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Analysis of the Evaporator Components of the Adsorption Cooling Machine Using 3D Simulation

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ABSTRACT

Solar Energy is the biggest energy on the earth, solar enegy in Indonesia can be utilized for variety of things. Based on solar radiation data collected from 18 locations in Indonesia, solar radiation for West Indonesia area has reached 4,5 kWh/m2/day with monthly variation about 10%, while East Indonesia area has reached about 5,1 kWh/m2 /day with monthly variation about 9%. Therefore, the solar energy can be utilized as the main source of energy for the adsorption refrigeration cycle cooling machine to produce cooling effect. The simulation object of this research is evaporator, which simulated with Ansys 15.0 and modeled with 3D CAD software. Evaporator is filled with 5 litres of methanol, and 6 liters of chilled water. This simulation simulated 30 minutes of desorption which start from 5.30 p.m to 6.00 p.m GMT+7 actual research time. The lowest chilled water temperature get from this simulation is about 19,79 ℃ at 12665 Pa pressure, and have an error presentage about 7,21% compared with the actual experiment. Theoretical efficiency of the evaporator is about 57,292% and have an error presentage about 5,21% compared with the actual experiment. Coefficient of Preformance from this cycle is 0,039.

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1. INTRODUCTION

The phenomenon of deficit electricity supply in Indonesia, especially in North Sumatra, has been experienced for years (Ronaldo & Wahyunissa, N.D.), one of the factors that use the largest electrical energy is in the field of air cooling (Ayu, 2019). The consumption of electrical energy for cooling and air conditioning in commercial buildings in big cities in Indonesia can reach 60% (Ratnasari, 2022). Therefore, one of the solutions currently being developed is renewable energy using solar energy. Indonesia is located at the equator, which is 60 LU–110 LS (Sudiyono & Antoko, 2008), where the apparent trajectory of the sun does not change throughout the year. Then the territory of Indonesia will always be exposed to the sun an average of 10-12 hours a day (Adhe, n.d.). According to Indonesia's white energy data in 2006, it is estimated that the average intensity of solar radiation that falls on the surface areas of the islands in Indonesia is around 4.8 kWh/m2 every day. This energy can be utilized in the form of direct electricity (photovoltic) and also in the form of thermal (Widayana, 2012). Utilization of solar energy can be used for several applications, such as drying and cooling (solar cooling) (T. B. Sitorus, 2018). From the two facts above, the need for cooling is quite large and the potential for solar energy is quite large (Ambarita, n.d.), became the background of this research. The big theme of research is capturing solar radiation energy in thermal form and utilizing it to produce cooling (refrigeration) (Wailanduw et al., n.d.). Therefore, the equipment used requires a tool (Heat Exchanger) that is able to convert the thermal energy, and utilizes the thermodynamic cycle, namely the adsorption cycle (Abu, 2014). Meanwhile, research and development of adsorption requires a lot of time and money (Arif et al., 2019). Therefore, to reduce the time required for development and reduce development costs, simulation technology is needed (Kamelia, 2015). Because it involves fluid flow, the CFD (Computational Fluid Dynamics) field can be used to help model the adsorption process (D. B. N. Sitorus et al., 2019). Lately, CFD is increasingly being used to perform simulation modeling analysis (Simbolon et al., 2015). The CFD program is one of the simulation technologies that can be used to conduct research in analyzing problems in the adsorption process (Arif et al., 2019).

The objectives of this simulation are: (1) Knowing what the lowest water temperature is in the simulation and the error compared to the experiment (Web, n.d.). (2) Knowing the occurrence of a phase change which is marked by a change in the volume of the methanol-liquid phase in the evaporator (Zahro & Riset, n.d.). (3) Knowing the efficiency of the evaporator from a theoretical point of view and its errors compared to the experiment.

The benefits of writing this thesis are: (1) Scientific and academic aspects. This research is related to the subject. Computational Fluid Dynamic (CFD) and Heat Transfer I and II, so that this research is expected to provide broad insight for researchers and develop knowledge in the field of desalination (Tarkono & Ali, 2016). (2) Aspects of practice and implementation. Focusing on drying case modeling on CFD software which is then compared with experimental results (Indriani et al., 2013). (3) Analysis using software will save research costs when compared to using equipment that will cost more (Musilah et al., 2021).

