

# Design and simulation of heat exchangers using Aspen HYSYS, and Aspen exchanger design and rating for paddy drying application

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**Abstract.** Air heating unit is one of the most important parts in paddy drying to ensure the efficiency of a drying process. In addition, an optimized air heating unit does not only promise a good paddy quality, but also save more for the operating cost. This study determined the suitable and best specifications heating unit to heat air for paddy drying in the LAMB dryer. In this study, Aspen HYSYS v7.3 was used to obtain the minimum flow rate of hot water needed. The resulting data obtained from Aspen HYSYS v7.3 were used in Aspen Exchanger Design and Rating (EDR) to generate heat exchanger design and costs. The designs include shell and tubes and plate heat exchanger. The heat exchanger was designed in order to produce various drying temperatures of 40, 50, 60 and 70°C of air with different flow rate, 300, 2500 and 5000 LPM. The optimum condition for the heat exchanger were found to be plate heat exchanger with 0.6 mm plate thickness, 198.75 mm plate width, 554.8 mm plate length and 11 numbers of plates operating at 5000 LPM air flow rate.

## 1. Introduction

Drying is a mass and heat transfer process which consisting of the removal of water by evaporation from solid. Drying of agricultural products is one of the preservation methods that used from long time ago. It is an important process for mankind due to the great effect on the quality of the products. The main purpose of drying is to reduce the moisture content in order to prevent the growth of microorganisms. Different drying methods are used to dry different agricultural products (1).

Rice is a staple crops used by half of the earth population as a basic needs (2) including diets, source of income, and is one of a major economic contributors (3), especially in Asia. According to (2), study shows that 586, 787 thousand tonnes of rice are annually consumed. In Malaysia itself, 600000 ha of the total area was covered solely for rice cultivation and a bulk of 2 million tonnes of paddy was produced annually from 400 rice mills of various capacity (4). Drying process for paddy however, has to be carried out right after the paddy is harvested. With the increasing demands, natural drying is no longer favourable as it requires longer time and massive space for drying. The moisture content of paddy typically needs to be reduced to 12-14 wt% (5) before it can be dehusked (3).

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There are many industrial paddy dryers such as inclined bed dryers (IBD), fluidized bed dryers (FBD), re-circulating bed dryers, and continuous-flow dryers. Inclined bed is a common example of fixed bed dryer which possess basic design of paddy drying technology. This type of dryer consists of perforated sheet floor (bed) with a plenum chamber below it that forced air directly or by the assistance of a duct system (6). Paddy that is about to be dried was placed a foot deep and hot air are forced to go through the bulk of paddy from below the bed. Currently, IBD is used by Padiberas National Berhad (BERNAS) as a second dryer after fluidized bed dryer (FBD) with the ability to dry grain with high moisture content of 20-26% w.b. (7). The advantages of this dryer are inexpensive compared to the other dryer and have a faster withdrawal of dried paddy. In addition, the operation of the machine is easy. However, this dryer has been associated with high energy consumption and produces uneven dried product due to an inconsistent air flow distribution. This may affect the head rice yield and rice quality.

Fluidized bed dryer operating in such ways where hot air passes through the bed and then through the suspended grains which is perpendicular to the direction of flow. This type of dryer are able to dry paddy from 24% to 18% moisture content in short period with air temperature 100°C and high air velocity (8) without changing the rice's quality. This dryer produces even drying of grain, rapid heat and mass transfer, and low capital cost (9), however, the power consumption is high, and that it possess a low thermal efficiency.

Re-circulating batch dryer is another dryer that can eliminate moisture gradient problems as the grain/paddy is loaded in a batch and mixed through the entire drying process (10). The dryer consists of drying chamber, a fan and a heater as well as a central auger for transport of paddy from the bottom part to the outlet, which is located at the top of the dryer. Despite its great contribution in solving the problem with moisture gradient, fast drying and ability to produce rice with great quality, this type of dryer used twice the temperature needed for paddy drying compared to the flat-bed dryer, the capital cost is high due to its complicated design.

