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ANALYSIS OF SOLAR ENERGY UTILIZATION OF HYBRID SYSTEMS FOR FREEZING MANGO FRUIT

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***Abstract*— The use of vapour compression refrigeration systems is growing both on a domestic and commercial scale. The impact of electrical energy consumption in this sector is quite large compared to the need for electrical energy in other electronic equipment. Various efforts were made to be able to reduce the consumption of electrical energy for the cooling system. One of the efforts made by utilizing the natural potential of energy around is solar energy and wind energy as a source of electrical energy in the freezing unit of mango fruit. This fruit is one of the main commodities in West Java, especially in Indramayu district. The purpose of this study is to find out the needs of electricity consumption and how efficient the use of alternative energy is for freezing mango fruit. In the process freezing is carried out at temperatures below the freezing point of the food. Good freezing usually ranges from -12 ºC to -24 ºC. With this temperature, food can last up to 3 to 12 months. In this study, the method was carried out for freezing mangoes by utilizing solar energy which was assembled hybrid with wind energy in the vapour compression refrigeration system for the freezing. The design method is carried out by taking into account the cooling load on the freezer to find out the cooling capacity is 1/2 PK. The test results can be analyzed comparing the performance of the utilization of the hybrid energy system with the design and use of PLN electricity, the length of time to reach the freezing temperature of a unit.**

***Keywords*— hybrid system, performance, freezing unit**

I. INTRODUCTION

The development of cooling system technology is something that is needed in various sectors, especially in the field of horticulture, especially in the process of handling post-harvest fruits. In Indramayu district, there is still not much technology for post-harvest handling of fruits, especially mangoes. Even though it is realized that the commodity value of mango fruit is quite large. Almost most of the houses have mango trees, so it is known as the city of mangoes. On the one hand, Indramayu has natural conditions in the tropics, where the potential for solar energy is easily obtained. Based on these conditions, research efforts were carried out that combined the potential of solar energy and wind energy to be utilized in the freezing system in mangoes. For the process of freezing this fruit, of course, it still needs additional treatment, so that the condition of the fruit remains fresh, and is not damaged by physical properties with freezing [1]. The purpose of the study was carried out considering that the productivity of mango harvests is quite large, while post-harvest handling for preservation with the freezing process is still rare, mostly after harvest, the existing mangoes are immediately sold until the harvest season runs out, and after that there is no handling process for storage so that they can be used for other commodities that can increase people's income. The method is carried out by utilizing two natural energy sources, namely solar energy and wind energy which are quite potential in Indramayu. The use of solar energy using solar panels where Indramayu is a tropical climate, while wind energy uses windmills / wind turbines because the wind potential exists almost all year round [2]. These two energy plants are then assembled in a hybrid manner so that a DC electric current is obtained which is then converted with an inverter into AC electric current. From the electrical energy produced is then supplied to move the compressor in the freezer system. The utilization of these two energies is expected to be able to reduce the use of electrical energy from PLN sources in the operating freezer system. How much the value of electricity consumption, the performance of the equipment used, and the cooling time achieved, will be used as a study in this study. In the process freezing is carried out at temperatures below the freezing point of the ingredients / food. Good freezing usually ranges from -12 ºC to -24 ºC. However, traditional frozen storage is done at 0 °F (-18 °C). Frozen storage at cabin temperatures around -15 °C and below can prevent microbiological damage, provided that there are no excessively large temperature fluctuations [3]. With this temperature, food can last up to 3 to 12 months.

II. METHODOLOGY

The research methods used can be carried out in theory or through testing. In theory, by making a calculation design from the specified parameters, then the design results become the basis for making a hybrid prototype system on the freezing unit,

where then the unit that has been made will be tested and the data taken to analyze the performance of the system.
For this stage of research to be in accordance with the research objectives, a systematic and directed research methodology is compiled according to the flow chart in Figure 1.

