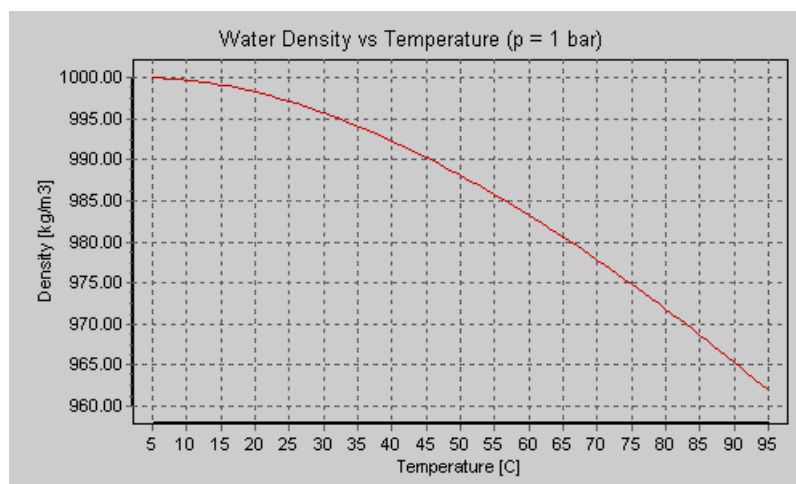

Figure 10: Water Density Chart

3.2.3. Heat Transfer, Energy Balance and Efficiencies

In heat exchangers, heat transfers or 'flows' from the hot water circuit to the cold-water circuit.

The heat transfer rate is a function of the fluid mass flow rate, the temperature change and the specific heat capacity of the fluid (at mean temperature)

$$\dot{Q} = M \times C_p \Delta T \,(4)$$

In an ideal heat exchanger, that does not lose or absorb heat from its surroundings, the cool fluid absorbs all the heat from the hot fluid. Therefore, the heat transfer rate is:

$$Q = \dot{Q}_e = \dot{Q}_a = V_H \times \rho_H \times C_{pH} \times \Delta T_H = V_C \times \rho_C \times C_{pC} \times \Delta T_C \,(5)$$

The mean temperature efficiency and heat transfer coefficient give more useful results for comparison between heat exchangers.

The **temperature efficiency** of the **hot** circuit of the Heat Exchanger is the ratio of the temperature change in the hot circuit, divided by the difference between the maximum and minimum temperatures of the hot and cold circuits:

$$\eta_H = \frac{T_{H1} - T_{H2}}{T_{H1} - T_{C1}} (6)$$

The **temperature efficiency** of the **cold** circuit of the Heat Exchanger is the ratio of the temperature change in the cold circuit, divided by the difference between the maximum and minimum temperatures of the hot and cold circuits:

$$\eta_H = \frac{T_{C2} - T_{C1}}{T_{H1} - T_{C1}} (7)$$

The **mean temperature efficiency** of the two circuits is the average efficiency of them both:

$$\bar{\eta} = \frac{\eta_H + \eta_C}{2} (8)$$

3.2.4. Logarithmic Mean Temperature Difference (LMTD)

This is a measure of the heat driving force that creates the heat transfer. It is a logarithmic average of the temperature difference between the hot and cold circuits at each end of the heat exchanger.

$$LMTD = \frac{(T_{H2} - T_{C2}) - (T_{H1} - T_{C1})}{\ln\left(\frac{(T_{H2} - T_{C2})}{(T_{H1} - T_{C1})}\right)} (9)$$

3.2.5. Heat Transfer Coefficient (U)

This is the overall heat transfer coefficient for the wall and boundary layers. It is a measure of how well the heat exchanger works. A good heat exchanger will give a high coefficient; therefore this value is important to engineers.

$$U = \frac{\dot{Q}e}{A \times LMTD} (10)$$

4. Collected Data

Table 2: Some of Data Collected form the Practical Experiments

Hex-Type	Flow-Type	T_{heater}	Hot Flow	Cold Flow	T_{h1}	T_{h2}	T_{c1}	T_{c2}
1	1	40	3	3	40.6	38	17.9	20.5
1	1	60	3	3	60.2	54.5	18.4	24.1

Hex-Type	Flow-Type	T_{heater}	Hot Flow	Cold Flow	T_{h1}	T_{h2}	T_{c1}	T_{c2}
1	2	40	3	3	40.5	37.9	17.3	19.8
1	2	60	3	3	60.1	54.3	17.5	23
2	1	40	3	3	40.3	38.9	16.8	18
2	1	60	3	3	61.3	58.7	18.4	20.9
2	2	40	3	3	40.8	39.5	18.1	19.5
2	2	60	3	3	60.6	58	18.7	21.3

These data represent the data we have collected from the practical experiments we did in the lab. The measurements may have some errors due to several reasons such as human error and measurements error with sensors and transducers used in the experiments. In other world, this data may be not accurate in some measurements for one of the variables. This type of experiments needs cost and time and may have some unexpected results due to some errors.

Due to that, simulations and modeling are used to remove and neglect those type of measurement errors to give us an accurate result and describe the right behavior of the system. They are faster, cheaper, and accurate since they help us to do the experiment without paying any cost or losing any time.

5. Simulation Results

By using the Model, we design to simulate the same input data. We will get the following accurate result.

Table 3: The Output Results from the Heat Exchangers Model

Hex-Type	Flow-Type	T_{heater}	Hot Flow	Cold Flow	T_{h1}	T_{h2}	T_{c1}	T_{c2}
1	1	40	3	3	40.81	38.21	17.97	20.45
1	1	60	3	3	60.07	54.45	18.71	24.05
1	2	40	3	3	40.02	37.28	15.59	18.68
1	2	60	3	3	60.21	54.59	17.91	23.29
2	1	40	3	3	40.35	39.16	17.16	18.52
2	1	60	3	3	61.1	58.61	18.43	20.95
2	2	40	3	3	40.79	39.52	18.17	19.52
2	2	60	3	3	60.72	58.2	18.54	21.2

By comparing the results and data in each of the two previous table, we can note the difference between them. We can conclude that the model gives us the optimal data without any nose or drop in the efficiency of the heat exchanger or any errors that may be occurred in the lab. Unlike the practical experiments which may contain some small error and abnormal values.

6. Conclusions

We have built and design the model using the MATLAB and Simulink tool using the artificial neural network ANN method instead of using the conventional way of modelling and simulating the system because by using this method our project will meet the new technology and science by of the Artificial intelligence "AI".

After that by comparing the results and data in each of the practical experiment and the simulating data, we concluded that the model gives us the optimal data without any nose or drop in the efficiency of the heat exchanger or any errors that may be occurred in the lab.

7. Recommendations

The most important point that we have to take in our consideration is that the ANN models in general depends on the input and output data which we trained these types of models. So, larger the data we have collected, larger will be the accuracy of the ANN models and more training time for the ANN model.

So, if we want to make the input and output data ranger for the Heat exchanger model larger and increase the accuracy. We must increase the number of data used in the training process of the ANN model. These extra data can be collected in the future from experiments or practical scenarios.

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