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THE ANALYSIS OF THE USE OF INTERCOOLER ON A MULTI STAGE COLD STORAGE SIMULATOR TOWARD THE COMPRESSOR WORK

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Abstract. Multistage type cold storage is a refrigeration machine required in an industry because it functions to store food products for a long time. Bali, as a world tourist destination, will rely heavily on this cooling system in preparing services for tourists, especially in the food and beverage sector. Multistage type cold storage is designed to reach the evaporator temperature below -30ºC thus the used compressor performance must be able to produce maximum refrigeration effect. Two compressors placed in succession or connected in series complete this cold storage system, which is expected to achieve higher operating pressures. The temperature occurring due to the pressure increase on the second compressor will be anticipated by installing an intercooler aiming at preventing excessive heat or over heat during the compression. The extent to which the important role of the intercooler as a stabilizer of operating temperature in this cooling cycle will be shown in its working cycle with a Mollier diagram (P-h diagram). The data obtained during the operation of the multistage type cold storage is then transferred to the P-h diagram of R134A to determine the cycle diagram and the enthalpy which then determines the amount of COP, the maximum temperature achieved by the system, and its energy requirements. The calculation results obtained using the intercooler COP is 1.83, and the maximum temperature achieved is 67ºC, and the energy consumption seen from the total entalphy difference due to compression work is 81 kJ/kg. Without using the intercooler, the system's COP is 1.72 and the maximum temperature achieved is 94.9ºC and 86 kJ/kg of energy consumption. The energy required for the operational becomes more eficient and the heat released to the environment is much less, therefore the multistage cold storage with intercooler can be categorized as an eco-friendly technology.

Keywords : Compression work, Intercoole, and Performance .

1. INTRODUCTION

A cold storage is often referred to as a cold room, which is one of the cooling machines or refrigerators that are widely required in the industrial sector. The ability to store products in sufficient quantities at a fairly low temperature for a long time makes it an alternative choice for the industrial sector in maintaining the freshness of its products. The stored products can vary from raw materials to processed products, when being produced in large quantities; it really depends on the cold storage. Bali as a world tourist destination will highly require the existence of cold storage. Every hotel that contributes the greatest support on tourism with a minimum level of three stars must have one or even more cold storages. In addition to hotels, businesses need the existence of cold storage as well for having essential role in tourism too.

Cold storage generally uses a vapor compression system, because it is more practical and simple in operation and maintenance [1][2]. The compressor is the main feature of the latest vapor compression system equipped with a condenser, an expansion device, and an evaporator. Several additional components will complete the system such as oil separator, liquid receiver, filter dryer, sigh glass, and accumulator. Compressors used in cold storage are mostly piston models because the cooling system is required to be able to achieve high working pressures, therefore a multi-stage compressor system is made, also known as multi-stage. Due to the high working pressure of the system, the operating temperature will also increase that it may cause overheating in cold storage. The inter cooler is finally used as an alternative to anticipate the process of the temperature increase, especially in the second compressor. Thus, it is necessary to have an additional system in the form of a heat exchanger that will be placed at intermediate pressure. The inter cooler will function and be positioned on the suction line of the second compressor or the first compressor output. This second compressor is in charge of increasing the working pressure of the refrigerant which has also experienced compression in the first compressor so that with the presence of this inter cooler, it is expected that the working temperature of the cooling system will not continue to increase but can be stabilized [2][3]. An experimental study will be conducted to see the effect of the presence of inter cooler in multistage cold storage on the performance and the system performance during operation, as well as the energy concumption in relation with the eco-friendliness.

Refrigeration is a process to produce and keep something cold. This refrigerant has been widely used in all fields along with the rapid development of technology, including the refrigeration machines [4][5]. In general, the use of refrigeration machines is to preserve food because room temperature causes the food to rot or spoil faster due to quickly grown bacteria. The utilization of refrigeration machine is intended to freeze the food to certain temperature and humidity based on the requirements thus it is preserved. Whereas the utilization of food refrigeration machine or coolant engine is for rooms conditioning, beverage chilling, ice making and so on. As for the household purpose this machine is used to preserve vegetables, fruits, meat and so on. Preservation in large quantities can be found in meat cuts, shrimp storage, marine fish and so on. We can even find it on meat, vegetables, and fish transporting vehicles that carry their goods to distant places thus the food are still fresh until they reach their destination.