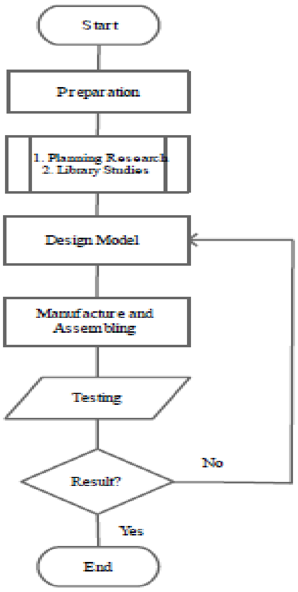

Fig. 1 Research Flowchart

A. *Preparation Stage*

At this stage, literature studies related to the research background, theoretical concepts for designing hybrid systems (solar energy and wind energy), studies of freezing systems and calculations in the analysis of test results.

B. *Design Stage*

This stage is the initial stage of designing the system to be created. In this stage, data collection and calculation of the initial design of the system is carried out such as determination of cooling load, temperature variables, tool dimensions, radiation intensity, and time required for freezing. For the design scheme can be seen in figure 2.

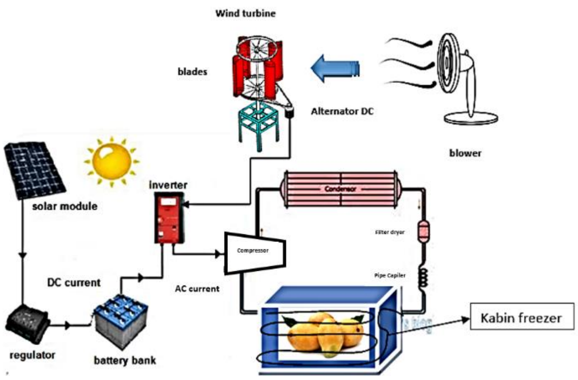

Fig. 2 Scheme Hybrid System on Mango Fruit Freezer Unit

The way the system works based on the picture above, is a scheme of the mango fruit freezing system using a hybrid system (solar panels and turbines / windmills) that utilizes solar energy and wind energy as a source of electrical energy. Using solar panels can generate electricity with a photovoltaic system (converting solar energy into electric current). This solar panel exposed to sunlight will charge with a panel output, namely 12 VDC which will be accommodated in the battery and will be converted using an inverter so that it obtains a voltage of 220 VAC and AC current so that it can be supplied to a Freezing trainer to move the compressor on the mango fruit unit. The use of solar panels is assembled off grid, so it can be known how much the electric current storage battery can be consumed to move the compressor in the freezer. Then for electrical energy from wind energy is obtained by using wind turbines as a converting medium from kinetic / motion energy to electrical energy produced by alternators mechanically from turbine rotation. Then it is accommodated into a unidirectional electric battery (DC) which is connected to the inverter to be converted into voltage and alternating electric current (AC) needed to drive the compressor in the freezer.
The calculations used in making this system are as follows:
The cabin size is designed and adjusted to the capacity of the product to be cooled in the cabin. The specifications of the cabin dimensions are 0.46 m x 0.47 m x 0.47 m.

1) *Calculation of Solar Panel*

- Mango freezing power needs

The required power is 375W during 3 hours of use
375W x 3 hours = 1125 Wh

- Inverter calculation

A detailed calculation must consider the loss of battery power to load, if the load used is AC current, then input the inverter efficiency factor. For this reason, it uses a PSW inverter type with a power loss factor of 5% [7]. So that the power obtained is 1125Wh using PSW to 1181.25 Wh.

- Battery calculation

For the calculation of the number of battery can be searched from the comparison of the amount of power needed for 3 hours to the battery power (12V x 100Ah). So that the number of batteries is obtained 1 piece with the type of VRLA battery.

- Calculation of the number of panels

The number of panels can be calculated by knowing the power requirement for 3 hours, then by determining the type of SCC (*Solar Charger Controller*) type PWM, the number of panels is 4 pieces.

