The Test Performance of Two Stage Refrigeration System and Comparison with Single Stage System in Freezing Unit of 5 kg Mango Puree

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Abstract. Currently, many local micro-industries have begun to process mango fruit into various kinds of food and drinks. Such as being processed into dodol, syrup, jelly, and even coffee from mango seeds. Before being processed into products as above, mangoes are first made in puree form, where puree is fruit pulp which is a semi-finished ingredient and can be further processed into juice, jam, dodol, candy and ice cream. This puree is rich in nutrients, contains various vitamins and minerals, because it is rich in nutrients, this product is very popular with microorganisms as a place to live. therefore the puree must be preserved to extend its shelf life. One of the efforts made to extend the shelf life of this puree is by freezing it using a freezer unit. Every industry that operates in the field of freezing mango puree has at least a blast freezer and freezer room. A blast freezer is a room used to freeze quickly (generally around 4 - 6 hours) so that the growth of microorganisms can be prevented. The standard temperature for the blast freezer room is -30 to -40 oC. With this low temperature, a blast freezer that uses a single stage system will result in a high compressor discharge temperature (more than 90 oC) and will also result in a short compressor lifetime. With a double stage refrigeration system, these problems can be avoided considering that in the two stage refrigeration system there is an additional cooling system with intercooler in order to prevent the occurrence of high compression ratios. A blast freezer unit with a two stage refrigeration system has been created where the unit is also parallel to the single stage system. The blast freezer unit is used to freeze 5 kg of mango puree within 2 hours for one testing process. Testing was carried out 2 times, the first using a two stage system and the second using a single stage system. It was found from the test results that the lowest evaporator temperature that could be achieved on two stages was -18.1 oC, while on a single stage it was only -13.4 oC. The actual COP value and refrigeration efficiency in the two stage system is 2.24 for COP and 69% efficiency, while in the single stage system the actual COP is 2.31 and the efficiency is 48%, lower than the test on the two stage system.

Keywords: Mango puree, refrigeration system, two stage system, single stage system.

1   **INTRODUCTION**

Indramayu is a supplier of mango fruit in West Java, this is in line with the city's nickname, namely the mango city, many preparations can be made from mango fruit. However, the export value of mangoes to total production is only around 0.05%. Majoring of them are damaged due to improper preservation [1].

Currently, many local micro-industries have begun to process mango fruit into various kinds of food and drinks. Such as being processed into dodol, syrup, jelly, and even coffee from mango seeds [2]. Before being processed into products as above, mangoes are first made in puree form, where puree is fruit pulp which is a semi-finished ingredient and can be further processed into juice, jam, dodol, candy and ice cream. This puree is rich in nutrients, contains various vitamins and minerals, because it is rich in nutrients, this product is very popular with microorganisms as a place to live. Therefore the puree must be preserved to extend its shelf life. One of the efforts made to extend the shelf life of this puree is by freezing it using a freezer unit [3].

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With a double stage refrigeration system, these problems can be avoided considering that in the two stage refrigeration system there is an additional cooling system with intercooler in order to prevent the occurrence of high compression ratios, so that the compressor performance is not too heavy [4]. However, even though the discharge temperature is lower, there are also negative effects from this two stage refrigeration system. Cakir [5] said that the use of a two stage refrigeration system will result in higher energy consumption of around 30.5% compared to a single stage system.

The purpose of this analysis is to study the differences between single stage and two stage refrigeration systems in fast freezing machines. Several factors that will be analyzed include efficiency, operating pressure, and power consumption. Apart from that, this research will also discuss the advantages and disadvantages of each system used.

This analysis will begin by explaining the working principle of the blast freezer machine and the role of the compressor in this machine. Then, a performance comparison analysis will be carried out between single stage and two stage refrigeration systems by considering the factors mentioned above. This research is expected to provide a better understanding of the differences between single stage and two stage system in fast freezing machines, so that it can help readers in choosing the most appropriate type of refrigeration system for their machines and increase the efficiency of using fast freezing machines.

