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FREEZE DRYER MACHINE DESIGN FOR MANGO FRUIT STORAGE

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Abstract. The purpose of the research on the design of this tool is to determine the cooling load on the freeze dryer and to determine the time it takes to reach a temperature of -20°C. This tool uses a vapor compression cooling system and a vacuum process means that this tool cools the storage space with air in the dry cabin. The research method is to determine the volume of the cabin to determine the capacity of the freeze dryer and determine the cooling load by calculating the product load and then calculating the heat load through the walls and other loads that generate heat. for a freeze dryer machine with a capacity of 1.8 PK. From testing the tool for 10 minutes once for 6 hours, the results of the system performance at the evaporator temperature -24.64°C and product temperature -16.2°C, COP_{Carnot} performance of 3.77, and COP_{Aktual} of 2.87 with an efficiency of 76%, This is in line with the performance values in the COP_{Carnot} design of 3.8 and COP_{Actual} of 3.30 with an efficiency of 87%.

Keywords : Mango, Freeze dryer, Cooling load, Engine performance

1. INTRODUCTION

Mango is a food ingredient commonly consumed by the people of Indonesia. Mangoes have a very high water content and are only harvested twice a year. From this problem, it is necessary to store mangoes with a drying process. The best process is freeze-drying because the freeze-drying process will not damage the mangoes, will not reduce the nutritional content of the mangoes, will not rot quickly and remain fresh. In contrast to other drying processes, it is necessary to design a freeze drying machine for this. The purpose of this research is to design a freeze-drying machine for mango storage

Indonesia is a tropical country that has a variety of fruits in the lowlands or highlands. Mango is one of the fruit products in the tropics which contains compounds to maintain body health such as carotenoids, vitamin C, and phenolic compounds that are useful for the prevention of cardiovascular disease and cancer [1], The water content in mangoes is very high, namely 84%, so freeze-drying is one of the best drying methods for drying fruit because it can maintain the distinctive characteristics of the fruit such as color, taste, and aroma as well as for the preservation of horticultural products limited.

In contrast to other drying methods which generally require a temperature that is hotter than the ambient temperature, in the freeze-drying method, most of the drying process takes place at temperatures below the ambient temperature. So in the freeze dryer, the temperature must be below 0°C. In the conventional drying process, the water content in the product is released due to the evaporation process, or the process of changing the liquid phase to gas. Meanwhile, in the freeze-drying method, the process that occurs is a sublimation process, which changes the solid phase (water content in the product) into gas.

Based on the description above, the author makes a journal with the title "Design of a Freeze Dryer Machine for Storage of 20 kg Mangoes". The expected cabin temperature is -20°C. With this tool, it is hoped that it will be useful, especially for the development of better refrigeration research.

The purpose of this journal is to determine the cooling load on the freeze dryer, to find out the time it takes to reach a temperature of -20°C, to find out the performance of the resulting freeze dryer.

According to [2], states that the vacuum freeze dryer with condenser heating with a working pressure of -1 to 3 millibars, chamber temperature to minus or below 0°C, condenser temperature to 35°C. In the drying process that does not use condenser heating until the sublimation process is completed for 13 hours and the detection limit value (LOD) is ± 98.6%, on the other hand, in the drying process that uses condenser heating, the time becomes 6.5 to 7 hours, and the obtained value is detection limit (LOD) of ± 95.6%.

According to Martin [3] and Ichsan [4], stated that 1 kg of dried yam products where the freezing system uses an R134a vapor compression system as a refrigerant. Freezing time is 20 minutes with temperatures and pressures below the triple point in the air phase diagram. The planned drying chamber is a cylinder with a diameter of 30 cm and a length of 30 cm. The final temperature of the material in the drying chamber is expected to be -18°C with a planned vacuum pressure of 10 Pa or 0.1 bar. In the design, an evaporator design with a total pipe length of 4.22 meters and a condenser design with a total pipe length of 15.09 meters is produced. Cooling the condenser using a fan motor whose capacity is adjusted to the airspeed of 0.08 m^3/s. From the calculation results, the compressor used is a compressor with an energy of 0.5 HP.