A cold storage is generally a specially designed room with certain temperature condition that will be used to store various kinds of products to maintain their freshness [6][7][8]. Cold storage is usually built based on the building area at the installation site. Cold storage machines are widely used by industrial parties to preserve the quality of food and beverages that are produced or will be produced. A multistage vapor compression refrigeration system (multistage) is an advanced vapor compression system that has two or more compressors as components that can pump and increase the pressure in series. This is done to obtain a low temperature that cannot be achieved with a typical vapor compression refrigeration system.

Figure 1. A Cold Storage

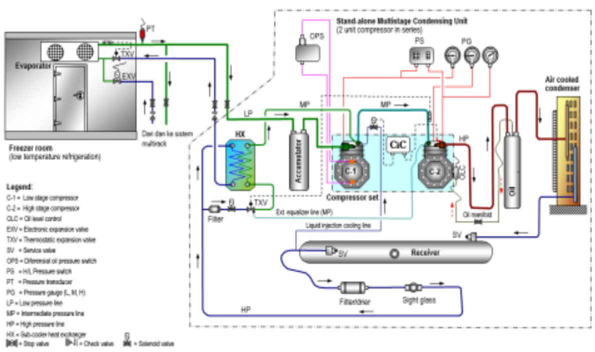

Figure 2. A Multi-stage Cold Storage Pipin

The intercooler is usually placed at an intermediate pressure or between high pressure and low pressure as well as between the two compression levels which will determine the compression work per kg of steam. For a system with compression levels or multistage, it will be able to save some work. Intercooling in a refrigeration system can be done a water cooled heat exchanger or by using a refrigerant [9][10][11]. A water-cooled intercooler may suffice for two-stage compressed air, but for refrigerant compression, the water is usually not cold enough. Another method is to use liquid refrigerant from the condenser to the intercooler. The gas released from the low-level compressor passes through the liquid in the intercooler. The refrigerant will leave the incooler in the form of saturated vapor. A 2-stage compressor with an intercooler is often an ideal way to service a single low-temperature evaporator [12][13][14]. These systems require less power than a single compressor and these power savings will frequently affect the cost for extra equipment [15]. Moreover, this can be categorized as a more eco-friendly technology.

A P – h diagram is a diagram showing the characteristics of the refrigerant gas. The x-axis represents the enthalpy (h) and the y-axis shows the pressure (P) as shown by the following figure.

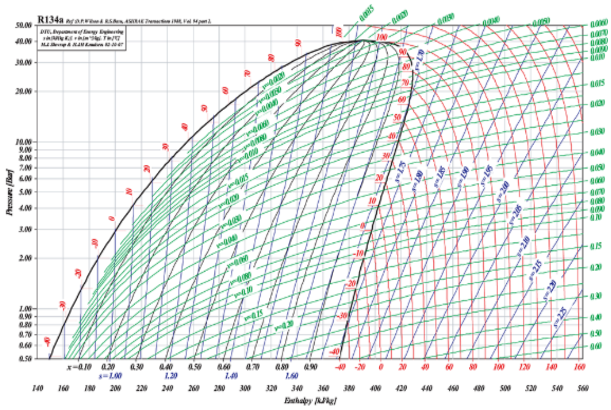

Figure 3. A P – h Diagram

Based on the description, it is deemed necessary to conduct research on the analysis of the use of intercooler on a multi stage cold storage simulator toward the compressor work.

2. METHODS

a. Research Design

The type of research carried out is the analysis of inter cooler on multi-stage type cold storage which includes numerical and experimental studies.

