Experimental Study on the Effect of Intercooler on a Compressor Performance on Multistage Type Cold-storage Simulation

by I Made Arsawan

Experimental Study on the Effect of Intercooler on a Compressor Performance on Multistage Type Cold-storage Simulation

I P. S. Negara[a] and I M. Arsawan[b]

Department of Mechanical Engineering, Politeknik Negeri Bali Badung Bali, Indonesia

Keywords: Intercooler, Compressor Work and Performance.

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. Without using the intercooler, the system's COP is 1.80 and the maximum temperature achieved is 89.5ºC.

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. 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

[a] https://orcid.org/0000-0002-1028-070X
[b] https://orcid.org/0000-0002-2365-9401

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. An experimental study will be conducted to see the effect of the presence of inter cooler in multistage cold storage on the performance and performance of the system during operation.

2 REFRIGERATION

2.1 The Definition of Refrigeration

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. 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 untill they reach their destination.
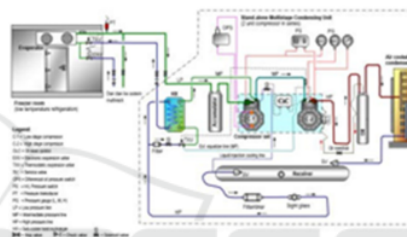
2.2 Multistage Cold Storage with Intercooler

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. 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 Piping.

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. 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. These systems require less power than a single compressor and these power savings will frequently cost extra equipment.

2.3 P - h Diagram

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
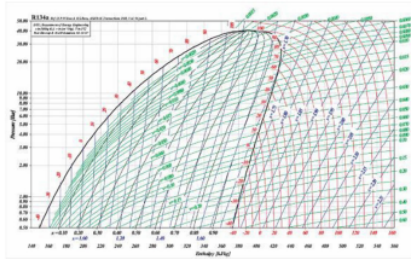

Figure 3: A P – h Diagram.

a. Saturated liquid line
    It is a curved line from the bottom left to the critical point. It is at this point that the refrigerant begins to evaporate. To the left of the line is the super-cooled liquid area. To the right of the line is the mixed phase.
b. Saturated vapor line
    It is a curved line from the right to the critical point. At this point the refrigerant is in the saturated vapor phase. To the right of the line is the area of superheated steam. To the left of the line is the mixed area.
c. Pressure (P, in Bar)
    Pressure is expressed by the ordinate axis (x). It is a line of constant pressure *(isobar),* expressed in psia (*pound per second absolute*) or bar.
d. Entalphy (h, in KJ/ kg)
    It is a vertical line on the Y axis, and is *isoenthalpy*. It is the heat energy possessed by a substance at a certain temperature.
e. Temperature (T, in °C)

    In the liquid area, the temperature line is constant *(isothermal)*. Inside the dome the temperature line is parallel to the pressure line *(isobar)* and in the area of superheated steam, the temperature rises do not curve towards the lower right

f. Specific Volume (v in m³/ kg)
    The constant specific volume line (*isovolumery*) connects the state points with the specific volume with a slightly curved top right oblique direction.
g. Entropy (s, in KJ/kg)
    It is the property of measuring the degree of disorder or irregularity at the microscopic level (one unit of weight). The line of constant entropy

(insentropic) connects points of the same state. It is a right slash from the bottom.

h. Degree of Dryness (x)
    The iso-degree dryness line shows the degree of dryness of the wet vapor. It is the dividing line of the flat lines between the saturated liquid line and the saturated vapor line.

3 EXPERIMENT SETUP AND PROCEDURE

3.1 Type of Research

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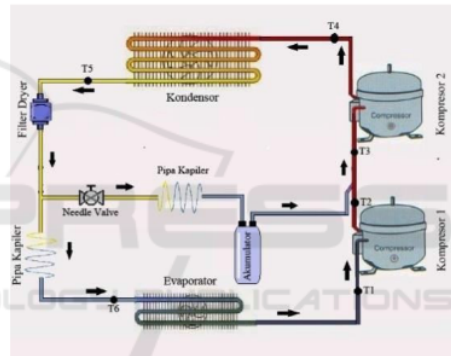

Figure 4: The design of multi-stage cold storage refrigeration simulation.

3.2 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.

3.3 Research Resources

The testing equipment used in this study is a *cold storage* simulation with a *multistage* system designed at the Refrigeration Laboratory, Mechanical Engineering, Bali State Polytechnic with the following specifications:

a. A Piston Compressor, 1/10 PK
b. A Condenser with fan cooling
c. An evaporator
d. A Capillary pipe
e. A Refrigerant R 134a

3.4 Research Instrument

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

a. 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

b. 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 s / d 34 bar.

c. 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.

d. Stop watch

A stop watch is used to set the duration when testing the system.