The results of the test performance prove that the final pressure of the drying chamber achieved is constant at 0.000667 bar or 66.7 Pa. Vacuum freeze-drying is used below the triple point of the air, under 6.1 bar or 610 Pa. The final pressure achieved is lower than 610 Pa, so this vacuum freeze dryer can be used as needed even if the final pressure reached is not following the design state of 10 Pa. Experimental testing of vacuum freeze-drying on yam can only remove 62% water content, and from the results of testing, drying, observation and analysis of vacuum freeze-drying characteristics of yam bean drying, it can be concluded that the drying procedure that can remove the mass and maximum water content is the freezing method manually. fast, but the drying method which shows the sublimation process (phase change of materials in the phase diagram) is very good, namely the method in which the temperature of the material in the drying chamber is kept constant at -5°C [5].

Ilyas [6], in her research entitled "Changes in the characteristics of food ingredients in fruit chips using the freeze-drying method" that freeze-drying is one of the non-thermal processing techniques to increase the shelf life of the product. Fruit chips produced from freeze-drying look better from a sensory, chemical, and physical point of view compared to thermal processing, but thermal processing has not been able to remove microbiological spores in the fruit so this technology is rarely used because it has high investment and operational costs.

According to Anna [7], states that freeze dryers are used to dry radiopharmaceuticals by manual or automatic methods for approximately 31 hours based on the drying procedure. From the observation, it is proved that the freeze-drying machine functions very well according to its specifications, namely the manual method in the freezing process reaches -40°C and -34°C on automatic, the drying process at a temperature of 15°C and a pressure of 0.050 bar produces a dry product in the form of powder at each – each method.

According to Kumar [8], states that freeze-drying is used for food products to determine the appropriate concentration of skimmed milk and maltodextrin binder combinations to produce the best viability and characteristics of Lactobacillus Plantarum microcapsules by the freeze-drying method. In Microencapsulation technology, an experiment with Lactobacillus Plantarum bacteria with the addition of a binder combination concentration of 20% Maltodextrin resulted in the best viability and characteristics of 10% skimmed milk, namely 3.93% moisture content, 19.79% yield, and 97.76% cell viability nutritional content.

The research of Yulfianti [9], entitled "Utilization of coconut dregs as raw material for high-fiber coconut flour using the freeze-drying method" states that the drying process of coconut dregs using the freeze-drying method is influenced by drying time, which results in differences in nutritional quality including protein. , fat, crude fiber, and water content. Efficient drying time is carried out for 1 day (24 hours), which results in higher fiber content than protein content. The freeze-drying process for 24 hours produced 37.1% crude fiber, 4.12% protein, 0.33% water content, and 12% fat. The decrease in crude fiber content is caused by the breakdown of hemicellulose in the material.

Pujihastuti [10] in his research entitled "Tomato Fruit Preservation Technology With Freeze Drying Method" that when freeze-drying at low temperatures has a minimum level of damage because the speed of the dryer depends on the intensity of the flow of water vapor passing through the dry suction layer. Dehydration and chemical interactions prevent damage to dead cells very effectively required at a rate to obtain a quality product. The effectiveness of the freeze dryer depends on the sample temperature and thickness after processing. At either 40°C or 80°C, a higher rate of rehydration occurs initially to prevent damage to dead cells resulting from freeze-drying.

According to Shamseieh [11], freeze-drying is a method for removing water using ice crystal sublimation. If this process goes well, it will produce products with the best quality compared to products with traditional methods. In the food industry and pharmaceutical field, powder products have become an important subject for ongoing development and expansion. The powdered product used in this project is not common in the Middle East, so a prototype will be built to produce a high-quality product during the freeze-drying process. So based on the results of the study that powder or powder products are an effective way to produce good quality with the freeze-drying method compared to traditional methods. The performance results obtained from the mass of the product decreased to 83% with a color change, vacuum pressure reached 10-kPa, the temperature reached -21°C, freezing time for 2 hours.

According to Solomon [12], stated that tomatoes and pepper were tested in a freeze dryer at temperatures of -1.4°C, -1.5°C and -2°C, and vacuum pressures of -22 inHg, -24 inHg, and -29 inHg, freeze-drying time is 10 hours and 20 hours, each data collection time is 10 hours. 0% moisture content is achieved with the help of a vacuum because moisture is not present in the vacuum chamber. Freeze-dried products can regain their freshness when dissolved in water. It was recommended among other things that farmers be encouraged to use freeze dryers to dry tomatoes and peppers. The results of the freeze-drying machine performance during the freezing process carried out for 10 hours obtained the freezing temperature of tomato and pepper products, namely -2°C and vacuum pressure of -29 inHg.

