MJIT 2019 Malaysian Journal of Industrial Technology

STUDY THE COP AND THE EFFECT OF AIR FLOW FOR PILOT PLANT AIR REFRIGERATION UNIT

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Abstract

An experiment was carried out to study the optimum condition of the parameters involved, which are air flow and coefficient of performance (COP) in order to increase the stability and efficiency of the refrigeration system for air conditioning unit (ACU) model. The instability of the refrigeration system may reduce the COP of the unit. The experiment was carried out in a lab scale, using R-134a as refrigerant with the maximum air throughput of 0.14 m^3/s. The ACU consist of air conditioning system and refrigeration system. Air flow was calculated from the differential pressure (DP) at 15%, 30%, 45%, 60%, 75% and 90%. All readings were taken after 20 minutes in order to achieve steady state. The ambient and refrigerant temperature was recorded at all DPs. Other than that, the enthalpy at every point was calculated, to identify the COP and the compressor work produced. Ambient temperature at point 5 (AT5) showed steady increment, from 20.8°C to 24.7°C with increasing air flow. From the study, it found that there is a strong relationship between air flow and temperature where the higher air flow will increase the temperature, which is not efficient for the system. Therefore, air flow of 15% DP showed the best optimum condition for this refrigeration system, with the desired COP achieved. In daily life, it can be applied for the ACU in the car, where increase in air flow is not desirable for a long time, due to its efficiency (temperature increase).

Keywords: Coefficient of Performance (COP); Air Flow; Refrigeration System; Ambient Temperature; R-134a

1.0 INTRODUCTION

Nowadays, destruction of the ozone layer is becoming more serious. Under the mandate of the Montreal Protocol, the use of chlorofluorocarbon (CFC) had been phased out and the use of hydrochlorofluorocarbon (HCFC) will also be phased out in a short period of time [1]. This is because CFC consists of volatile derivatives of methane and ethane in combination with halogenated element like chlorine and fluorine. The use of CFC's would lead to the destruction of atmospheric ozone was predicted as early in 1974 by Rowland and Molina [2]. The chemical stability of CFCs allows them to gradually diffuse and be transported from the lower atmosphere to the stratosphere. Their photolysis releases chlorine atoms which then participate in a series of reactions, which leads to the catalytic destruction of ozone [2].

Therefore, various non CFC refrigerants were introduced and used in different air conditioning and refrigeration systems. It includes hydrofluorocarbon (HFC) refrigerants R-143a which is used in many home and automobile air conditioning system. This is because it can avoid the destruction of the ozone layer in the outer atmosphere around the Earth.

In terms of energy conservation and space saving, the design should be more compact and efficient [3]. Every system has their own level of stability. For example, if the pressure of a system is high, it will affect the other parameters too such temperature and power consumption. This will lead to the instability of the system. Same with refrigeration system, the parameters can be affected easily. Therefore, study need to be done to identify the most effective condition of the parameters involved in order to increase the stability and efficiency of the system.

In refrigeration system, the need to achieve high efficiency are crucial. Refrigeration or reverse heat pump have four processes which it run in cycle; isentropic compression in condenser, constant pressure heat rejection, throttling in expansion device and constant heat adsorption in evaporator. The performance of refrigerant is usually measure in coefficient of performance (COP). In the ideal refrigeration cycle it is assumed that the pressure drops are negligible, the compression is isentropic, and the evaporator and condenser are adiabatic [4]. The blower is needed in air refrigeration unit to produce air movement to the space that being conditioned.

However, the measured values will include the pressure drops due to friction, the compressor is not isentropic and the evaporator and condenser are not adiabatic. Since the compressor is not isentropic there will be more work required to get from the compressor to condensor. The path from compressor (Fig. 2) will be slightly slip to the superheated region. Therefore, the work input will increase which affects the COP. The instability of the refrigerant system may reduce COP of the unit. Our aim of study is to identify the effect of blower on temperature in an Air Conditioning Unit (ACU) and to study the optimum COP of the air conditioning system in Faculty Chemical Engineering's (UiTM Pasir Gudang Campus) Pilot Plant.

2.0 EXPERIMENTAL

Refrigeration unit. This study was conducted at the Pilot Plant, Faculty of Chemical Engineering, UiTM Pasir Gudang in lab scale. The SOLTEQ Air-Conditioning Unit (Model AC 01) uses R-134a refrigerant, protected by low and high pressure cut-off switch. The blower strength is 0. 14 m^3/s maximum with cross-sectional area about of $0.09m^2$. The air-conditioning unit principally consists of two assemblies, which are air-conditioning system and refrigeration unit. Fig. 1 shows the detail unit construction for ACU use in this study.