2. RESEARCH METHOD

2.1 Simulation Flowchart

Broadly speaking, the implementation of this simulation is carried out sequentially and systematically as shown in Figure 1.

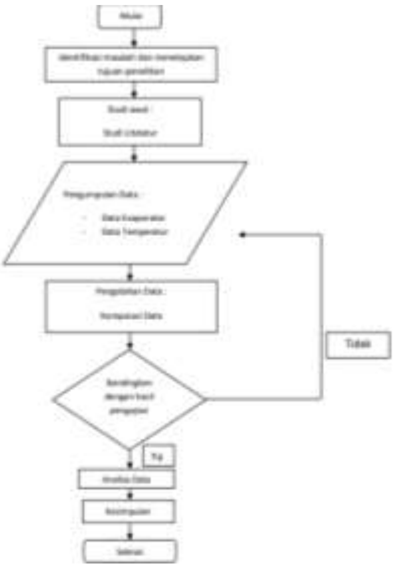

Figure 1. Simulation Flowchart

The description of the flow chart in Figure 3.3 is explained as follows:

2.1.1 Study of Literature

Writing conducts literature studies in the form of collecting writing materials such as books, scientific journals, and previous research results (Sari & Asmendri, 2020). In addition, the author also collects material from sources on the internet to study the technical work of research and simulations (Priyanthi et al., 2017).

2.1.2 Experiment and Data Collection

At this stage, experiments are carried out based on the methods used by previous researchers. The experiment carried out is the adsorption-desorption principle where the absorbent is heated using solar energy during the day, then at night by utilizing natural convection and opening the absorbate separator valve with the absorbent opened causing the adsorbate to evaporate and be absorbed by the absorbent (this process is called the adsorption process). Then during the day the valve which was opened was closed and then opened the valve that connects the reactor to the condenser and to the place of origin of the absorbate for the desorption process to occur. Then the required data from the experimental results are recorded, then these data will be entered and then the results will be compared with the simulation process of the ansys 15.0 program.

2.1.3 CFD Simulation

The CFD simulation is carried out in several stages, namely geometric modeling, meshing, determining boundary conditions, inputting the required data such as initial pressure and heating temperature, then proceed with simulation.

2.1.4 Data Analysis

Simulation results are recorded and compared with experimental results such as temperature data displayed in the form of graphs and calculating errors.

2.1.5 Conclusion Drawing

This conclusion is based on the correlation with the research objectives that have been previously set.

2.2 Test Scheme

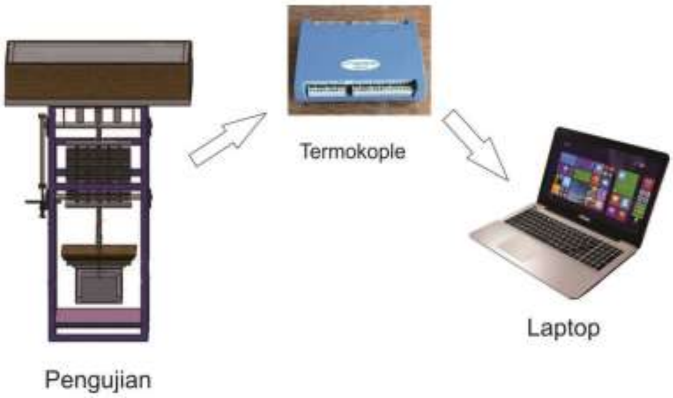

Figure 2. Adsorption Cooling Machine Test Scheme.

The working principle of the test scheme, namely: (1) A thermocouple is used to measure the change in water temperature that occurs in the test and sends the data to a Cole-Palmer thermocouple. (2) The Cole-Palmer thermocouple will record the temperature every 5 seconds and the data will be sent to the laptop by USB. (3) The temperature change data is then displayed on the laptop so that it can then be used for analysis purposes. The practical data used as input to the ansys 15.0 program and the desired output from the simulation can be seen in table 3.1 below.

