Performance of oil-free water-cooled chiller for a shopping center air conditioning system

A Yatim¹, J A Prima¹, M A Jofansya¹, M I Alhamid¹, Budihardjo¹ and A Lubis¹

¹Department of Mechanical Engineering, University of Indonesia, Depok, Indonesia

Abstract. Many researches have been conducted on cooling equipment to reduce its energy consumption, maintenance and operation cost. Oil-free chiller uses a magnetic bearing compressor to avoid friction loss from the bearing’s contact surface. In comparison to a conventional compressor, the magnetic bearing of the motor, with the help of variable speed drive (VSD), runs more efficiently at partial loads. This paper presents the application of oil-free compressors in a chiller plant. The chiller plant also includes a chilled water system. In designing an energy-efficient air conditioning system it is important to choose proper chilled water and cooling water system. The evaporator is used to absorb the heat from the conditioned room while the condenser rejects the heat from the chiller to the environment through circulating cooling water. This research also aims to analyze the chiller plant for the air conditioning system operates in one of the shopping malls in Indonesia and how it affects the performance of the magnetic bearing chiller. The research also presents an analysis of the efficiency of the chiller plant, the coefficient of performance of each compressor, and their compliance with both national and international standards.

1. Introduction

In modern times like today, comfort is very important for the needs of both social and personal life such as office buildings, malls, to housing. In the field of HVAC (heating, ventilation, and air conditioning), comfort can be categorized or can be used as thermal comfort. A chiller is a refrigerating machine that cools the medium air on the evaporator side. This is because the chiller has two types of sides in the condenser, namely the air-cooled chiller and the water-cooled chiller. An air-cooled cooler is a refraction machine that functions to dissipate heat without using a cooling tower. Inside the condenser, the air-cooled cooler uses a propeller fan to take outside air through the fins to condenser the refrigerant. This causes many users to use air-cooled refrigerants because it is very easy to operate and has a very high place efficiency [1]. A water-cooled chiller is a refrigeration machine that has the main function of removing heat from space into the outside air using water as the media with a cycle of vapor-compression or absorption refrigeration cycle. In the Evaporator, water that has been cooled from the chiller will be channeled to the AHU (air handling unit), where cooling from the water will be channeled into the room through the heat exchange process. The cold absorbed water returns to the chiller at higher temperature. In the condenser, the water from the chiller is directed to the cooling tower where the water will be cooled by removing the heat inside it and reject it to the outside air using a cooling fan tower. Water from the cooling tower that has been cooled is taken back to the chiller. The above process forms a cycle that occurs in a water-cooled chiller plant [2].
A poor cooling tower system can cause an increasing dissolved solid or change in pH number in cooling water circulation to Insufficient cooling water can cause a refrigeration machine-like chiller, to corrode or form scaling that will reduce the effectiveness of the cooling tower system [3][4].

A chiller will benefit from both the economic side of electricity and the usage of water. Savings on expenses that can be obtained from the substitute electricity expenditure to the amount of cooling produced should meet both national and international minimum standards. The amount of water that is used also has a linear impact on the chiller to avoid the associated cavitation and turbulence in the piping system of the chiller plant [5].

Conventional chillers use a vapor-compression compressor which requires lubrication or oil for its operation. A small amount of oil from the compressor will find its way to refrigerant circulation in the system component. Oil accumulating in the heat exchanger is reducing heat transfer capacity and increasing the pressure loss [6][7][8]. This research presents an application of an oil-free compressor in a chiller plant for the air conditioning system. the magnetic bearing of the chiller’s motor, with the help of variable speed drive (VSD), runs more efficiently at partial loads. This paper presents the application of oil-free compressors in a chiller plant for a shopping mall.

2. Methodology

2.1. Specification and Load

The air conditioning system under study consists of 4 water-cooled chiller plants that are used for comfort air conditioning for the whole building of the shopping center. Chillers are specification is detailed in Table 1.

| Table 1. Chiller specification |
|-----------------------------|
| Cooling Capacity kW | 281.4 |
| Power Input kW | 457.6 |
| Refrigerant Type | R134a |
| Charge (kg) | 1000 |
| Condenser Type | Flooded Type |
| Evaporator Water inlet/outlet temp | 12°C/7°C |
| Rated Water Flow (m³/h) | 484 |
| Condenser Water inlet/outlet temp | 30°C/35°C |
| Rated Water Flow (m³/h) | 563 |

