15-Thermal Design

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Thermal Design Approach of a Shell and Tube Heat Exchanger for Pyrolysis-Vapor Condensations

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Abstract. This study aimed to design a condenser for a special application of condensing the vapor of pyrolysis process of hydrocarbon-based material such as plastic and biomass into liquid form or pyrolytic oil. Numerous condensers have been available in the market. However, a condenser cannot be selected and utilized directly for pyrolysis vapor condensation purposes. Before doing selection, the condenser must be designed first to meet the heat transfer requirements. In this work, the condenser was designed based on thermal analysis and validated with numerous published experimental data and the pyrolytic characteristics from related industry. A theoretical model is formulated for describing condensation of the pyrolysis vapor in the condenser to determine heat transfer requirement and the rate of condensation obtained. The effect of operating parameters such as cooling water rate in liters per minute (LPM) and temperature on the condensation rate was examined through an iterative procedure which rely to the heat transfer rate and the allowed pressure drop in the condenser. In this study, it was obtained that the highest cooling load is obtained when the flow rate of cooling water is 1.95 LPM. It was also obtained that the condenser effectiveness decreased of about 29.3 % with the ranges of cooling flow rate from 1.3 to 2.6 LPM.

1. Introduction

Until now, the utilization of pyrolytic oil from material of hydrocarbon based such as plastic and biomass as an energy alternative is continuing to increase. There is no doubt that the use of pyrolytic oil has become an important alternative energy source that is considered in Indonesia's national energy security. According to the researchers, the promising pyrolytic oil as energy source can be used as a guide in energy diversification and development [1, 2, 3]. Theoretically, there are many ways to convert materials of hydrocarbon based into alternative energy. One of the most preferred processes is the thermochemical process, which is a process that involves high temperatures. Thermochemical process which is include pyrolysis, carbonization, gasification, and combustion have been performed by few researchers to produce mainly solid fuel, pyrolytic oil, flammable gases, and thermal energy [4, 5, 6]. Interestingly, the thermal energy can be stored by using a simple system and utilized further when it's required [7].

Plastic and biomass have been studied for a long time as a source of energy as described through literature review [8]. Plastics material are processed mainly through molecule degradation instead of burning [9]. Whilst biomass can be burned directly to obtain mainly heat by conventional open-air combustion methods using a three-stone fire stove. However, this method is inefficient and wasteful of firewood. The efficiency of a conventional three-stone stove usually ranges from 5 – 17 % [10]. Until now, biomass of wood has also been widely used as a source of energy for heating living rooms in winter using modern stoves equipped with temperature and emission control devices [11]. Even wood has also been used as a source of energy in the power generation system using an improved stove. For example, efficiency of a modern wood-burning stove can increase up to 20% and is capable of producing electrical energy of 1,133 kW [12].

Until now, efforts to the biomass exploitation have been increased. For instance, the carbonization process of wood to produce charcoal that has a market value, even commodity export to be the most preferred because it is easy to do, and the process does not require high temperatures. It is an incomplete combustion process by employing a simple stove. However, incomplete combustion produces a lot of smoke that contain volatiles vapor which some its ingredient is very detrimental to the health of the human [13]. However, the hot volatiles vapor still contain substances which are very useful and has a high commercial value of biochemical products [14].

Industrial processes wood through combustion using a simple big stove made of bricks and coated with clays as shown in Figure 1. Several large stoves were utilized to increase their production of wood charcoal according to the market demand. But on the other hand, the combustion products in the form of volatiles vapor are very abundant. By employing a simple and primitive appliance, namely using several series of used oil-tank with natural cooling using ambient air, the pyrolysis vapor condensed inside and flows into the collector tank. This type of product was called as bio-crude pyrolysis oil or pyrolysis liquid.

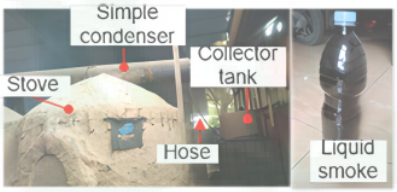

Fig. 1. A conventional carbonization stoves.

However, some problems encountered, such as the pyrolysis liquid quality. The quality of the pyrolysis liquid obtained is still low with a dark color as shown in Figure 1, where the pyrolysis liquid mainly contains of water and tar. Moreover, it is not all the smoke can be condensed and partially wasted into the surrounding. According to observations result, these problems can be overcome by utilizing a condenser with an appropriate cooling system instead of natural cooling. Thus, this study aims to design a proper cooling device that will be used to cool the pyrolysis vapor of hydrocarbon-based material to obtain a pyrolysis liquid or pyrolytic oil, free of tar and water. This type of pyrolytic oil is categorized as Grade 3 and its quality still can be improved by means distillation. The purpose of this study is to get a condenser that can control the water and tar content in pyrolysis liquid to improve its quality. This study is conducted based on heat transfer theories, especially heat transfer by conduction and convection. The equations used were tested using data on the property pyrolysis liquid collected from previous studies.