Freeze-drying is a process in which water is removed from the product after freezing and the air in the cabin is removed by the vacuum process, allowing the ice to change from solid to vapor without passing through the liquid phase. Freeze drying is one method that has advantages in maintaining the quality of drying results, especially for products that are sensitive to heat [13] [14].

The freeze-drying process is described using the water phase diagram in Figure 1 [15] [16].

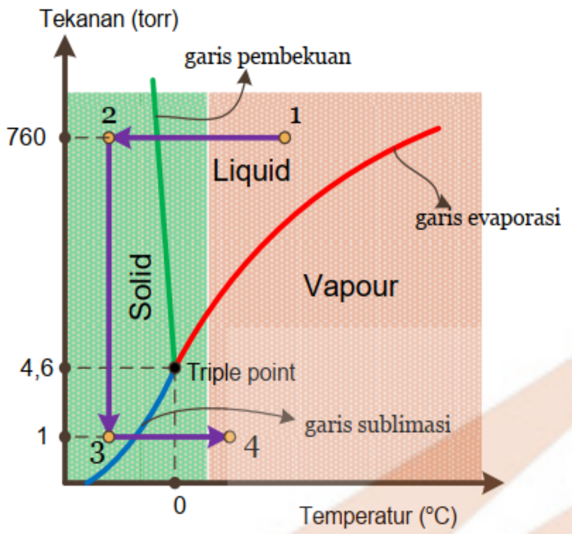


Figure 1. Freeze-drying process on the liquid phase diagram [12]

In Figure 1. 3 (three) main processes. The first process is the freezing process, which is the process from point 1 to point 2. This process is generally carried out in a separate frozen machine with a freeze dryer, with a product temperature of around -20°C. The second process is the vacuum process, namely the process from point 2 to point 3. This process takes place in a freeze dryer machine, and the vacuum is carried out with a vacuum pump. The third process is the drying process, which is from point 3 to point 4. Similar to the second process, this third process also takes place in the freeze dryer. In this drying process (point 3 to point 4), the addition of heat (heat) should not be too high, or in other words, the product temperature should not be too hot. In this third process, it can be seen that the drying process does not pass through the evaporation line, but passes through the sublimation line [15] [17] [18].

The stages in the freeze-drying machine are first freezing the product, followed by drying the product. Both vacuums mean that after freezing, the air in the cabin will come out. This allows the frozen solvent to evaporate without going through the liquid phase or sublimation. The third heating will be carried out on the product so that the sublimation process takes place quickly. Fourth, low-temperature condensation will remove the solvent that evaporates in the vacuum which turns into a solid [4] [19].

Cooling load is the total heat that moves from the air conditioning system at any time [20]. The cooling load consists of room heat and additional heat from lighting and living things that affect the performance of the air conditioning machine. The influence of the cooling load with the Coefficient of Performance (COP) is important because a refrigeration machine that has a high COP value means it has a large cooling capacity but uses a small compressor power.

2. METHODS

This type of research uses the design method, which is carried out to obtain data on the design, manufacture of the machine, and the performance of the freeze dryer. The flow of this research can be seen in Figure 2.