Table 1. Simulation Input And Output

Input	Output
Temperatur air awal	Temperatur air akhir
Tekanan sistem	Tekanan akhir sistem
Dimensi Evaporator	Volume frasa metanol
Volume air	Effisiensi teoritis metanol
Volume metanol	

3. RESULTS AND DISCUSSIONS

In this chapter, we will discuss the results of the three-dimensional analysis simulation on the evaporator. The analysis carried out on the evaporator includes phase analysis (volume fraction), the temperature distribution that occurs in the evaporator which will be displayed in the form of contours, accompanied by a graph of the temperature increase from the simulation results.

3.1. 3D Evaporator Design

The evaporator is designed with three-dimensional (3D) CAD software. The design is made based on data from the results of the evaporator design. The evaporator is made of stainless steel with a thickness of 1 mm, connected to 3 inch stainless steel pipes. The first pipe (from left to right) is connected directly to the absorber as an adsorption channel while the third pipe is connected to the condenser as a desorption channel. While the pipe in the middle is for filling methanol after the assembly process is complete. Then imported to
in ansys geometry and changing the materials. Like the working fluid part, the material is a fluid.

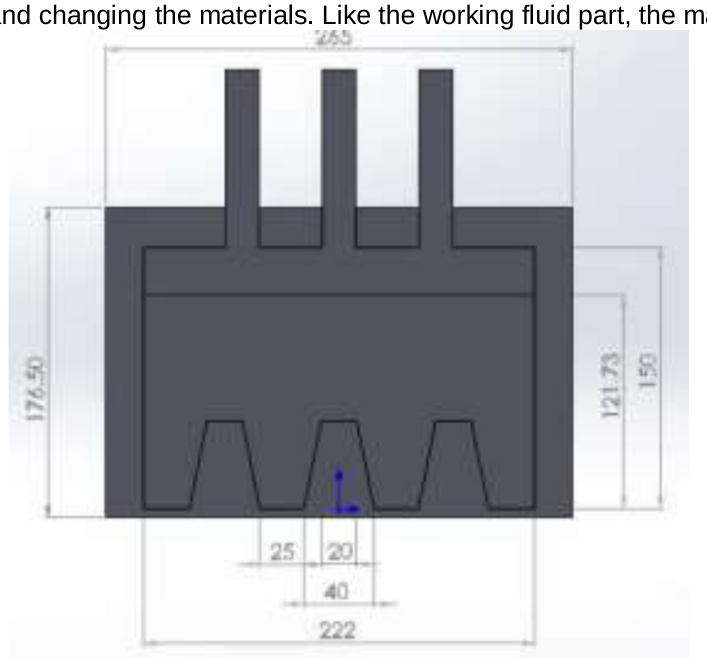

Figure 3. Evaporator Dimensions (In Mm)

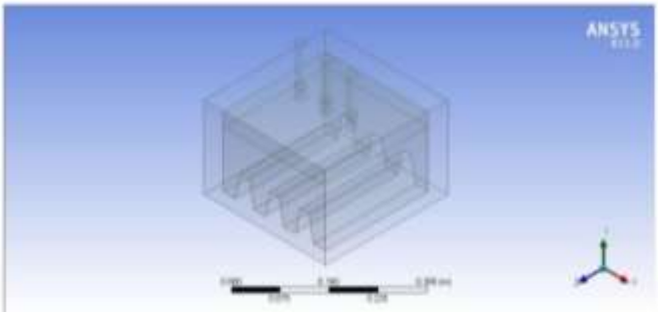

Figure 4. 3D Evaporator View on Ansys 15.0 Software Software

3.2. Boundary and Meshing Conditions in Ansys 15.0 Software Software

The boundary condition used in the evaporator is that the boundary between methanol and water is limited by stainless-steel material to limit the movement of liquid and vapor flow in the evaporator. One of the three stainless-steel pipes is constrained in the form of an outflow for the steam output flow from the evaporator. While the rest are given a wall boundary. After the boundary conditions are given, the mesh settings on the evaporator are adjusted accordingly
with initial conditions. Meshing on this evaporator produces 65,618 points and 280,924 parts, it can clearly be seen in Figure 4.3