2. Literature Review

2.1 Pyrolysis liquid

Pyrolysis liquid or liquid smoke consists of a mixture of heavy and light hydrocarbon, where the heavy carbon condensed first than light one. Therefore, the condensation temperature must be at a certain range, and not at a single temperature. Thus, a condenser must be able to provide sufficient cooling so that the hydrocarbon mixture can melt perfectly.

Pyrolysis is a process in which the carbon content of feedstock is increased by performing a thermal process with limited or without oxygen. Carbonization known as slow pyrolysis that occurs with the slow heating rate process produces mainly charcoal or char and volatiles matter [15]. The volatiles include condensable and non-condensable compounds. The condensable in which, upon cooling and condensation changes to pyrolysis liquid, some called as bio-oil or bio crude oil. This product is categorized as secondary oil or tar and can be upgraded to liquid hydrocarbon fuels [16, 17, 18]. This bio-oil consists of the organic mixture of alcohols, ketones, aldehydes, phenols, ethers, esters, sugars, furans, alkenes, carboxylic acids, and phenols nitrogen and oxygen compounds. Whilst non-condensable is in the form of permanent gases that comprises CO_2, CO, CH_4, C_6H_6, and C_2H_n and hydrocarbons [19].

The optimal temperature for the slow pyrolysis process, usually at moderate temperatures, ranges from about 277 – 677 °C [18], [20, 21]. However, an inorganic material such as unburned particles, soot, and also hazardous chemicals which are often referred to as PAH (Polycyclic Aromatic Hydric also formed [22]. As a condensable compound, few efforts have been performed to condense it. However, most research focuses only on the pyrolysis product capacity improvement by varying the operating temperature of the pyrolysis process [23, 24, 25], or even by varying the feedstock sizes [26, 27, 28]. Conversely, research on upgrading the quality of the pyrolysis liquid to a higher quality utilizing shell and tube type condenser is rare.

2.2 Condenser

A condenser is a two-phase flow heat exchanger where heat is transferred between two fluids during condensation, mainly between hot vapor and coolant. There are two primary categories of condensers: those in which the coolant and condensate stream are separated by a solid surface, often a tube wall, and those in which the coolant and condensing vapor are brought into direct contact. The most adaptable kind of heat exchangers are shell-and-tube units. They are proposed for various alternative energy applications, including ocean, thermal, and geothermal. They are utilized in the process industries, in conventional and nuclear power stations as condensers, steam generators in pressurized water reactor power plants, and feed water heaters.

Condensers are also utilized in a few refrigeration and air conditioning systems. The ratio of heat transfer area to volume and weight in shell-and-tube heat exchangers is often high, and they are also simple to clean. For practically every service demand, they provide excellent flexibility. For its effective design and construction, dependable design methodologies and shop facilities are provided. It is possible to build shell-and-tube heat exchangers for both high ambient pressures and high-pressure variations between the fluid streams.

Condensation processes are common in many sectors; however, they usually use steam as the pure fluid. Because the fluids in this study are a mixture of condensable and non-condensable substances, the condensation process is quite complicated. By rejecting heat from the hot pyrolysis vapor through cooling water, a shell and tube type condenser is used to condense the pyrolysis vapor into the pyrolytic oil. Few researchers have found that the condenser's cooling fluid's temperature and flow rate have a significant impact on condensation.

The success of pyrolysis vapor condensation depends on low temperature and quick quenching. Increased condensate product is achieved by keeping the cooling fluid temperature below that of ordinary water [29]. The condensate rate increases as the cooling flow rate is increased, according to modeling results from other studies [30].

As previously mentioned, there are numerous components in the pyrolysis vapor of materials based on hydrocarbons. When polymer and biomass are pyrolyzed at a temperature between 350 and 420 °C, thus polymer has at least 21 different components and the biomass has an average of 19 different compounds. Each constituent has the saturation pressure and temperature at which it begins to condense. Other characteristics with a significant impact on condensation processes include density and molecular weight. A strong impact on the condenser's performance is also caused by the presence of inorganic material [31]. As a result, at the pyrolysis outlet, a cyclone was used to separate the particles before they entered the condenser.