2   RESEARCH METHODS

The first stage carried out in this research was starting from determining the object for the fast freezing machine, namely 5 kg of mango puree. Next, make a custom cabin with dimensions of 0.70 m long, 0.50 m high and 0.50 m wide. The cabin is equipped with armaflex insulation with a thickness of around 3cm. The compressor used for the two stage system uses 2 compressors measuring ¼ PK for the low stage (first) and ½ PK for the high stage (second) and uses 1 evaporator. The condenser used is an air cooled condenser type with an additional fan and a capacity that is adjusted to the capacity of the compressor, while for the expansion device it uses 2 capillary pipes made of copper pipe with a diameter and length adjusted to the capacity of the compressor.

In a two-stage refrigeration system, an intercooler is needed to further cool (subcool) the condenser output refrigerant with the aim of increasing the COP of the refrigeration machine. There are several types of intercoolers commonly used in two-stage refrigeration systems, including: flash intercooler, flash chamber intercooler and dry intercooler. The intercooler used in this system is a dry intercooler type, considering that its design and installation is relatively easy to do. Meanwhile, the construction of the dry intercooler is designed with a double pipe type. This is also intended to make it easy to manufacture and also so that it is not too complicated in analyzing the heat transfer that occurs in the intercooler. Figure 1 is images of the piping system and its cycles in the pressure-enthalpy (P-h) diagram of a two-stage refrigeration system.
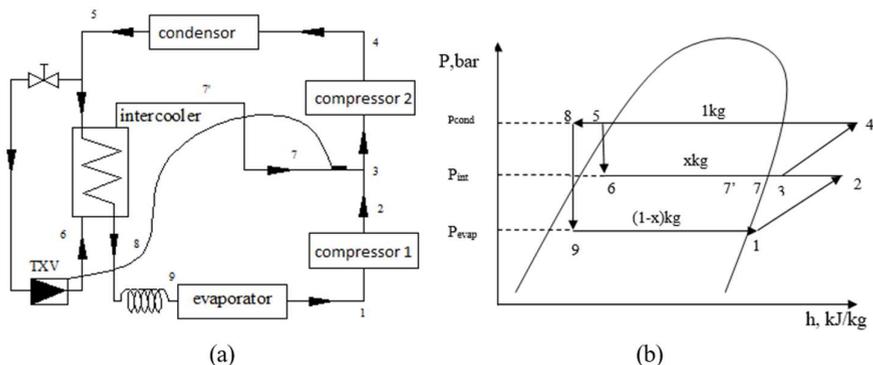

Fig. 1. Scheme of two stage refrigeration cycle (a) piping system, (b), pressure-enthalpy (P-h) diagram.

Next, the assembly process is carried out using the equipment and materials that have been provided until a unit is formed that matches the design. The evaporator temperature designed for this unit is for low temperature (below - 20°C) and the refrigerant used in the system uses R404A refrigerant. For the refrigeration load is about 5 kg mango puree in the freezer room. Before the mango is cooled in this unit, the mango is first peeled and chopped with a blender machine until it forms like puree. The mango puree is then placed in a small container and tightly closed for easy storage. The following is the process of making mango puree.

Fig. 2. Process making of mango puree

The test was carried out by measuring the temperature of the four main components of the existing refrigeration system and the intercooler component using GSP-6 type data acquisition from ELITECH. The temperature data that has been obtained is then plotted on a Mollier diagram to determine the performance of each component of the refrigeration system. The test was carried out twice, the first was a test on a two stage refrigeration system and the second was a test on a single stage refrigeration system.