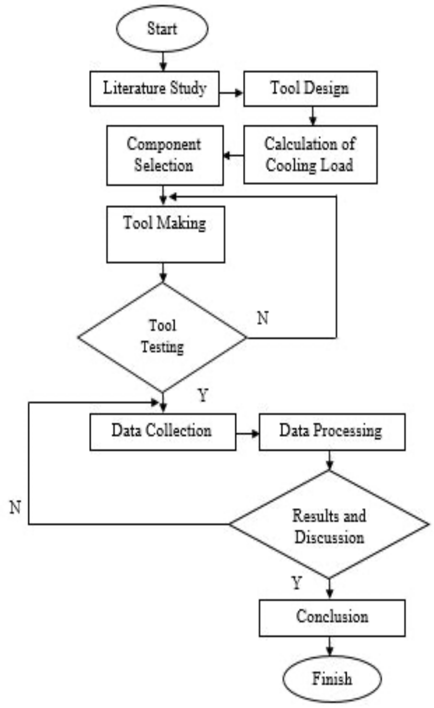


Figure 2. Implementation Flow Chart

The design used in this study was started from the manufacture of a custom cylindrical cabin with a height of 0.5 m and a diameter of 0.35 m for storage of 20 kg mangoes. The component unit uses a 1 unit 1.8 HP compressor. The evaporator as much as 1 unit used is a custom evaporator, the evaporator adjusts to the diameter of the suction pipe and is then wrapped around the cylindrical cabin with solid coils. The condenser used is an air-cooled condenser with an additional fan with a capacity equal to the capacity of the compressor, while the expansion device uses a capillary tube made of copper pipe with a diameter and length adjusted to the compressor capacity.

Of the four components, the assembly process was carried out with the equipment and materials that had been provided with colleagues to form a unit according to design, the unit used for research was designed and built in such a way that it could be used as research for colleagues with different titles. The design of the assembled unit is with the cabin design temperature for the freeze dryer, which is -20°C, the refrigeration system that we designed uses 404A refrigerant, while the capillary pipe calculation is based on the capillary pipe conversion table reference.

The cooling load is divided into several parts, namely the calculation of the cooling load on the wall and the cooling load on the product.

To calculate the cooling load on the wall, namely :

$Q = U \times A \times \Delta T$

Where :

Q = The heat generated (watts)

U = Heat transfer coefficient on the wall (watt/m^2.K)

A = The surface area of wall space (m^2)

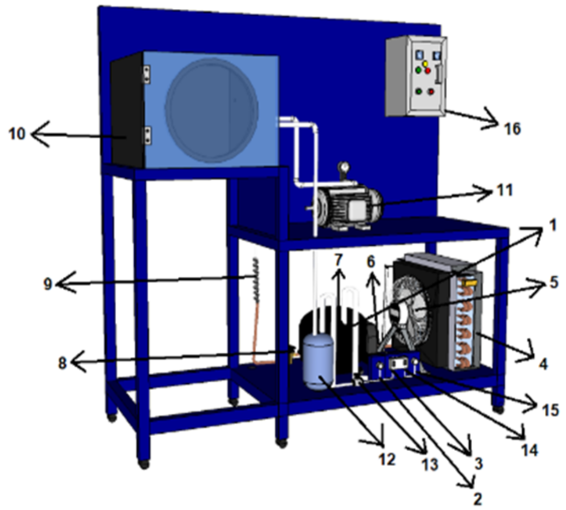
ΔT = Difference between ambient and room temperature (K)

To get the value of U, a formula is needed, namely :

$$U = \frac{1}{\frac{1}{f_o} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{1}{f_i}}$$

Where :

f_0 = Coefficient of convection in the environment (Watt/m^2.K)
k_n = Thermal conductivity of the nth wall layer (Watt/m .K)
x_n = The thickness of the nth wall (meter)
f_i = Coefficient of convection in space (Watt/m^2.K)



Description:
1. Compressor
2. HPG
3. HPS
5. Condensor
6. Pan
7. Sigh glass
8. Hand valve
9. Capiller
10.Evaporator
11.Pump vacum
12.Accumulat
13.Hand valve
14.LPS
15.HPH
16.Panel box