2.3 Heat exchanger for pyrolysis vapor condensation

The process of converting hot fluids in the form of gas, steam, and smoke into liquid form is known as condensation. When the hot vapor's temperature and pressure fall below those of saturated liquid and vapor, condensation takes place [32]. In this work, a condenser is created with the capacity to cool the pyrolysis vapor by pumping cooling water through it. To keep the surface temperature (T_s) of each component as low as possible or at least below the T_{sat}, effective cooling is necessary. However, it is difficult to determine (T_s). The simplest method is to quantify the temperature of the condenser's cooling water.

Knowing the temperature and the rate at which the vapor leaves the stove is another approach to forecast and simply manage the cooling rate. We can presume that this is the same as the pyrolizer's working temperature or the temperature of the pyrolysis vapor entering the condenser. The temperature at which each compound distills can be used to approach this. A condenser's performance and lifespan will also be significantly impacted by the type that is employed. The industrial partner continues to use a basic condensing system that consists of a number of oil drums and ambient air as the cooling medium. Heat is transferred between the tubes by conduction and convection, which causes a cooling process, and liquid smoke moves toward the collector tank. The quantity and quality of the liquid smoke that is produced in this technique are still poor.

The piece of equipment where condensation occurs is referred to as a condenser. The condenser must be suitably built and chosen to fulfill the necessary heat transfer for the condensation process to take place. In order for the temperature of the hot pyrolysis smoke to immediately fall, adequate heat transfers between the hot pyrolysis smoke and the cooling water must take place. A cooling system, such as one that uses a pump to circulate water, is used for this purpose. The temperature and flow rate of the cooling fluid have a significant impact on condensation. The most common type of condenser is a shell and tube type, which has emerged as the preferred option in terms of heat transfer due to its simplicity in adjusting to the needs of the fluid being condensed for optimum process performance [33, 34].

In order to calculate the amount of heat contained in the smoke, this design heavily relies on data from industry, namely the rate and temperature of the hot pyrolysis vapor coming out of the burner (kW). The temperature of the cooling water input and outlet, as well as the temperature of the hot fluid in the condenser, are additional factors that can be assumed or used as references in other studies. The Effectiveness-NTU (E-NTU) method can be used to approach the condenser design if these four parameters are known or can be estimated with ease. The condenser's heat transfer surface area can be calculated after ΔT_{lm}, the mass flow rates and the total heat transfer coefficient are known.

3. Methodology

3.1 Design step

Because the heat transfer coefficient of the condenser is influenced by geometric factors like the diameter of the shell and tube, the length and number of pipes used, the arrangement or layout of pipes, and the type and spacing between baffles used, designing a new condenser can be done analytically and iteratively. The conditions of the input and output streams, such as temperature, pressure, composition, flow rate, and fluid phase, are often known or can be inferred to some extent from field measurements. In order to create a precise condenser for pyrolysis vapor, Figure 2 illustrates the design process and concept.

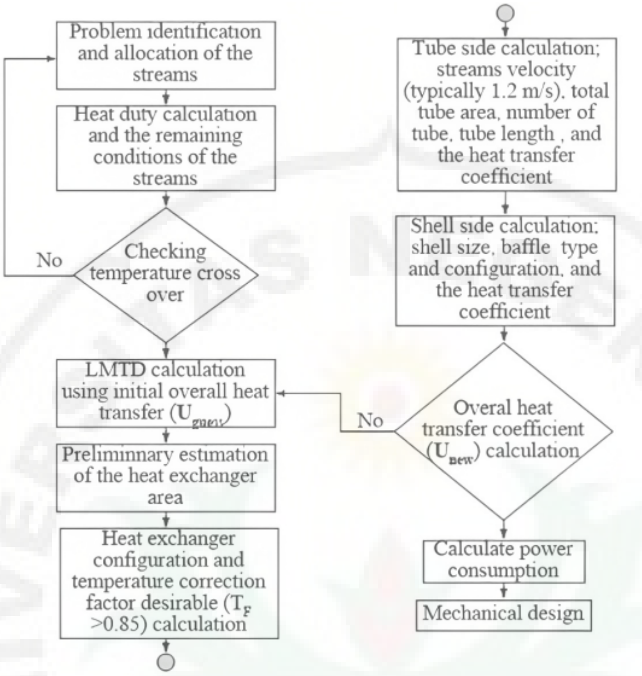

Fig. 2. Condenser design concept.

3.2 Thermal design approach

The following image is the allocation of streams in the designed condenser. This condenser is a cross-flow type heat exchanger model, where the heat stream flows perpendicular to the pipe banks inside the heat exchanger shell as shown in Figure 3. In order to avoid violation of the principle of the 2nd Thermodynamics, then the cold stream outlet ($T_{c,o}$) must less than the hot stream outlet ($T_{h,o}$).