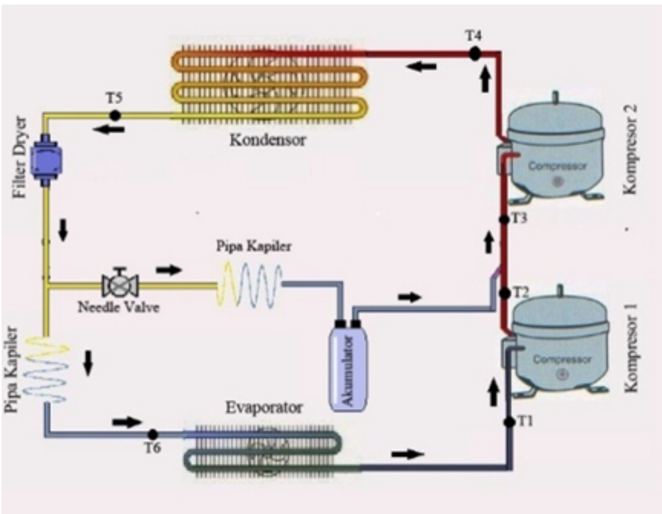

Figure 4. The design of multi-stage cold storage refrigeration simulation

b. Data Source

In this study, the data were obtained by conducting direct testing on cold storage simulations with a multistage system with and without an intercooler. The data can be retrieved after the system works normally. The data were immediately collected and carried out 10 times with a time difference of 5 minutes.

c. Research Resources

The testing equipment used in this study is a cold storage simulation with a multistage system designed at the Refrigeration Laboratory, Department of Mechanical Engineering, Politeknik Negeri Bali with the following specifications:

1) A Piston Compressor, 1/10 PK
2) A Condenser with fan cooling
3) An evaporator
4) A Capillary pipe
5) A Refrigerant R 134a

d. Research Instrument

To assist the research, it is essential to provide the supporting research instrument. The instruments are described as follows.

1) Clamp Meter, It is a measuring instrument used to measure electric current in a conductor cable energized by electric current using its two clamping jaws without having to have direct contact with the electrical terminals. In general, Clamp Meter has two functions: as an amperemeter and a multimeter. Thus in addition to having two clamping jaws, the Clamp Meter also has two probes that can be used to measure Resistance, AC Voltage, DC Voltage and there are even certain models that can measure Frequency, DC Electric Current, Capacitance and Temperature
2) Manifold Gauge, The manifold gauge has very large functions such as refrigerant filling, pressure monitoring, and repairing which involves the cooling medium, namely the refrigerant in the refrigeration system. The manifold is designed with a standard construction so that it is easy to understand. There are two gauges for checking the suction side and the discharge side. The low pressure gauge has a scale - 1 bar to 8.2 bar, meanwhile the high pressure gauge has a scale of 0 bar to 34 bar.
3) Thermocouple, a thermocouple is used to detect or calculate temperature through two different types of metal conductors which are joined at the ends to cause a thermo-electric effect.
4) Stop watch, a stop watch is used to set the duration when testing the system.

e. Research Procedure

The data collection process in a multistage cold storage simulation system is carried out by following the following test procedures

Preparation Steps

1) Preparing the measuring instruments that will be used to collect data and check high pressure components in the system.
2) Installing the thermocouple.
3) Installing the manifold gauge.
4) Ensuring that the measuring tools are properly installed.
5) Ensuring that all tools attached to the system function properly.

Data Collection Steps

The processes of cold storage simulation testing with a multistage system are carried out as follows.

1) Turn the multistage cold storage simulation engine on and make sure the system runs normally. Let it runs for ± 30 minutes.
2) After the system is running normally, record the results of data collection on the high pressure, medium pressure, and low pressure sides.
3) Perform data collection at the intervals of five minutes, and the recording is done for twelve times.
4) After completing data collection, turn off the system.
5) The test results are then recorded in a table.

3. RESULTS AND DISCUSSION

The data obtained from the multi stage type cold storage simulator covering the temperature, pressure, current, and voltage are presented in Table 1 and Table 2.