Continuous-flow dryers can be considered as another version of re-circulating batch dryers, in which it allows the grain to re-circulate in the drying chamber. The difference between these two is, instead of discharging the dried grain from the top, continuous-flow dryer discharges the grain from the bottom part, cooled and transport to the storage. Similar to that of re-circulating batch, it assist in eliminating moisture gradient of paddy drying due to the baffle system exist in the dryer that operates to mix the grain. This dryer offers low operating cost when compared to batch dryer, however, continuous flow dryer is only applicable for large scale process and cannot be used for small scale since it is quite a complicated dryer.

The recent dryer for paddy drying application is Laterally Aerated Moving Bed (LAMB) dryer (11) invented by our group (12). LAMB dryer is also recognized as radial packed bed and consists of a single perforated tube inside the drying vessel. Same as the other conventional dryers, LAMB operates with hot air flow as the drying medium through the perforated tubes and distributes the hot air laterally throughout the drying vessel where the paddy is feed into. The principle of the system is to aerate the paddy bed laterally so that even drying can be achieved more effectively, and lower aeration energy requirement since pressure drop across the bed is smaller due to shorter distance. Typically in large scale paddy drying, hot air is generated by using steam boiler or by burning of rice husk in a furnace.

Nevertheless, understanding on the effective and efficient air heating system for LAMB dryer has not been well established. Choosing the right heating unit is crucial to minimize the operational cost. Various air heating technologies have been developed and each has its advantages and disadvantages. Apart from using electrical, combustible fluids air heater and solar air heater are also commonly used for producing hot air. However, heating air using a furnace powered by combustion of rice husk is very economical but it produces air and solid waste pollutions. Furthermore, the ashes produced from the rice husk combustion often clog the filter of the dryer causing frequent maintenance. In this case, the use of heat exchanger is more favourable. Hence, this research is to determine the suitable heat exchanger to be used to supply hot air for paddy drying in the 2000 kg capacity LAMB dryer, as well as to find the optimum specifications and condition of the said heating

unit. In order to find a suitable heat exchanger, this process can be simulated by using ASPEN HYSYS V7.3 and ASPEN Exchanger Design and Rating (EDR).

Heat exchanger is equipment that deals with transfer of heat between two fluids. There are various heat exchangers such as shell and tubes heat exchanger, plate heat, and others. Shell and tubes heat exchanger is broadly used in various industries such as energy generation and preservation system (13). For shell and tubes water to air heat exchanger, usually the fluid with high pressure is located in tubes and fluid with low pressure is located in shell. Through this, it can relieve shell for high pressure and gives a large centreline spacing for tubes (14). Water to air heat exchanger is usually designed as cross counter flow and individual tube passes are connected by bends to form the multi-pass tube. The hot water flow direction are cross to the cold air (15)

Aspen HYSYS and Aspen EDR are comprehensive process modelling tools used for process simulation and process optimization in design. Aspen EDR is a software that delivers the comprehensive range of heat exchanger designs (16). Aspen HYSYS is able to solve the problem to determine the flow rate of hot and cold stream passing through the heat exchanger in different stream conditions. In this software, the heat exchangers are very flexible as it can solve for the problem of temperature, pressures, heat flows and material streams flow. Heat exchanger model can be chosen for analysis purpose in Aspen HYSYS. It is able to operate a heat exchanger and model the heat transfer process (17) occurring inside of the heat exchanger. Aspen Exchanger Design and Rating (EDR) is a software that provides the designs and rating of heat exchanger. It assists the users to reduce the equipment cost up to 10 to 30 % with the effective design of Aspen EDR. The software is able to give an optimum cost arrangement design by providing the process requirement's physical data. The details of heat exchanger will be shown in a specification sheet, setting plan and tubes layout.