3   CALCULATION FORMULA

It can be seen in Figure 1 above that in this two-stage refrigeration system there are three system working pressures, namely: condensation pressure on the condenser, evaporation pressure on the evaporator, and another one is evaporation pressure on the intercooler. To determine the evaporation pressure in the intercooler to match the condenser and evaporator pressure design conditions, use the following equation [6] :

$$P_{int} = \sqrt{P_{cond.} \cdot P_{evap.}}$$

(1)

Note :
P_{int} = Pressure of intercooler (bar.abs.)
P_{cond} = Pressure of condenser (bar.abs.)
P_{evap} = Pressure of evaporator (bar.abs)

3.1   Energy Balance

It can be seen from Figure 1 above that in a two-stage refrigeration system there is a division of flow, namely on the side before entering and after leaving the intercooler. The flow that first flows into the TXV and enters the intercooler is called flow fraction x. The second flow fraction goes directly to the intercooler and then directly to the evaporator as the main cooling component in this system. This flow is called the flow fraction (1-x).
Look at figure 1 above!
In this system, the amount of refrigerant flow flowing in the condenser is 1 (100%) kg/s, the flow flowing in the intercooler is (x) kg/s, and the flow flowing in the evaporator is (1-x) kg/s. Point 7' is the refrigerant output point of the intercooler, point 2 is the refrigerant output of compressor 1, and point 3 is the mixing point of the two refrigerants. Based on the law of conservation of energy, which implies that the energy received by one object is the same as the energy released by another object, then [6] :

$$(x)(h_3 - h_{7'}) = (1 - x)(h_2 - h_3)$$

$$xh_{7'} = xh_3 - (1-x)(h_2 - h_3) \tag{2}$$

And because the refrigerant in the intercooler is used to further cool the refrigerant from the condenser to the evaporator, then :

$$(1-x)(h_5 - h_8) = (x)(h_{7'} - h_5)$$
$$xh_{7'} = (1-x)(h_5 - h_8) + xh_5 \tag{3}$$

Because the left side of equation (2) and equation (3) are the same one, that two equations can be combined to produce the flow fraction equation (x), where x formula is :

$$\therefore x = \frac{(h_5 - h_8) + (h_2 - h_3)}{(h_2 - h_8)} \tag{4}$$

Equation (4) above is a formula for determining the flow distribution fraction that passes through the TXV or passes through the intercooler outer pipe. From the equation above, the flow fraction can be known after the refrigeration system data is known and plotted on the P-h diagram. where the x value obtained in this research is 0.34.

3.2   Coefficient of Performance (COP)

The basic formula for calculating the actual COP of a two-stage refrigeration system is the same as the actual COP equation for a single-stage refrigeration system, namely the ratio between the energy/power absorbed in the evaporator and the energy/power released by the compressor. It's just that the compressor energy/power in a double stage system is the sum of the energy/power from two compressors after multiplying the flow fraction from each compressor.

Apart from that, because the mass flow rate of the refrigerant flowing in the evaporator is not the same as the flow rate on the high pressure side of the compressor, the refrigeration capacity is also the product of the flow fraction (1-x) and the enthalpy difference. So the equation of the actual COP is [6] :

$$COP = \frac{Q_{evaporator}}{W_{comp1} + W_{comp2}}$$

$$COP = \frac{(1-x)(h_1 - h_9)}{(1-x)(h_2 - h_1) + (x)(h_4 - h_3)} \tag{5}$$

4   RESULTS AND DISCUSSIONS

Here Figure 2 below is the measurement result of the discharge and suction temperatures from each test (single test and two stage system test). It can be seen in Figure 1 below that the presence of an intercooler in the two stage system can actually improve the discharge temperature, where the discharge temperature in the two stage

test is lower than in the single stage system test. Likewise, the evaporator temperature in the two stage test is lower when compared to the single stage system test. This shows that the addition of an intercooler to the two stage system has an important role in improving the performance of the refrigeration system. Sihombing et all [7] also tested the difference between single stage and two stage refrigeration systems using the Aspen-Plus simulation program and found that both evaporator and condenser temperatures had a difference of around 8.8%, which was better for the two stage system than the single stage system.