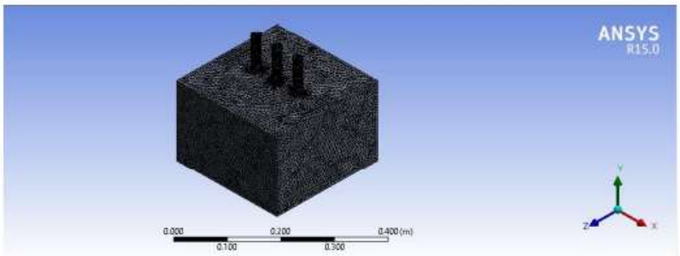

Figure 5. 3D Mesh Evaporator Model on Ansys Software 15.0

3.3. Analysis on Software Ansys 15.0

After the design is complete and the boundary conditions are given in Geometry Software Ansys 15.0, the evaporator analysis is continued by entering the initial data for the calculation, both material properties and initial conditions of the system for further calculation and analysis. Simulation on Ansys 15.0 Software was carried out for half an hour, starting at 17.30 WIB when the adsorption process occurred. With assumptions such as heat from water with an initial temperature of 377.32 K, a stainless-steel wall thickness of 0.001 m, a pressure below 1 atm, namely a vacuum pressure of 12.6 kPa obtained from a vacuum pressure gauge, the initial temperature of the system is 298 K. , gravity is 9.81 m/s2.

3.3.1. Analysis Results on Ansys 15.0 . Software

After the data is inputted, the evaporator analysis is iterated with a flow time of 1800s or half an hour, the analysis results obtained are in accordance with the results of the study. The results of the analysis of the phase change (volume fraction) of liquid into steam, temperature, and fluid flow in the evaporator along with the achieved parameters will be shown in the image below: 4.3.1.1 Fas Contour Analysis Analysis Results on Ansys 15.0 Software

3.3.2. Phase Contour Analysis

From the results of the contour analysis, it can be noted that in Figures 4.5 and 4.6, there is a phase change of methanol liquid to methanol vapor.

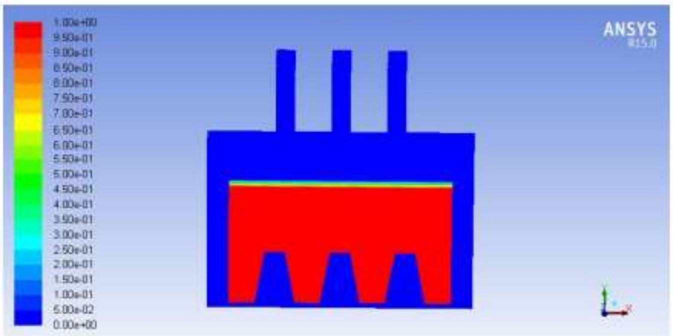

Figure 6. Initial Liquid Methanol Phase Contour

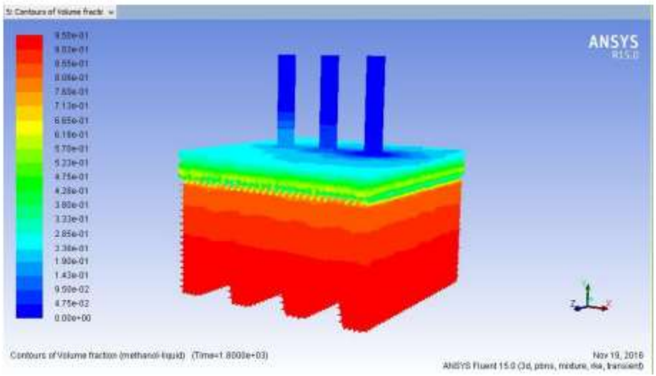

Figure 7. Initial Liquid Methanol Phase Contour

The phase contour has a value between 0 and 1, and the red color indicates the liquid methanol phase and the blue color above indicates the gas methanol phase. So it can be seen that the liquid methanol phase decreases from the bottom to the top of the evaporator which means that the liquid methanol undergoes an evaporation process. The average value of the phrase volume of liquid methanol is 0.883.