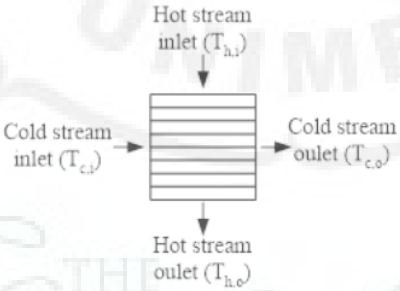

Fig. 3. Streams allocation in designed condenser.

In this study, the shell and tube heat exchanger is chosen with the geometric features as shown in Figure 4. It is planned that condenser consists of one pass shell with one bundled pass tube arranged in line with the number of rows and the number of tubes per row is 6 respectively, so the total tubes are 36. The box-shaped shell was chosen to avoid pressure drop.

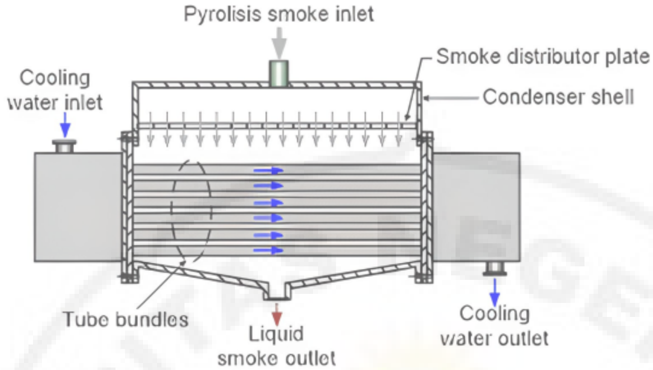

Fig. 4. Design features of a typical one-pass shell cross flow heat exchanger.

The square inline array tube bundles of vertical tire arrangement with downward flows were performed as drawn in Figure 5. Cooling water flows horizontally inside the tubes, while the pyrolysis vapor flows vertically downward through the plate distributor, passing transversely over the tube bundles as shown in Figure 6.

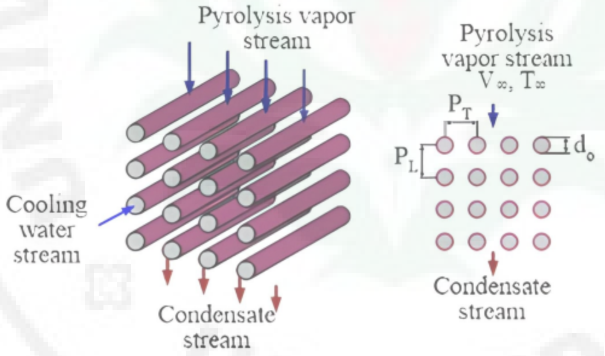

Fig. 5. Inline array tube bundle arrangement.

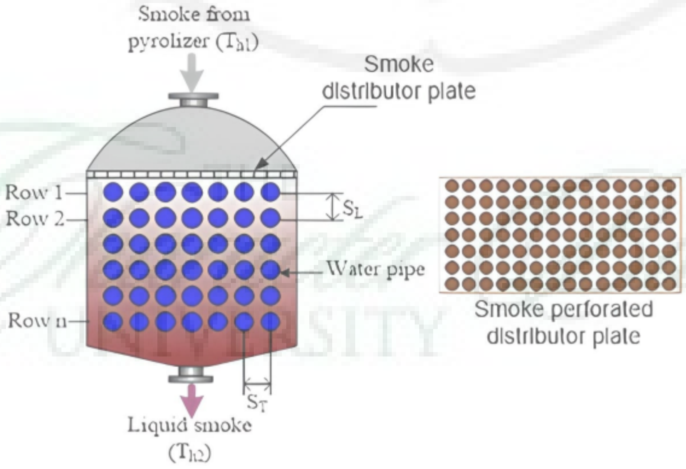

Fig. 6. Schematic of the designed condenser.