## 2. Experimental procedure

### 2.1. Aspen HYSYS simulation for heat exchanger

Aspen HYSYS v7.3 was used to simulate a simple model of heat exchanger. The components chosen in Aspen HYSYS were air and water, and the fluid package used in this simulation model was General Non Random two liquid (NRTL). In the component that was labelled 'Inlet cold' was filled with air in component selection and the temperature and pressure inlet cold air was set as ambient condition. The flow rate of air used are 300, 2500 and 5000 litre per minute (LPM). On the other hand, for component labelled 'inlet hot' was filled with water in component selection. The inlet temperature of water was set to 60, 80 and 100°C and the flow rate of hot water was key-in using trial and error method until the minimum value of flow rate was obtained. The Aspen HYSYS will show complete comment if the flow rate of hot water can be used in this system. The outlet air temperatures were set as 40, 50, 60 and 70°C. The other values were left blank and Aspen HYSYS was used to simulate it.

### 2.2. Aspen exchanger design and rating (EDR)

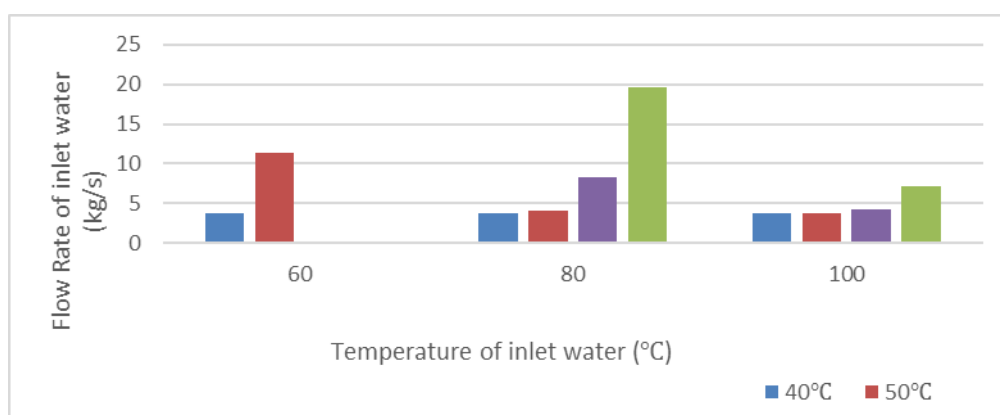
Aspen Exchanger Design and Rating (EDR) were used to design the heat exchanger after the data of temperature and flow rate of hot water and cold air was obtained. There were two major types of heat exchangers in Aspen Exchanger Design and Rating (EDR), which are shell and tube heat exchanger and plate heat exchanger. A new tab was opened and the types of heat exchanger were chosen and it will re-direct to the navigator. The calculation mode was set as design mode and filled the location of hot fluid. The temperature and flow rate of hot fluid and cold fluid were inserted in the process data and the temperature of hot fluid used was similar to the temperature used in Aspen HYSYS which were 60, 80 and 100°C. The temperature of inlet air was set in ambient condition and the targeted temperature (outlet air) was set as 40, 50, 60 and 70°C. Aspen properties were chosen as the physical properties package for the properties data of both hot and cold stream. The components used in heat exchanger were selected in databank and the percentage of composition of components was filled for both hot stream and cold stream. NRTL was selected as the properties method for the design of heat

exchanger. The “run” button was clicked and the design of heat exchanger was simulated by the program. The result of the design can be viewed in the results and discussions section.