3.4. Comparison of Experimental Results and Simulation Results

In this section, a graph of the experimental temperature per 10 seconds will be presented for half an hour from 17.30 compared to the simulation with Ansys. As previously explained, the temperature measurement results were measured using a Cole Palmer Thermocouple with a position as shown in Figure 3.3, Channel 6 is positioned to measure water temperature.

In Figure 4.13 below it is shown that the water temperature at the beginning of the simulation was 299.32K and decreased sharply in the first minutes and after that it decreased slowly until it reached a temperature of 292.79 K in the 1800th second. The data in appendix 3, shows the results and comparison of the simulation results.

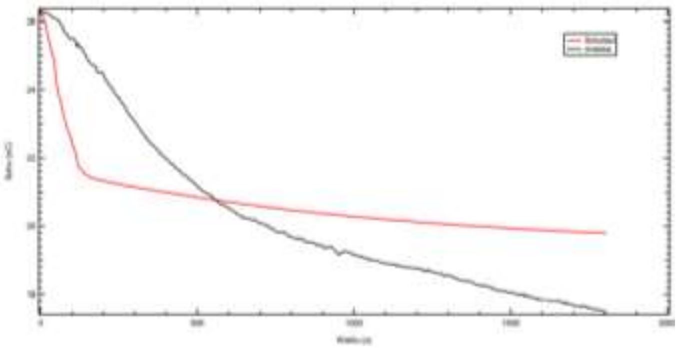

Figure 8. Graphics Simulation vs Analysis

Figure 4.13 is a comparison of the temperature of the simulation results with the temperature of the test results with the Cole Palmer Thermocouple on channel 6 for 30 minutes of experimentation starting from 17.30 to 18.00 WIB.

3.5. Theoretical Calculation of Condenser and Evaporator

3.5.1. Condenser

The average temperature data owned by the inlet and outlet of the condenser as well as the ambient temperature from the 3 days of the research experiment were obtained
Tin = 34.2816°C , Tout = 32.1824°C and $T\infty$ = 29.533°C
So, Ts = Ts = $(Tin + Tout)/2$ (1)
Ts = (34.2816 + 32.1824)/2
Ts = 33.23°C
The physical properties of air at film temperature are:
Tf = $(Ts + Ts)/2$ (2)
Tf = (33.232 + 29.533)/2
Tf = 31.38°C
k value, ϑ, and Pr obtained from the interpolation of the data between the temperature of 30°C with a temperature of 35°C, obtained:
k = 0.0259 W/mK, ϑ = 1.621e-05 m2/s, and Pr = 0.727
Score β calculated by the formula β = 1/(Tf +273) 1/K.
So, β = 1/(31,38265 + 273) = 3,285e-03 1/K
Finding the Rayleigh value: Because the condenser contains vertical and horizontal pipes and horizontal plates (fins), the calculation is carried out for the whole:
- For vertical pipe:

$$R_{a_L} = \frac{g\beta(T_s - T_\infty)L^3}{\vartheta^2} Pr \tag{3}$$

$$R_{a_L} = \frac{9{,}8x0{,}003285\ (32{,}232 - 29{,}533)x0{,}4^3}{(1{,}621e^{-5})^2}\ x\ 0{,}727812858$$

$$R_{a_L} = 2{,}113\ x\ 10^7$$

- For horizontal pipe:

$$R_{a_L} = \frac{g\beta(T_s - T_\infty)L^3}{\vartheta^2} Pr \tag{4}$$

$$R_{a_L} = \frac{9{,}8x0{,}003285\ (32{,}232 - 29{,}533)x0{,}4^3}{(1{,}621e^{-5})^2}\ x\ 0{,}727812858$$

$$R_{a_L} = 2{,}113\ x\ 10^7$$

Untuk pipa horizontal:

$$R_{a_D} = \frac{g\beta(T_s - T_\infty)D^3}{\vartheta^2}\,Pr \quad (5)$$

$$R_{a_D} = \frac{9{,}8x0{,}003285\,(32{,}232 - 29{,}533)x(0{,}0254)^3}{(1{,}621e^{-5})^2}\,x\,0{,}727812858$$

$$R_{a_D} = 5{,}41\,x\,10^3$$

3.5.2. Evaporator

The evaporator is lined with an insulating box. The main function of this insulation box is to inhibit the rate of heat transfer from the environment into the system.