Fig. 3. Temperature measurement results of testing unit two stage and single stage system. (a) discharge temperature, (b) suction temperature.

Beside that, performance comparisons also need to be carried out to find out more about the character of this two stage system. Table 1 below is a summary of the calculation results from the two stage and single stage system tests. It can be seen in table 1 below that the COP value in a two-stage system is smaller than in a single-stage system. This is because the evaporator temperature in the two stage system is lower than the single stage system. However, even though the COP value on two stages is smaller, the efficiency value is greater than the single stage system. This shows that the performance of this two stage system is more effective when compared to a single stage system.

Table 1. Resume data from system performance calculation.

Variable	Single Stage	Two Stage
qw (kJ/kg)	33	38
qc (kJ/kg)	126	131
qe (kJ/kg)	92	98
Qw (kW)	0.506	0.527
Qc (kW)	1.67	1.83
Qe (kW)	1.17	1.18
COP Actual	2.31	2.24
COP Carnot	4.4	3.8
Efficiency (%)	48	59

5   CONCLUSION

1. The evaporator or suction temperature that can be achieved in a two stage system is lower than in a single stage as indicated by the final temperature in the two stage reaching -18.1°C. With an average efficiency of 59%, whereas when using a single stage system the temperature suction is only -13.4°C with an average efficiency of 48%.

2. The discharge temperature in the two stage test is also lower when compared to the single stage, this shows that the intercooler in the two stage system can reduce the discharge temperature so that it can improve system performance.

3. The type of refrigeration system that is most suitable for fast freezing in terms of performance prefers a two stage system because it has high efficiency with a figure of 59% compared to single stage which is only 48%.

REFERENCES

1. Rasmikayati, E. (2018). Kajian Potensi dan Kendala Dalam Proses Usaha Tani dan Pemasaran Mangga di Kabupaten Indramayu. Jurnal Sosiohumaniora, Fakultas Ilmu Sosial dan Ilmu Politik, Universitas Padjadjaran 20(3), 215. Available online at : https://doi.org/10.24198/sosiohumaniora.v20i3.15859

2. Tribunnews.com. Rabu, 14 November 2018. Mangga Gedong Gincu di Kabupaten Cirebon yang Tak Pernah Henti Produksi, https://www.tribunnews.com/nasional/2018/11/14/mangga-gedong-gincu-di-kabupaten-cirebon-yang-tak-pernah-henti-produksi.

3. Owino, W.O.; Ambuko, J.L. Mango Fruit Processing: Options for Small-Scale Processors in Developing Countries. Agriculture 2021, 11, 1105. https://doi.org/10.3390/agriculture 11111105.

4. Negara, I. P. S., Arsawan, I. M., Subagia, I. W. A., & Rimpung, I. K. (2020). Rancang Bangun Simulasi Cold Storage Type Multy Stage Sebagai Materi Praktek Mahasiswa pada Lab refrigerasi terapan. Prosiding Seminar Nasional Terapan Riset Inovatif (SENTRINOV), 6(1), 178-185. Retrieved from https://proceeding.isas.or.id/index.php/sentrinov/article/view/360

5. Çakır M.T., Tunçil İ., "The effect of condenser type and refrigerant type on the two-stage vapour compression refrigeration system: An experimental study", Journal of Polytechnic, 26(2): 983-990, (2023).

6. Wang, Shan K. (Shan Kuo). 2000. Handbook of air conditioning and refrigeration 2nd ed. McGraw-Hill Companies. ISBN 0-07-068167-8

7. Sihombing, HV et al. Effect of multi –stages vapor compression refrigeration cycle using refrigerant R32 for Air-Conditioning unit.Published under licence by IOP Publishing Ltd. 3rd Nommensen International Conference on Technology and Engineering 2019 (3rd NICTE) 25–26 July 2019, Nommensen HKBP University, Indonesia.