3.5 Research Procedure

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

a. 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.

b. 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

4 RESULTS AND DISCUSSION

The data oftained 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.

No	T1 (ºC)	T2 (ºC)	T3 (ºC)	T4 (ºC)	T5 (ºC)	T6 (ºC)	LP (Psi)
1	-6	45	19	55	30	-9	10
2	-7	48	19	56	31	-11	10
3	-10	48	19	59	31	-14	9
4	-10	49	18	69	31	-14	9
5	-10	49	18	69	32	-15	8
6	-10	49	18	70	32	-16	7
7	-12	50	18	70	32	-17	6
8	-14	50	18	70	32	-19	6
9	-16	50	18	72	32	-19	5
10	-16	51	18	72	33	-19	5
11	-17	53	18	75	33	-19	5
12	-17	55	18	75	33	-19	5
R	-12	49,7	18,2	67	31,8	-15,5	7,08
							1,56 (Bar)

Table 1: Measurement Result Data on Multistage Cool Storage System with Intercooler (cont.).

No	MP (Psi)	HP (Psi)	A1 (Amp)	A2 (Amp)	V (Volt)
1	60	200	0,81	0,91	220
2	68	200	0,82	0,90	220
3	60	210	0,82	0,90	220
4	62	210	0,82	0,90	220
5	65	210	0,82	0,90	220
6	65	215	0,82	0,90	220
7	65	215	0,82	0,90	220
8	65	215	0,82	0,90	220
9	68	220	0,82	0,90	220
10	68	220	0,82	0,90	220
11	68	220	0,82	0,90	220
12	68	220	0,82	0,90	220
R	64,7	211	0,81	0,90	220
	5,46 (Bar)	15,7 (Bar)			

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

No	T1 (ºC)	T2 (ºC)	T3 (ºC)	T4 (ºC)	LP (Psi)
1	-6	85	37	-11	10
2	-7	86	38	-14	10
3	-9	87	38	-14	9
4	-10	88	38	-15	9
5	-11	88	39	-16	8
6	-12	90	39	-17	7
7	-14	90	39	-19	6
8	-14	91	39	-19	6
9	-16	92	39	-19	5
10	-18	92	40	-20	5
11	-18	93	40	-20	5
12	-18	93	40	-20	5
R	-12,7	89,5	39	-17	7,08
					1,50 (Bar)

No	MP (Psi)	HP (Psi)	A1 (Amp)	A2 (Amp)	V (Volt)
1	60	200	0,81	0,91	220
2	68	200	0,82	0,90	220
3	60	210	0,82	0,90	220
4	62	210	0,82	0,90	220
5	65	210	0,82	0,90	220
6	65	215	0,82	0,90	220
7	65	215	0,82	0,90	220
8	65	215	0,82	0,90	220
9	68	220	0,82	0,90	220
10	68	220	0,82	0,90	220
11	68	220	0,82	0,90	220
12	68	220	0,82	0,90	220
R	64,7	211	0,81	0,90	220
	5,46 (Bar)	15,7 (Bar)			

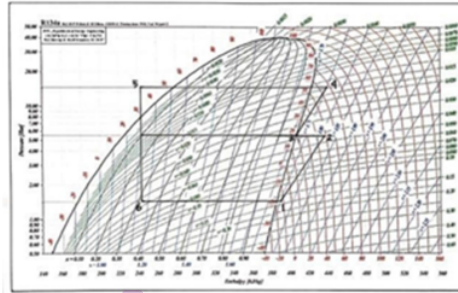Based on table 1 and 2 a P-h diagram can be drawn as follows.

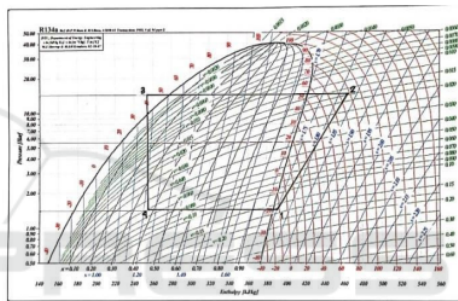Figure 5: P-h Diagram system with intercooler.

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)
$= 148$ kJ/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)
$= 81$ kJ/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:

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

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 = h2 – h1 (kJ/kg)
= 390 – 255(kJ/kg)
= 135kJ/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 =
(h1 – h4) (kJ/kg)
= (465 – 390)(kJ/kg)
= 75(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:

$$COP = \frac{RE}{Cw}$$
$$= \frac{135}{75}$$
$$= 1,80$$

Where:

COP = *Coeffision of Performance*

RE = Refrigeration Effect

Cw = Compression work

Therefore the theoretical COP obtained from a system without an intercooler is 1.80. 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.

5 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 67°C. Without an intercooler, its COP is 1.80 and the maximum temperature of the system is 89.5°C. Thus the system's performance by using an intercooler is better than without an intercooler.

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