Figure 3. Freeze Dryer Tool Design

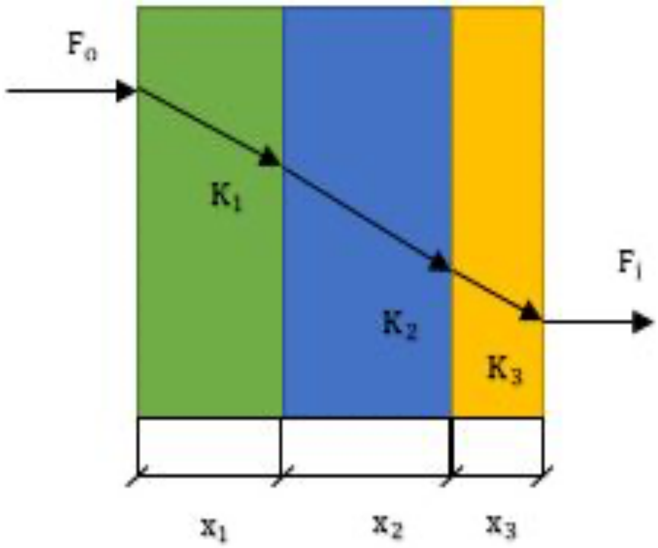


Figure 4. Cabin Material

Table 1. Wall Material

Ingredients	Thickness	Unit (m)	Thermal Conduktivity W/mK
Steel Plate (K_1)	1,4 mm	0,0014	14
Polyurethane (K_2)	30 mm	0,03	0,023
Stainless Steel (K_3)	0,8 mm	0,0008	19
Still air (F_{in})	-	-	9,37
Moving Air (F_{out})	-	-	22,70

Calculation of the cooling load on the wall, namely:

$$U = \frac{1}{\frac{1}{fi}+\frac{x_1}{k_1}+\frac{x_2}{k_2}+\frac{x_3}{k_3}+\frac{1}{f_o}} = \frac{1}{\frac{1}{9,37}+\frac{0,0014}{14}+\frac{0,03}{0,023}+\frac{0,0008}{19}+\frac{1}{22,70}}$$

$$= \frac{1}{0,11 + 0,0001 + 1,30 + 0,000042 + 0,04}$$

$$= \frac{1}{0,11 + 0,0001 + 1,30 + 0,000042 + 0,04}$$

$$= \frac{1}{1,45}$$

$$= 0,69\ W/m^2K$$

Calculation of the heat load generated by the wall, namely:

$$Q = U \times A \times \Delta T$$
$$= 0,69\ W/m^2K \times 0,82\ m^2 \times 52°K$$
$$= 29,42\ W$$

3. RESULTS AND DISCUSSION

Mango is a food ingredient commonly consumed by the people of Indonesia. Mangoes have a very high-water content and are only harvested twice a year. From this problem, it is necessary to store mangoes with a drying process. The best process is freeze-drying because the freeze-drying process will not damage the mangoes, will not reduce the nutritional content of the mangoes, will not rot quickly, and remain fresh. In contrast to other drying processes, it is necessary to design a freeze-drying machine for this. The comparison of system performance between the design and the test results is shown in the table below:

Table 2. System Performance Comparison

System Performance	Design	Test Result
Compression Process (kJ/kg)	29,2	34,5
Condensation Process (kJ/kg)	125,6	133,43
Evaporation Process (kJ/kg)	96,4	98,93
Refrigerant Mass Flow Rate (kg/s)	0,04	0,04
Condenser Capacity (kJ/s)	5,02	5,34
Evaporation Capacity (kJ/s)	3,86	3,96
Compression Capacity (kJ/s)	1,8	1,8
COP_{Actual}	3,30	2,87
COP_{Carnot}	3,8	3,77
Efficiency (%)	87	76
Compression Ratio	12,67	15
Electric Power (Watt)	201.177	223.891

The results from the table 2 above show that the design with the test results is not much different in value, so that the design of the freeze dryer machine can run well. From the results of electric power consumption for one month it is more efficient than other freeze dryer designs. The results of this study can be distributed to the community or community service because the consumption of electric power is very efficient and this design is very easy to use for the community in general and has used very sophisticated technology to regulate the freeze dryer.

Figure 5. Freeze Dryer Design Result

4. CONCLUSION

From the results of this journal research, it can be concluded that the cooling load obtained is 1,352.36 watt so that the compressor used for the freeze dryer is 1.8 HP. Data retrieval was carried out for 8 hours, the freeze-drying machine with cabin design temperature -20°C, while for the results obtained cabin temperature -13.1°C. The cabin temperature was not reached because the cabin experienced condensation so that the temperature in the cabin was not maximal or not reached. The COP_{Carnot} value for the design data is 3.8 while the COP_{Carnot} value for the test results is 3.77. The COP_{Aktual} value for the design data is 3.30 while the COP_{Aktual} value for the test results is 2.87. The efficiency value for the design data is 87% while the efficiency of the test results is 76%. The consumption of electrical power for the design data is 880 watt while for the test results it is 990 Watt.

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