Table 1. Measurement Result Data on Multistage Cool Storage System with Intercooler

Data	T1 (ºC)	T2 (ºC)	T3 (ºC)	T4 (ºC)	T5 (ºC)	T6 (ºC)	LP (Psi)	MP (Psi)	HP (Psi)	A1 (Amp)	A2 (Amp)	V (Volt)
1	-6	45	19	55	30	-9	10	60	200	0,81	0,91	220
2	-7	48	19	56	31	-11	10	68	200	0,82	0,90	220
3	-10	48	19	59	31	-14	9	60	210	0,82	0,90	220
4	-10	49	18	69	31	-14	9	62	210	0,82	0,90	220
5	-10	49	18	69	32	-15	8	65	210	0,82	0,90	220
6	-10	49	18	70	32	-16	7	65	215	0,82	0,90	220
7	-12	50	18	70	32	-17	6	65	215	0,82	0,90	220
8	-14	50	18	70	32	-19	6	65	215	0,82	0,90	220
9	-16	50	18	72	32	-19	5	68	220	0,82	0,90	220
10	-16	51	18	72	33	-19	5	68	220	0,82	0,90	220
11	-17	53	18	75	33	-19	5	68	220	0,82	0,90	220
12	-17	55	18	75	33	-19	5	68	220	0,82	0,90	220
R	-12	49,7	18,2	67	31,8	-15,5	7,08	64,7	211	0,81	0,90	220
	1,56 (Bar)								5,46 (Bar)	15,7 (Bar)		

Table 2. Measurement Result Data on Multistage Cool Storage System without Intercooler

Data	T1 (ºC)	T2 (ºC)	T3 (ºC)	T4 (ºC)	LP (Psi)	MP (Psi)	HP (Psi)	A1 (Amp)	A2 (Amp)	V (Volt)
1	-6	87	37	-11	10	60	200	0,81	0,91	220
2	-7	89	38	-14	10	68	200	0,82	0,90	220
3	-9	90	38	-14	9	60	210	0,82	0,90	220
4	-10	92	38	-15	9	62	210	0,82	0,90	220
5	-11	96	39	-16	8	65	210	0,82	0,90	220
6	-12	97	39	-17	7	65	215	0,82	0,90	220
7	-14	98	39	-19	6	65	215	0,82	0,90	220
8	-14	98	39	-19	6	65	215	0,82	0,90	220
9	-16	99	39	-19	5	68	220	0,82	0,90	220
10	-18	99	40	-20	5	68	220	0,82	0,90	220
11	-18	99,5	40	-20	5	68	220	0,82	0,90	220
12	-18	99,5	40	-20	5	68	220	0,82	0,90	220
R	-12,7	94,9	39	-17	7,08	64,7	211	0,81	0,90	220
					1,50 (Bar)	5,46 (Bar)	15,7 (Bar)			

Based on table 1 and 2 a P-h diagram can be drawn as follow.

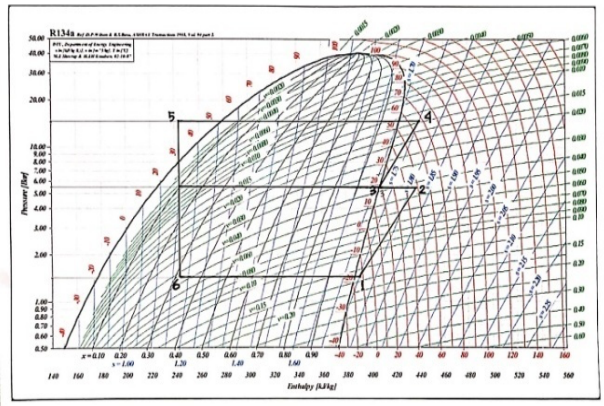

Figure 5. P-h Diagram system with intercooler

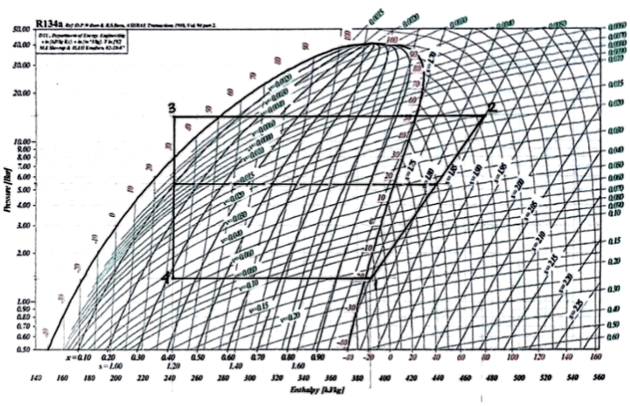

Figure 6. P-h Diagram system without intercooler

Based on the figure, the effect of refrigeration and compressor work from the system with an intercooler can be calculated as follows:

a. Refrigeratiom Effect (RE)
RE = h1 - h6 (kJ/kg)
= 390 – 242(kJ/kg)
= 148kJ/kg
Where:
RE = Refrigeration Effect
h1 = The enthalpy of refrigerant leaving the evaporator (kJ/kg)
h6 = The enthalpy of refrigerant entering the evaporator (kJ/kg)
Thus the refrigeration effect of a multistage cold storage system with an intercooler is 148 Kj/Kg.

b. Compression Work (Cw)
Cw = (h4 – h3) + (h2 – h1) (kJ/kg)
= (441 – 408) + (438 – 390) (kJ/kg)
= 33 + 48 (kJ/kg)
= 81kJ/kg
Where:
Cw = Compression work
h4 = enthalpy of refrigerant vapor leaving compressor 2 (kJ/kg)
h3 = enthalpy of refrigerant vapor entering compressor 2 (kJ/kg)
h2 = enthalpy of refrigerant vapor leaving compressor 1 (kJ/kg)

h1 = enthalpy of refrigerant vapor entering compressor 1 (kJ/kg)
Therefore the compression work of a multistage cold storage system with an intercooler is 81 Kj/Kg.

From the obtained results of the refrigeration effect and compression work, it can be applied into the following COP formula:

$$\text{COP} = \frac{RE}{Cw} = \frac{148}{81} = 1{,}83$$

Where:
COP = Coeffision of Performance
RE = Refrigeration Effect
Cw = Compression work

Therefore the theoretical COP obtained from a system with an intercooler is 1.83.
For a multistage cool-storage system without an intercooler, the following results are obtained.

a. Refrigeration Effect (RE)

$$RE = h1 - h4 \text{ (kJ/kg)} = 390 - 242 \text{(kJ/kg)} = 148 \text{kJ/kg}$$

Where:
RE = Refrigeration Effect
h1 = The enthalpy of refrigerant leaving the evaporator (kJ/kg)
h2 = The enthalpy of refrigerant vapor leaving compressor 1 (kJ/kg)
So the refrigeration effect from cold storage without an intercooler is 135 Kj/Kg.

b. Compression work (Wc)

$$Wc = (h2 - h1) \text{ (kJ/kg)} = (476 - 390)\text{(kJ/kg)} = 86 \text{ (kJ/kg)}$$

Where:
W = Work compression
h4 = The enthalpy of refrigerant vapor leaving compressor 2 (kJ/kg)
h1 = The enthalpy of refrigerant vapor entering compressor 1 (kJ/kg)
So the compression work of a cold storage without an intercooler is 75 Kj/Kg.

From the obtained results of the refrigeration effect and compression work, it can be applied into the following COP formula:

$$\text{COP} = \frac{ER}{Wk} = \frac{148}{86} = 1{,}72$$

Where:
COP = Coeffision of Performance
RE = Refrigeration Effect
Cw = Compression work

Therefore the theoretical COP obtained from a system without an intercooler is 1.72. The maximum temperature of the system can also be directly seen on the pH diagram and the energy consumption will be obtained from the enthalpy difference in the system's compression work [16][17].

4. CONCLUSION

Based on the research results obtained a cool-storage system with intercooler has a COP of 1.83 and the maximum temperature of the system is 67oC and the use of compression energy is 81 kj/kg. Without an intercooler, its COP is 1.72 and the maximum temperature of the system is 94,9oC and the use of compression energy is 86 kJ/kg. Thus the system's performance by using an intercooler is better than without an intercooler. Furthermore, a more economical energy use on a cold storage with intercooler can be categorized as a more eco-friendly technology.

5. ACKNOWLEDGEMENT

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