Heat transfer in a condenser usually involves convection and conduction through the wall separating two (hot and cold) flowing fluids. To determine the size of condenser required, such as the required heat transfer area (A_s), a parametric study is carried out based on the thermal characteristics of the two fluids stream. The energy balance principle is used to predict the heat transfer load $\dot{Q}$ based on hot or cold streams according to the relations

The rate of latent heat $\dot{Q}_h$ released during condensation of pyrolysis vapor is

$$\dot{Q}_h = \dot{m}_v * h_{lv} \tag{1}$$

Where, the $\dot{m}_v(\frac{kg}{h})$ and $h_{lv}(\frac{kJ}{kg})$ are the rate flow of the pyrolysis vapor and the heat released during phase change (latent heat) respectively. Otherwise, the rate of heat (sensible heat) $\dot{Q}_c$ gained by the coolant is

$$\dot{Q}_c = \dot{m}_w c_{p,w}(T_{w,o} - T_{w,i}) \tag{2}$$

Assuming that the stream temperatures and flow rates at the inlet and outlet side of the condenser are specified or easily be determined, it is very simple to use the log mean temperature difference (ΔT_{lm}) methods for preliminary determining surface area A_s of heat transfer required by using the following equation

$$A_s = \frac{\dot{Q}}{UF\Delta T_{lm}} \tag{3}$$

Where U is the overall heat transfer coefficient of the designed condenser. The correction factor, F=1 was taken due to the condenser task as condensation [35]. In this work, shell and tube heat exchanger is chosen according to Rathore, 2006 [36] with the material made of stainless steel due to high corrosion resistance. It is also that the outlet temperature of the cooling fluid is plotted does not exceed the smoke temperature out of the condenser, thus the temperature difference can be determined as follows

$$\begin{gathered} \Delta T_{lm} = \frac{(T_{v,i} - T_s) - (T_{v,i} - T_{l,o})}{ln\frac{(T_{v,i} - T_s)}{(T_{v,i} - T_{l,o})}} \\ (T_{v,i} - T_{l,o}) = (T_{v,i} - T_w)\ exp\frac{\pi\ d_o\ N\ h_o}{\rho_v c_{p,v}\ V_{\infty,v}\ N_{tub}\ P_T} \end{gathered} \tag{4}$$

Where $T_{v,i}$ is the pyrolysis vapor temperature come in to the condenser, $T_{l,o}$ is the condensate temperature leaving the condenser, and T_s is the tube surface temperature during operation. Properties of the pyrolysis vapor such as density ρ_v and heat capacity $c_{p,v}$ are determined at the pyrolysis vapor temperature at the entrance T_∞. High heat transferability is the main purpose of the designed condenser in this study. Several factors that influence the heat transfer rates include convection coefficient of the hot and cold streams (h), conduction resistant due to the wall thickness and conductivity thermal of the tube (R_{cond}), and the stream fouling at the outside and inside of the tubes (R_f). The resistances due to deposits are called fouling resistances. The values of fouling resistances can be obtained from tabulated values in the available references. By considering all factors, the overall heat transfer coefficient of the designed condenser (U) is expressed as

$$U = \frac{1}{\frac{A_o}{A_i h_i} + \frac{A_o}{A_i} R_{f,i} + \frac{A_o \ln(d_o/d_i)}{2\pi kl} + R_{f,o} + \frac{1}{h_o}} \tag{5}$$

3.3 Heat transfer coefficient on the shell side (h_o)

The average convective heat transfer coefficient on the pyrolysis vapor or the shell side based on the outer diameter of the tube (h_o) as

$$h_o = \frac{Nu_{d_o*} d_o}{k_l} \tag{6}$$

Where, two-phase film condensation Nusselt number was used. In this study, the condensation occurs on a number of designed rows of horizontal tubes with in-lined configuration so that the condensate from the top rows flows directly on to the next rows below as shown in Figure 7.

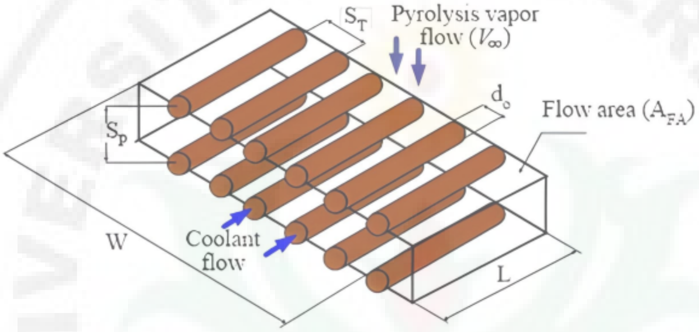

Fig. 7. Flow area of stream cross the tube banks

For such system, the two-phase film condensation Nusselt number was used which is obtained as follows,

$$Nu_{d,o} = 0{,}8\,\chi\left(1 + \frac{0{,}276}{\chi^4 FrH}\right)^{1/4} Re_{do,max}^{1/2} \tag{7}$$

Were

$$\chi = 0{,}9[1 + (RH)^{-1}]^{1/3} \tag{8}$$

$$R = \left(\frac{\rho_l \mu_l}{\rho_v \mu_v}\right)^{1/2} \tag{9}$$

$$H = \frac{c_{p,l}(T_{sat} - T_s)}{Pr_l \Delta h_v} \tag{10}$$

$$Fr = \frac{V_\infty^2}{g d_o} \tag{11}$$

Where T_{sat} is the pyrolysis vapor temperature, T_s is the inside wall temperature of the tube, The μ_l, h_{lv}, and k_l are the dynamic viscosity, latent enthalpy, and the thermal conductivity of the pyrolysis liquid respectively.