2) *Performance Calculation of Solar panel and Wind turbine*

The calculation of performance on solar panels can be obtained using the equation [4]:

Solar panel efficiency =

$$\frac{Maximum\ Output\ power}{Solar\ intensity\ x\ Area} \text{ x } 100\ \% \qquad (1)$$

Known:
Maximum Output Power (panel output power required by freezer) = 360 (Watts)
Solar radiation intensity = 1100 (W/m2) (actual data in Indramayu)
Panel Area = 3.08 m2
So that Solar panel efficiency is 10 %.

For the calculation of the hybrid system performance design can be obtained from the equation:

Hybrid System performance =

$$\frac{Daya\ Output}{Daya\ (Panel\ Surya + Kincir\ Angin)} \times 100\ \% \qquad (2)$$

Known:
Output power = 360 watts
Solar panel power = 400 watts (for 4 panels with a power of 100 wp each)
Windmill power = 2.16 watts (from alternator/DC generator)
So that the efficiency of the Hybrid System =

$$\frac{360}{400+2.16} \times 100\ \% = 89\ \%$$

To calculate the efficiency of the wind turbine can use the following equation [5]:

$$\text{Wind turbine Efficiency} = \frac{Pout}{Pin} \times 100\% \qquad (3)$$

From the data it is known:
Voltage from the generator (V) = 12 V
Generator electric current (I) = 0.18 A
Wind turbine diameter (D) = 0.3 m
Wind speed = 3.9 m/s
Assumed density value of air ρ = 1.2 kg/m3
Using the formula Generator Power (Pout) is obtained:

Generator power (P_{out}) = V x I (4)
= 12 x 0.18
= 2.16 watt

As for the Wind Power (P_{in}) formula, it is obtained:

Wind Power (P_{in}) = ½ x ρ x A x v^3 (5)
= 1/2 x 1.2 x 0.28 x $(3.9)^3$
= 9.9 watt

So, wind turbine efficiency is obtained:

$$\text{Wind turbine Efficiency} = \frac{Pout}{Pin} \times 100\%$$

$$= \frac{2{,}16}{9{,}9} \times 100\%$$

= 21%

3) Calculation of System Design Performance in Freezer

For calculations on the design of the freezer unit, you can use the p-h diagram of the R404a refrigerant to determine the performance or efficiency value of the cooling system, the following data is needed [6]:

- Condenser Temperature (Tc) = 40ºC =313.15K
- Evaporator Temperature (Te) = -20ºC = 253.15K

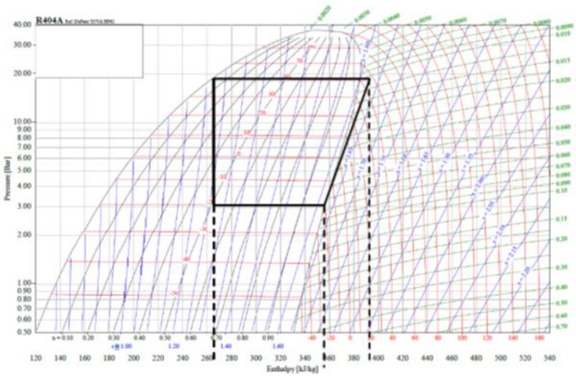

Fig. 3 P-H Diagram of System Design Using R404a[8]

The enthalpy value obtained:

- h1 = 358 kJ/kg
- h3 = h4 = 265 kJ/kg
- h2 = 392 kJ/kg

1. Determine the compression work (q_w)

The amount of compression work per unit of refrigerant mass can be calculated by the equation:

$q_w = h_2 – h_1$ (6)
= 392 – 358 = 34 kJ/kg

2. Determine the heat removed (q_c)

The amount of heat refrigerant released in the condenser is expressed in the equation:

$q_c = h_2 – h_3$ (7)
= 392 – 265 = 127 kJ/kg

3. Determine the refrigeration effect (q_e)

The amount of heat absorbed by the evaporator is expressed in the equation:

$q_e = h_1 – h_4$ (8)
= 358 – 265 = 93 kJ/kg

4. Determine refrigeration of the coefficient of performance (COP_R) divided into:

a. COP of actual cycle

The amount of actual COP is expressed as a comparison between refrigerant effect and compression work is:

$$\text{COP actual} = \frac{qe}{qw} \qquad (9)$$

$$= \frac{93}{34} = 2.7$$

b. COP of Carnot cycle

The theoretical COP for an air conditioning system is expressed by Carnot's theorem, reduced to the following equation:

$$\text{COP carnot} = \frac{Te}{Tc - Te} \qquad (10)$$

$$= \frac{253}{313 - 253} = 4.2$$

5. Determine the refrigeration efficiency (η_R)

The efficiency of a refrigeration can be described more precisely of a real process in relation to a certain (ideal) reference process by Carnot's theorem. Referring to the above mentioned considerations it can be defined [6]:

$$\eta_R = \frac{\text{COP actual}}{\text{COP carnot}} \quad (13)$$

$$\eta_R = \frac{2.7}{4.2} = 64\%$$

C. Assembling and installation stage

After the design is completed, then prepare the components that will be assembled into a freezer unit with a hybrid system. Then make a system and manufacturing as well as a testing system, whether the machine can work properly. This mango freezing system uses two sources of energy, namely a combination of solar energy in the form of solar modules / panels and wind energy in the form of wind turbines which will be converted as a source of electrical energy to drive the compressor in the freezer system. In this freezing system prototype, it has a capacity of 1/2 PK (350 watts) with refrigerant R404a.

For components in the solar panel system, there are 4 solar panel units arranged in parallel type *polycrystalline*, each of which has a power of 100 WP. Then it is also equipped with SSC (*Solar Charger Controller*), hybrid inverter, and solar panel batteries with VRLA type. For wind turbine installations consisting of 4 angular-mounted blades mounted vertically on the sides of the turbine shaft, then equipped with a 12V DC alternator, and a battery. For a series of installation drawings can be seen in figures 4, 5, and 6.

Fig. 4 Freezer Trainer Unit

Fig. 5. Installation system of Solar Panels

Fig. 6 Installation System of Wind Turbine

D. Testing stage

The next step is to test after the components are installed, then testing to ensure the system operates properly, then after that data collection is carried out, which later the data will be analyzed. The data is taken using measuring instruments such as digital thermometers and thermocouples, pressure gauges, multimeters, anemometers, and solar power meters.

Meanwhile, the data needed in the test are refrigerant temperature, refrigerant pressure, electric voltage and current, electrical power, wind speed, and solar radiation intensity. For this test is carried out for 2 hours, with data retrieval every 5 minutes. Before the data is obtained from the test, it is necessary to calculate based on the design data to compare when analyzing the test results.

III. RESULT AND DISCUSSION

The test result data is then processed to be analyzed both in the form of graphs and tables of calculation results to determine the performance of the hybrid system utilization in the mango freezing unit.

The following are the test results stated in the Graph of the relationship of Cabin Temperature to Time using PLN electricity and a hybrid system.

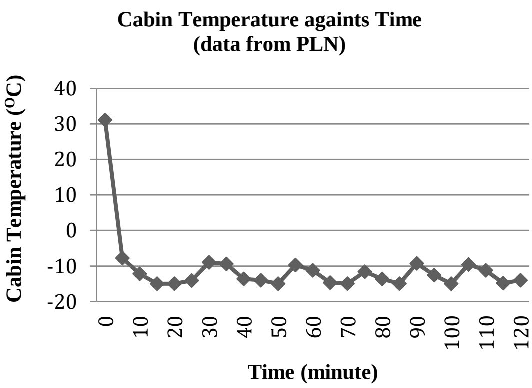

Fig. 7 Graph of Cabin Temperature against Time (PLN electricity usage data)

From the chart above we can see that the cabin temperature reaches set points in 15 minutes after which the temperature starts to steady state.