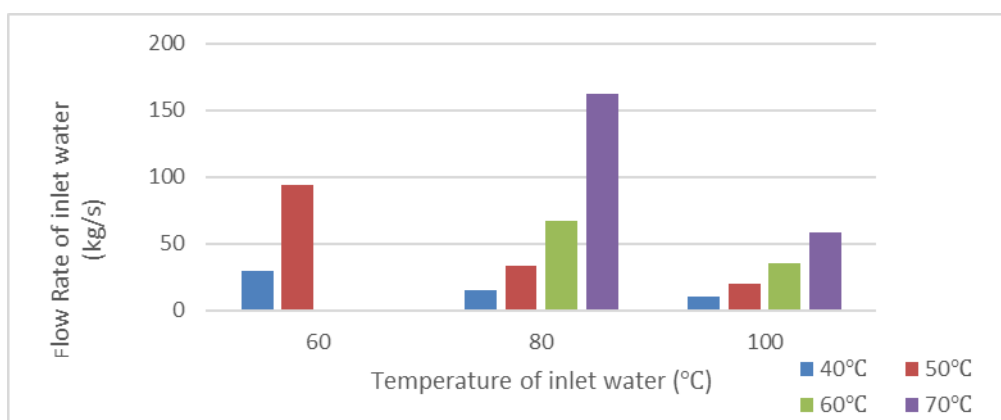
### 3. Results and discussion

#### 3.1. Relationship between heating fluids and cold fluids flow rates and temperatures

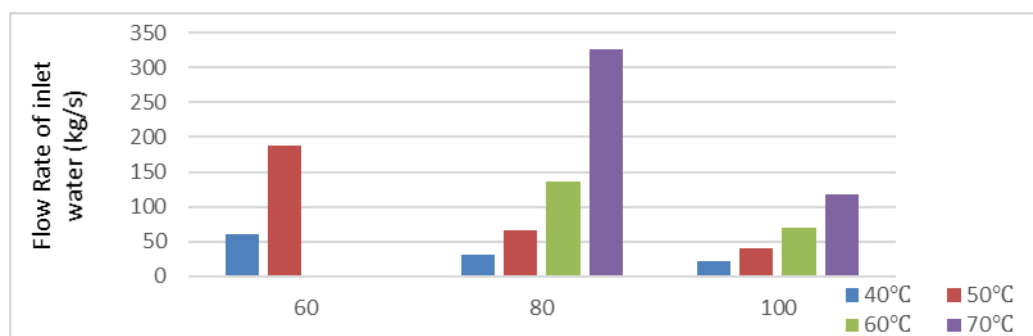
Based on this study, the relationship between water's inlet temperature and flow rates with outlet air temperature were determined at different air flow rates, 300LPM, 2500LPM and 5000LPM. The study was performed using Aspen HYSYS and Aspen EDR.



**Figure 1.** Water inlet Flow Rate against Inlet Temperature with different outlet Air Temperature at 300LPM air flow rate



**Figure 2.** Water inlet Flow Rate against Inlet Temperature with different outlet Air Temperature at 2500LPM air flow rate



**Figure 3.** Water inlet Flow Rate against Inlet Temperature with different outlet Air Temperature at 5000LPM air flow rate

Comparing the data obtained by using different air flow rates, the pattern is almost similar for the entire graph as observed in Figures 1, 2 and 3. Referring to the data plotted, it can be seen that at different heating temperature, higher water flow rates are needed to heat up air and reach similar targeted temperature. Figure 1 for instance, represents the heating of air with flow of 300 LPM in a heat exchanger, it needs 3.7 kg/s of water at 60°C to be able to heat up 300 LPM ambient air (25°C) to 40°C. Higher water flow rates at 60°C are needed to heat up the same 300LPM air to 50°C. Whereas, water at 80°C requires lower flow rate to achieve lower targeted temperature and even lower flow rate when the water is at 100°C. This can be implied that, at lower temperature, higher flow rates of heating fluid is required for heating. In contrast, at higher heating fluid temperature, lower flow rates are needed for heating to reach similar targeted temperature.