The $Re_{d_o,max}$ is defined as the two-phase Reynolds number which involving the maximum pyrolysis vapor velocity ($V_{v,max}$) and the condensate properties instead of the oncoming pyrolysis vapor velocity V_∞. The $V_{v,max}$ through the tube banks in this study can be determined as follows. For aligned tubes arrangement, the continuity equation through the tube banks can be written as

$$V_\infty * P_T = V_{v,max} * (P_T - d_o) \tag{12}$$

Flow area (AFA) is determined as

$$A_{FA} = W * N_t * L \tag{13}$$

Were

$$W = \frac{P_L * P_T - \frac{\pi {d_o}^2}{4}}{P_L} \tag{14}$$

Thus, the oncoming pyrolysis vapor velocity V_∞ and the maximum flow velocity $V_{v,max}$ on the shell side can be calculated as

$$V_\infty = \frac{\dot{m}_v}{\rho_v * A_{FA}} \tag{15}$$

$$V_{v,max} = \frac{P_T}{P_T - d_o} * V_\infty$$

Thus, the two-phase Reynolds number on the shell side can be determined as

$$Re_{d_o,max} = \frac{\rho_l * V_{v,max} * d_o}{\mu_l} \tag{16}$$

3.4 Heat transfer coefficient on the tube bank side

$$h_i = \frac{Nu_{d_i} * d_i}{k_w} \tag{17}$$

The fluid flows in the tube banks is water without phase changes. The water receive heat from the hot pyrolysis vapor as sensible heat. The water average velocity in the tube can be determined as

$$V_w = \frac{\dot{m}_w}{\rho_w * A_{tub} * N_{tub}} \tag{18}$$

In the tube banks configuration, the characteristic length used is the inner diameter of the tube d_i, thus the Reynolds number can be calculated as

$$Re_{d_i} = \frac{\rho_w * V_w * d_i}{\mu_w} \tag{19}$$

Where $\dot{m}_c$ is the rate flow of water, ρ_w is the water density, and μ_w is the dynamic viscosity of the water. The flow regime in the tubes is assumed to be turbulent. Thus, the following empirical equation is used to calculate the Nusselt number as

$$Nu_{d_i} = \frac{\left(\frac{f}{8}\right)(Re_{d_i} - 1000)\,Pr}{1 + 12.7(\frac{f}{8})^{0.5}\,(Pr^{\frac{2}{3}} - 1)} \tag{20}$$

With the conditions of 0.5<Pr<200 and 3.103<Re_{d_i}<5.106. The factor correction (f) is determined from Colebrook equations as follows. By employing iteration, the f value can be obtained.

$$\frac{1}{\sqrt{f}} = -2.0\,log\left(\frac{\varepsilon/d_i}{3.7} + \frac{2.51}{Re_{d_i}\sqrt{f}}\right) \tag{21}$$

A correlation for the smooth surface condition that encompasses a large Reynolds number range has been developed by Petukhov and is of the form.

$$f = (0{,}790 \ln Re_{d,i} - 1{,}64)^{-2} \qquad 3000 \leq Re_{d,i} \leq 5 \times 10^6 \tag{22}$$

The designed condenser is assumed limited to the location where the condenser is to be placed. Spacing is very important to be considered, so sometimes the length (L) of the tube must be assumed first. The problem now is to convert the area calculated from Equation 2 into reasonable dimensions of the first trial. The objective is to find the right number of tubes N_{tub} of diameter d_o with the given L:

$$N_{tub} = \frac{A_s}{\pi d_o L} \tag{23}$$

$$N_{tub} = 0.785 \left(\frac{CTP}{CL}\right) \frac{D_S^2}{(PR)^2 d_o^2} \tag{24}$$

Where CTP and CL show the tube sheet and tube layout respectively. CTP=0.93 for one tube pass, and CL=1 for layout 90º as shown in Fig 4. PR is the tube pitch ratio [37]. In this work, PL = PT = P then PR=P/d_o. The diameter of the shell required is calculated as follows

$$D_s = 0.637 \sqrt{\frac{CL}{CTP}} \left[\frac{A_s (PR)^2 d_o}{L}\right]^{\frac{1}{2}} \tag{25}$$