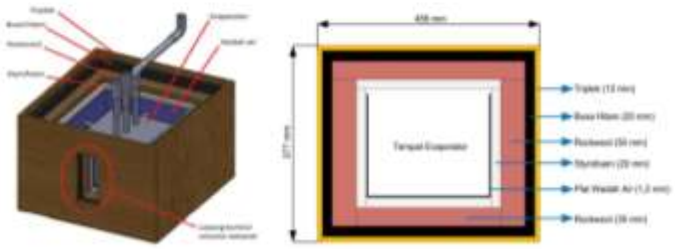

Figure 9. Evaporator Insulation Box

Then, the rate of heat transfer from the surroundings can be calculated by:

$$\dot{Q}_{\infty-w} = \frac{T_{awal\ air} - T_{akhir\ air}}{R_{tot}} \quad (6)$$

Where, $T\infty$ from the HOBO data obtained 24.4666^{o}C, $Takhir\ air$ from the test obtained 9.82^{o}C, $Rtot$ is the total convection resistance of the air and the conduction resistance of the insulation, namely:

$$\sum R_{tot} = R_{air} + R_{iron} + R_{sterofoam} + R_{rockwool} + R_{busa} + R_{triplek} + R_{udara} \quad (7)$$

Data from the insulation design of the evaporator is obtained:

Table 2. Evaporator Insulation Data

Material	Ketebalan, Δx (m)	Konduktivitas Themal, k (W/m.°C)	*Convective Thermal Resistance*, h (W/m^2°C)	Luas Material, A (m^2)
Air	-	-	50	0,2906
Iron	1x10^{-3}	80	-	0,2906
Sterofoam	20 x10^{-3}	0.036	-	0,5031
Rockwool	50 x10^{-3}	0.03	-	0,93415
Busa	15 x10^{-3}	0.14	-	1,07284
Triplek	12 x10^{-3}	0.12	-	1,15011
Udara	-	-	10	1,15011

The efficiency obtained from the study was obtained by

$$\eta_{evaporator\ p} = \frac{Q_{terpakai}}{Q_{penguapan}} \quad (8)$$

$$\eta_{evaporator\ p} = \frac{612{,}6\ kJ}{1122\ kJ}$$

$$\eta_{evaporator\ p} = 54{,}598\ \%$$

The efficiency errors are:

$$Ralat\ Effisiensi = \frac{\eta_{evaporator} - \eta_{evaporator\ p}}{\eta_{evaporator\ p}}$$

(9)

$$Ralat\ Effisiensi = \frac{57{,}397 - 54{,}598}{54{,}598}$$

$Ralat\ Effisiensi$ = 5.21 %

The error is obtained because the error from the temperature data recording device is also due to the error from the assembly of the tool which is not all the same as the assumption of the condition of the tool when calculating efficiency through theory.

4. CONCLUSION

The conclusions obtained from this research are: (1) The lowest water temperature from the 3D simulation results using ansys 15.0 software in the first 30 minutes after opening the connecting valve between the evaporator and the collector from 17:30 in the afternoon is 19.79℃ at a pressure of 12.66 kPa. (2) From the simulation results using ansys 15.0 software, that in the evaporator there is a volume phase change during the desorption process, the average value of the liquid methanol volume phase is 0.883. (3) The theoretical evaporator efficiency is 57.393% and has an error of 5.21% against the experimental evaporator efficiency of 54.598%.

The suggestions given for further research are: (1) To get more accurate analysis results, the meshing size can be reduced and refined. (2) In order for further research to use UDF when determining the evaporation temperature of methanol-liquid in ansys 15.0 software. (3) For further research, simulations will be carried out on one system of collector, condenser, and evaporator simultaneously. So that the results from the simulation can be directly compared with the experimental results. (4) So that when performing a CFD simulation analysis, make sure the computer or laptop has high specifications and is in good condition. (5) Data collection in research is recommended to use tools that have little or digital accuracy in order to minimize the occurrence of large errors.

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