There are 5 compressors for each chiller that responsible to maintain the temperature of the shopping center. For efficiency, the system is set to allow for each one of the chillers to not use full load power or operating 5 chiller altogether at the same time. Instead, they use partial load. The compressor partial load management is detailed in Table 2.

| Table 2. Chiller load management |
|--------------------------------|
| Day | Chiller 1 | Chiller 2 | Chiller 3 | Chiller 4 |
| Saturday | 3 (60%) | 2 (40%) | 2 (40%) | - |
| Sunday | 3 (60%) | 2 (40%) | - | 3 (60%) |
| Monday | 3 (60%) | 2 (40%) | - | 3 (60%) |
2.2. Chiller Plant Layout
The chiller plant consists of 4 chillers, 4 cooling towers, 4 chilled water supply pump, and 4 chilled water return pump and the layout is presented in figure 1.

![Chiller Plant Layout](image)

**Figure 1.** Chiller plant layout

The data collection was done to find the relationship and comparison between the cooling produced by the cooling system and the electrical energy used and the parameters that affect it. Data retrieval was taken from panels that had been installed or built-in conjunction with the system and also measuring devices prepared outside those that had been installed. Each chiller is installed with a one-panel screen each. On the panel screen, the information provided consists of data from the water entering and exiting the chiller, as well as the compressor working.

The chiller shopping center is directly connected to the data center with an internet cloud, where the recorded data on the chiller is directly stored in an MS Excel form. In the first menu of the cloud chiller system, shown in figure 2, information would appear on how many chillers were active, broken (error), and not active. To find out in detail the chiller data such as water temperature, refrigerant temperature, and power of the compressor, these three things can be accessed by pressing one of the chillers in the soundbox.

2.3. Performance Parameter
For application, in general conditions with a water temperature of 6.7 °C and a flow of 2.4 GPM/ton, changes in temperature in the condenser or evaporator use [3]:

[1]
[2]
[3]
\[ Q = W \cdot C \cdot \Delta T \]

Where \( Q \) is the energy of heat entering or leaving (Joule/s), \( W \) is the flow rate of chilled water (kg/s), \( C \) is the specific heat of fluid (Joule/kg \( \cdot \) °C) and \( \Delta T \) is the difference between water entering and leaving the evaporator.

![Figure 2. Cloud display of chiller system](image)

3. Result and Analysis

3.1. Chiller power consumption

The power consumption of the chiller on Saturday is shown in figure 3. The maximum power consumption of each cooling tower and chilled water return pump were 22 and 54.83 kW, respectively. Hence the total for each cooling tower system was 76.83 kW. There were 2 cooling towers and 2 pumps operating in zone A so the maximum energy consumption was 153.66 kW. According to figure 3, the cooling tower system in zone A was operating as its specification. However, there was only 1 cooling tower and 1 pump operating in zone B which meant the cooling tower system in zone B consumed more than its maximum according to specification. The excessive amount of energy consumption in zone B could be the reason for low performance in the chiller system.
3.2. Chiller Performance

Chiller performance was evaluated in COP which was calculated from ratio of the cooling from the evaporator and compressor energy consumption from each chiller.

On Saturday after 15.00, the failure of 1 compressor causing a drastic decrease in chiller 3 performance. The following performance increase at 16.00 is due to the leftover cooling and the broken compressor that had been fully shut down. Chiller 3 had a higher performance value because chiller 3 has higher flow rate and chilled water temperature difference.

On the beginning of Sunday, there is a significant difference on chiller 1 and chiller 2 performance caused by the use of 2 compressor in chiller 2 which each didn’t exceed 90 kW of power consumption. At 19.00 the cooling load had decreased therefore there is a slight improvement in each chiller performance.
3.3. Chiller Performance

Chiller system performance was evaluated in kW/TR which was calculated from total energy consumption divided by the cooling from the evaporators at each zone.

- On Saturday the list of component operating is CH-1, CH-2, CH-3, CHWSP-1, CHWSP-2, CHWSP-4, CHWRP-1, CHWRP-2, CHWRP-4, CT-1, CT-2, and CT-3.
- On Sunday the list of component operating is CH-1, CH-2, CH-4, CHWSP-1, CHWSP-2, CHWSP-4, CHWRP-1, CHWRP-2, CHWRP-4, CT-1, CT-2, and CT-3.
- On Monday the list of component operating is CH-1, CH-2, CH-4, CHWSP-1, CHWSP-2, CHWSP-4, CHWRP-1, CHWRP-2, CHWRP-4, CT-1, CT-2, and CT-3.