The pyrolysis liquid $\dot{m}_{pl}$ rate is calculated by equation

$$\dot{m}_{pl} = \frac{\dot{Q}_{max}}{h_{fg}^*} \tag{26}$$

The h_{fg}^* comes from the origin of latent heat evaporation, h_{fg} at T_{sat}. During the condensation process, the latent heat of vaporization occurred not only at T_{sat}. However, the condensate in an actual condensation process is cooled further to some average temperature between T_{sat} and T_s, releasing more heat. As such condition, the origin latent heat of evaporation is modified into h_{fg}^* as follows [35].

$$h_{fg}^* = h_{fg} + 0.6 c_{pl} (T_{sat} - T_w) \tag{27}$$

The cooling water pumping power is proportional to the pressure drop occurred inside the tubes is calculated by

$$W_P = \frac{\dot{m}_{cw} \Delta p}{\rho \eta_p} \tag{28}$$

Where η_p is the pump efficiency usually in the ranges of (η_p=0.80 – 0.85) [31] and Δp is the total pressure drop across the tube bundle is given by [34]

$$\Delta p = \left(4f \frac{LN}{d_i} + 4N\right) \frac{\rho u_{cw}^2}{2} \tag{29}$$

Where $\boldsymbol{f}$ is the pipe friction factor that can be found from the Darchy-Weisbach diagram

3.5 Performance analysis

The correct cooling process' occurrence is crucial to the condensation process. So that the temperature reaches a saturation point where the saturated steam of the pyrolysis vapor cools and transforms into a condensate pyrolysis, the condenser must have an appropriate cooling system to dissipate thermal energy from the saturated pyrolysis vapor. By adjusting the flow rate of the cooling fluid inside the condenser, the working temperature of the condenser is controlled. It is possible to conduct analysis on a condenser's effectiveness using empirical correlations. The cooling water will always be the minimum fluid for the proposed condenser since the pyrolysis liquid has a far higher heat capacity than water. Consequently, the value of C on the correlation of the efficiency of heat-bearing is zero. Thus,

$$\varepsilon = 1 - e^{-NTU} \tag{30}$$

$$NTU = -\ln{(1-\varepsilon)} \tag{31}$$

4. Special Case

To examine the design thermal, data from other studies as well as geometric size data from the designed condenser are used. Take some data from the results of the study and try to simulate to find out the accuracy of the design theoretically before laboratory testing is carried out. For example, determining the rate of heat transfer that occurs in a condenser as well as the rate of condensate produced.

Tabel 1. Specified value used for simulation

Fluids	Units	Value	Reff
Pyrolysis vapor (Hot stream)			
$T_{v,i}$	°C	350	Designed
$T_{l,o}$	°C	70	Designed
$c_{p,l}$	kJ/kg.°C	2,075	Data
$\dot{m}_h$	kg/s	Counted	
μ_l	Ns/m^2		Data
$P_{r,l}$	-		Data
k_l	W/m.K		Data
ρ_v			Data
h_v			Data
h_{vl}			Data
Water (Cold stream)			
$T_{c,i}$	°C	27	Designed
$T_{c,o}$	°C	45-60	Designed
$c_{p,c}$	kJ/kg.K	4,2	Data
$\dot{m}_c$	L/h	80-160	Designed
Cross flow shell and tube heat exchanger (One shell pass through one pass tube banks)			
Q	kW	Counted	
U	W/m^2. K	240-650	Designed
ΔP	Bar	1	Designed
d_o, d_i, L &	m	Designed	
A	m^2	Designed	
N_{tube}	tube	Counted	

5. Results and Discussion

This article explains the condenser's thermal design operating parameters and operating guidelines for condensing the volatiles from pyrolysis vapor of hydrocarbon-base materials into pyrolytic oil. Condensers can be used to save energy while producing higher-quality pyrolytic oil and product streams that can be further processed to produce valuable chemicals like methanol. This study employed heat and mass transfer equations to conceptualize condensation using an energy balance-based theoretical model. Several equations that can be employed in the preliminary design of the necessary condenser have been developed and tested. To determine whether the equations utilized can generate data that can be used as a reference for constructing and experimentally testing a condenser necessary for the condensation process, a number of parameters are simulated. The simulation findings listed below are shown and discussed.