The heating of 2500 LPM and 5000 LPM of air in a heat exchanger are illustrated by Figure 2 and Figure 3, respectively. The trend of the graph shows that the inlet flow rate of water need to be used was increasing with increasing targeted air temperature. Figure 2 represents inlet flow rate of water at several temperatures required to heat 2500 LPM of ambient air to 40, 50, 60 and 70°C. Based on Figure 2, the trend of graph shows that the inlet flow rate of water required to heat air was increasing with increasing targeted air temperature regardless of the water temperature. From the Figures, it can be observed that higher water flow rates (30.1 kg/s) of water at 60°C was needed to heat 2500 LPM of ambient air to 40°C compared to the water at 80°C (15.4 kg/s) and 100°C (10.4 kg/s) temperature. Similar result can be seen when air was heated to 50°C. Identical trend can be monitored for water with 80 and 100°C temperature where 67.7 kg/s of water at 80°C is needed instead of 35.1 kg/s at 100°C to heat air to 60°C. It shows that water at lower temperature requires higher flow rates to reach the targeted temperature compared to water at higher temperature. Other than that, it can also be monitored that higher air flow rates tend to require higher water flow rates to heat up air. The increase of mass flow rate with increasing flow velocity will lead to increasing heat transfer coefficient and thus have higher heat transfer (18). This trend is also applicable to Figure 3.

Seeing from the perspectives of the whole pattern, it can be said that air flow rate affects the water flow rate required to heat air to certain temperature. By relating the air flow rates and the pattern obtained, it shows that higher air flow rate contributes to higher water flow rates required.

### 3.2. Costs of heat exchanger with optimum conditions

**Table 1.** Costs of Heat Exchangers

Heat Exchanger	Temperature of inlet hot fluid (water, °C)	Targeted Temperature of outlet cold fluid (air, °C)	Air Flow Rate (LPM)	Cost (RM)
Shell and Tubes	60	40	300	34000
Shell and Tubes	80	50	300	34000
Shell and Tubes	100	60	300	34000
Shell and Tubes	100	70	300	34000
Shell and Tubes	80	40	2500	35000
Shell and Tubes	100	50	2500	35000
Shell and Tubes	100	60	2500	35000
Shell and Tubes	100	70	2500	36000
Shell and Tubes	80	40	5000	42000
Shell and Tubes	100	50	5000	42000
Shell and Tubes	80	60	5000	44000
Shell and Tubes	80	70	5000	45000
Plate	-	Low Flow rate	300	-
Plate	80	40	2500	2700
Plate	100	50	2500	2700
Plate	100	60	2500	2800
Plate	100	70	2500	2800
Plate	80	40	5000	3100
Plate	100	50	5000	3100
Plate	80	60	5000	3300
Plate	80	70	5000	3400

The costs of the heat exchangers were determined after the simulation was performed using Aspen EDR and only the heating unit with the highest efficiency was compared. This is to ensure that the heat exchanger is able to meet the requirement needed for paddy drying. Shell and tube as well as plate heat exchanger was chosen for the simulation due to its flexibility as a heating device in a process.

Based on Table 1, it shows that the cost of shell and tubes heat exchanger is higher compared to plate heat exchanger. Shell and tube heat exchanger shows that the cost is increasing with increasing air flow rate and temperature. It can also be observed that to heat up 5000 LPM of air to 70°C, the cost recorded are RM45000. It is significantly higher than those of with lower air flow rates. Plate heat exchanger, on the other hand, cost almost ten times lower than the shell and tube heat exchanger with similar condition (heating 5000LPM of air to 70°C), which is only RM3400. Shell and tube heat exchanger are more flexible compared to plate heat exchanger in term of operating for both small scale and larger scale process and it can stands higher pressure.

#### 4. Conclusions

Two types of heat exchangers, shell and tube, and plate heat exchanger were simulated using Aspen HYSIS to study the temperature profile of each device and to obtain the optimum specifications to be applied on paddy drying and its cost was determined by using Aspen EDR. The desired drying temperature used in this study was 40°C, which was a typical temperature used in industrial paddy drying. For 2000 kg capacity LAMB dryer, the simulation showed that the best heat exchanger was plate heat exchanger with air flow rate of 5000 LPM. The simulations showed that 80°C of water can heat 5000 LPM of air to 40°C, and the cost was RM3100. From the designs, the best specifications for the plate heat exchanger were 0.6mm plate thickness, 198.75mm plate width, 554.8mm plate length and using 11 numbers of plates.

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