As depicted in figure 4, on Saturday at 16.00, there was an increase in chiller system performance value in zone B this can be caused by the failure of 1 compressor in chiller 3. The alarm indicating the compressor failure rang at 17.53 but the performance degradation or the break down can occur before 17.53. The broken compressor is suspected to continue consuming the energy while it was degrading before it was shut down.
On Sunday the chiller system performance in zone A was better than in Zone B as shown in figure 5. This was caused by the performance of chiller 4 which was operated instead of the chiller 3 was having worse performance than chiller 3. Chiller 4 was having worse performance because Chiller 4 had less refrigerant, chiller 4 had approximately 700 kg of refrigerant out of 1 ton or 1000 kg maximum.

Figure 6 showed the chiller system performance on Monday. On Monday at 17.00, there was a decrease in chiller system performance value in Zone A followed by an increase at 18.00. These changes in performance value were because chiller 2 was shut down at 17.00 so there was a decrease in energy consumption while there was left over cooling in chilled water in the evaporator but due to the heavy
rain the cooling tower and pump for chiller 2 had not been shut down this caused an increase in performance value when there was no more leftover cooling.

The standard of chiller system performance or efficiency with more than 600 tons capacity chiller is 0.56 kW/TR for full load and 0.5 kW/TR for part-load [3]. The performance of the chiller system measured was not according to ASHRAE Standard 90.1-2013 [3] for either full load or part load standard. There was an exception on Saturday at 11.00, the performance value was 0.5 kW/TR for zone B which is the same as the standard for part load. This lower chiller system performance could be caused by the lack of several compressors on the current chiller. The chiller was designed with 5 compressors but chiller 1 operated with 3 compressors, chiller 2 operated with 2 compressors, chiller 3 operated with 2 compressors, and chiller 4 operated with 3 compressors when they were measured. The lacking number compressors could give more work for each compressor which could lead to more energy consumption and/or less cooling. The poor chiller system performance could also be caused by the high energy consumption from the cooling tower and/or chilled water return pump.

4. Conclusion
The value of chiller system performance in both zone A and zone B is more than 0.5 and 0.56 kW/TR, respectively. These values are below the values recommended in ASHRAE Standard 90.1-2013 for part load and full load of 600-ton capacity chiller. The poor chiller system performance is due to the lack of compressor operating and excessive energy consumption in the cooling tower system.

References
[1] K. W. Shan, “Handbook of Air Conditioning and Refrigeration”, 2nd ed., New York, USA: McGraw-Hill, 2001, pp. 38-40.
[2] “Ventilation for Acceptable Indoor Air Quality” in ASHRAE Standard 62.1 – 2013, 1791 Tullie Circle NE, Atlanta, USA: ANSI, 2013, pp. 3-4.
[3] M. I. Alhamid et al., “Performance analysis and water quality after ozone application in closed circuit cooling tower systems,” in AIP, 25 Jan. 2019, pp. 020043.
[4] M. I. Alhamid et al., “Analysis of the effectiveness of ozonation on corrosion and bacteria on closed system cooling towers,” in AIP, 25 Jan. 2019, pp. 020046.
[5] P. Byrne et al, “Design of a Solar AC System Including a PCM Storage for Sustainable Resorts in Tropical Region,” in EVERGREEN, June 2019, pp. 143-148
[6] A. S. Yatim et al., “Oil retention in a microchannel type condenser and its effects on heat transfer rate performance and the pressure drop,” in Taylor&Francis, 18 Oct. 2016, pp. 166-180.
[7] L. Cremaaschi. et al., “Experimental study of oil retention in microchannel type evaporators of air-source heat pump systems,” in Elsevier, 17 May 2018, pp. 158-166.
[8] L. Cremaaschi. and A. S. Yatim, “Oil retention in microchannel heat exchangers of an R134a refrigeration system and effects on their energy performance and system COP,” in Taylor&Francis, 28 Nov. 2018, pp. 272-281.
[9] “Energy Standard for Building Except Low-Rise Residential Building” in ASHRAE Standard 90.1-2013, 1791 Tullie Circle NE, Atlanta, USA: ANSI, 2016

Acknowledgments
We would like to acknowledge Universitas Indonesia for its funding support PUTI Grant 2020.