5.1 Effect of cooling flow rate on the condenser heat load

Figure 8 shows the effect of the cooling water flow rate inside the condenser pipes on the cooling load. It was found that the cooling load increases when the flow rate of the cooling water is increased. In this analysis, it was obtained that the highest cooling load is obtained when the flow rate of cooling water is 1.95 LPM. When the cooling water flow rate is increased further, the cooling load will decrease. This is due to the influence of the length of the cooling pipe used. In this study, the length of the pipe used is 50 cm. For the specified pipe length, the flow rate of the cooling fluid will be limited, because if the flow rate of the cooling fluid is increased, the effectiveness of heat transfer will decrease resulting in a decrease in cooling load.

In designing the length of the cooling pipe, it is sometimes limited to situations in the field where the pipe cannot be made longer due to space limitations. Indeed, if the cooling pipe increases in length, the heat transfer coefficient will increase.

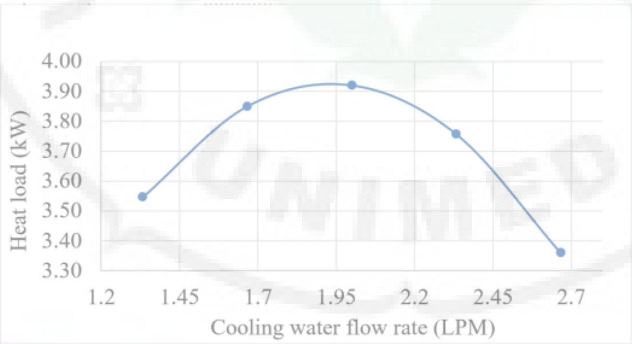

Fig. 8. Heat load vs cooling water flow rate .

5.2 Effect of cooling flow rate on the condenser effectiveness

Figure 9 below shows the effect of water velocity in the cooling process. From the simulation results, it was obtained that by increasing the velocity of the water cooling, the efficiency of the condenser will decrease. This can be seen from the temperature of the cooling water exit from the condenser which is decreasing whilst the temperature of the hot fluid is increased. This indicates that the heat transfer from the hot fluid to the cooling fluid is not good enough. This will make the condenser performance is no longer efficient as indicated by a decrease in the effectivity of the condenser when the flow speed of the cooling fluid is increased.

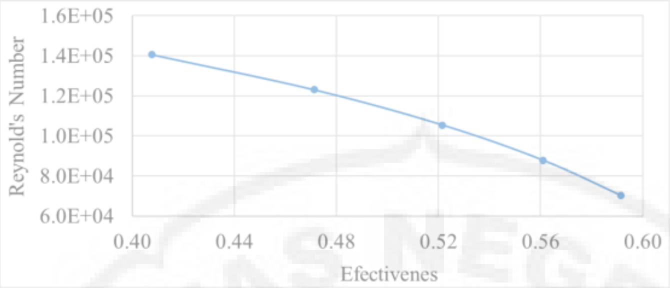

Fig. 9. Condenser effectiveness as the Reynolds Number function.

Several parameters have been simulated which resulted data which can be used for the preliminary designing of a condenser for pyrolysis condensation. However, the condenser prototype needs to be examined experimentally to validate the analysis. The most important is that during the actual testing, the condenser must be coupled directly to the reactor.

Due to the degradation of cellulose, lignin, and hemicellulose, the pyrolizer temperature should be performed ranges from 300 – 600 ºC in increments of 100 ºC, because the yields of volatiles rapidly rose as the pyrolysis temperature is increased. However, the temperature cannot be increased further because the bio-oil product yield tent to decrease at high temperature. To ensure appropriate reactions, the reactor was kept at its final temperature for 60 minutes. The liquid smoke, as well as charcoal and tar are produced under this state. Raw materials that can be used to produce liquid smoke can be of wood species, palm, coconut shell or sawdust wood, and also plastic waste.

The smoke generated during the pyrolysis process can be directly fed into the condenser where condensable hydrocarbon vapor condensed and non-condensable gases were released and flared. The smoke entering the condenser has to be controlled through the temperature and flow rate of the smoke. The success of the condensation process in the condenser can be known directly through the liquid smoke generated flow rate and the quality. However, to analyze the operational parameters used, the temperature of the cooling water out flowing of the condenser is used as the main indicator.

6. Conclusion

A condenser has been designed to allow the hot pyrolyzed smoke to cool and condense into liquid. The technique employed is known as the thermal design approach, and it relies on the concepts of energy balance to create the necessary equations. The condenser's performance is evaluated using the equations created combined with physical data from the design condenser, data of the pyrolysis process, and operational data. According to some modeling findings, the kind and flow rate of the coolant being utilized have a significant impact on the cooling process. The cooling fluid's flow rate can also be utilized to determine how well the design condenser works. It can be inferred from this study that a condenser that will be used for the smoke cooling process that resulted from the pyrolysis process can be designed using a thermal technique before designing a real condenser is built.

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