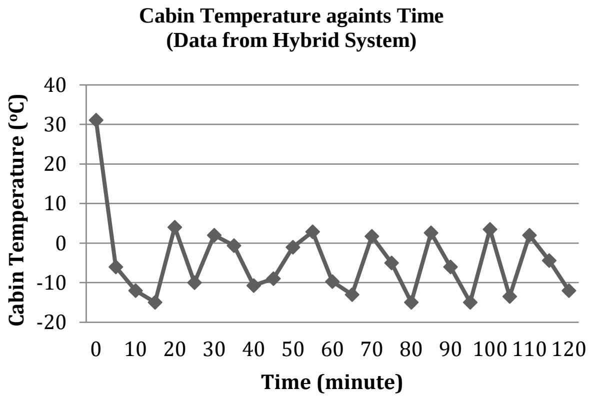

Fig. 8 Graph of Cabin Temperature against Time (Hybrid system usage data)

From the chart above we can see that the cabin temperature reaches set points at 15 minutes.

For analysis on system performance in the mango freezing unit, it is calculated related to the refrigeration efficiency of freezing, solar panel efficiency, and wind turbine efficiency. The analysis was carried out by comparing the results of the design calculation with the calculation of testing the use of PLN electricity and electricity from the hybrid system (solar panels and wind turbines). A comparison of system performance between the design and the test results is shown in table 1.

TABLE I
COMPARISON OF SYSTEM PERFORMANCE

No	**Variable**	**Design Calculation**	**Test result using electricity from PLN**	**Test result using electricity from hybrid system**
1	Compression work, qw (kJ/kg)	34	44	52
2	Heat removed, qc (kJ/kg)	127	151	159
3	Refrigeration effect, qe (kJ/kg)	93	107	107
4	COPaktual	2.73	2.73	2.05
5	COPcarnot	4.2	3,9	3,91
6	Refrigeration efficiency (freezer) (%)	64	61	52
7	Wind input power, Pin (watt)	9.9		42
8	Wind output power, Pout (watt)	2.16		2.32
9	Wind turbine efficiency (%)	21		5
10	Solar radiation power, Pin (watt)	3388		3147
11	solar output panel, Pout (watt)	360		338
12	Solar panel efficiency (%)	10		10
13	Hybrid system efficiency (%)	89		94

From the table above, it can be seen that the comparison of the efficiency value of the freezer cooling system in the hybrid system is lower when compared to the efficiency of the system that uses electrical energy from PLN, this is due to the influence of the electrical power input generated from the hybrid system is less stable. In addition, the value of compression work produced in a hybrid system is quite high compared to compression work in a system that uses PLN electricity, so that the performance of the freezer system with a hybrid system decreases.

In the table above, it can also be seen that the comparison of the efficiency of the hybrid system from the design and testing value obtained is higher for the hybrid system from the test with a difference of 5%.

IV. CONCLUSION

Based on the results of the test and analysis, can be concluded as follows:

1. The cooling load obtained is 359.70 Watts, so that the compressor used for the frozen cooling machine is 1/2 PK.
2. Data collection is carried out for 2 hours, mango freezing machine using a hybrid system with a cabin design temperature of -15 °C, for the results obtained cabin temperature of -15 °C, Cabin temperature is reached within 15 minutes.
3. The COP_{Carnot} value for the design data is 4.2 while the COP_{Carnot} value of the test results with PLN electricity is 3.9 and the COP_{Carnot} from the hybrid system is 3.91. The COP_{Actual} value for the design data is 2.73 while the COP_{Actual} value of the test results with PLN electricity is 2.73 and the COP_{Carnot} test results used a hybrid system is 2.05. The efficiency value for the design data is 64% while the efficiency of the test results with PLN electricity is 61% and the efficiency of the test results using a hybrid system is 51%. The efficiency value for hybrid system design data is 89% while for the efficiency of hybrid system test results is 94%.

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