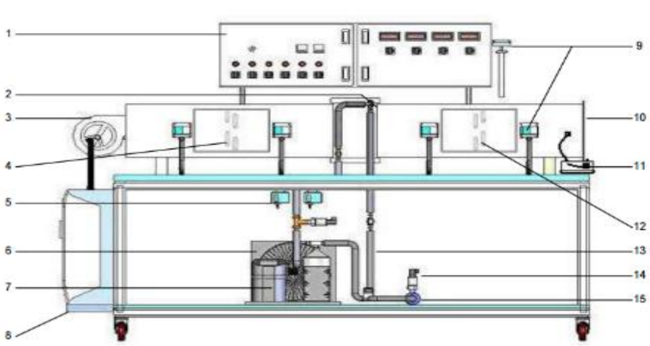

Fig. 1. Unit construction for ACU (Model: AC 01);1. Control Panel, 2. Expansion Valve, 3. Fan, 4. Pre-Heater, 5. Pressure Switch, 6. Refrigerant Condenser, 7. Refrigerant Compressor, 8. Steam Humidifier, 9. Humidity/Temperature Sensor, 10. Orifice, 11. Differential Pressure Transmitter, 12. Re-Heater, 13. Refrigerant Flowmeter, 14. Refrigerant Pressure Transmitter, 15. Filter Dryer

There are four main process in refrigeration system; i.e. compression, condensing, expansion and vaporizing process as illustrate in Fig. 2. Compression process occurred between point 1 and 2. At point 1, the temperature and pressure of refrigerant was low. Therefore, pressure can be increased by compressing the refrigerant so do with the temperature.

Meanwhile for condensing occurred between point 2 and 3. The refrigerant left the compressor in gas state at high temperature and high pressure. Heat was removed in this process in order to change from gas state to liquid state. The refrigerant flow through air finned condenser and cooled down by electrical fan. The refrigerant was then condensed to a liquid state at point 3.

Expansion process occurred between point 3 and 4. Refrigerant from point 3 flow through the expansion valve, where it loses pressure and therefore small portion of refrigerant vaporizes into gas form. In order to vaporize, the refrigerant gained heat thus resulted in cooling.

The last process was vaporizing process where this process occurred between point 4 and 1. The refrigerant flow through the evaporator. The fluid was cooled at slightly higher temperature than the refrigerant, therefore heat was transferred from fluid to the refrigerant, where the desired cooling effect was produced. These four processes were illustrating in Fig. 2.

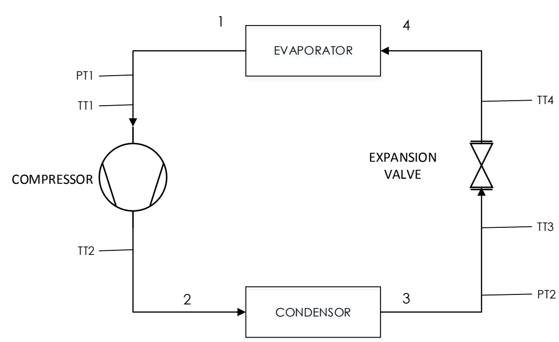

Fig. 2. Schematic diagram of the refrigeration system.

Air conditioning system. The air-conditioning system is designed as Fig. 3 based on the various measurement locations. In the ACU, it consists of seven main parts. First, it consists of combined temperature or relative humidity transmitter which measured temperature or relative humidity. A radial fan was located at the front of the ACU, where the air volume flow can be varied with the aid of speed adjuster. Next to the radial fan, a steam humidifier with a power consumption of 2kW was placed, followed by the pre-heater. The pre-heater consists of four electric air heaters, with an output of 0.5kW for each. The evaporator used in this system is direct evaporator of a refrigeration unit. After the evaporator, re-heater was placed and it was constructed exactly the same way as the pre-heater. The individual air heaters only delivered an output of 0.25kW, which means a maximum heating power of 1kW was achieved. The last part of the air conditioning was an orifice, where the mass flow rate was calculated from the orifice correlation by measuring differential pressure across the orifice. Additional thermometer was added in front of mouth of AC unit to show the additional ambient temperature (AT6).

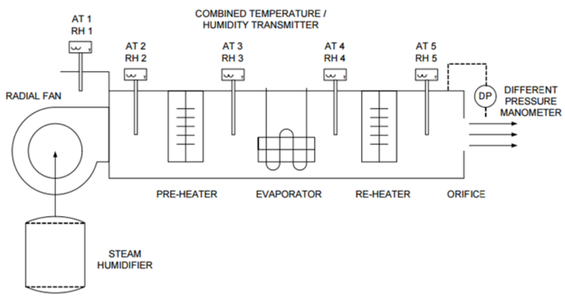

Fig. 3. Process schematic diagram of ACU

Blower regulation. The percentage of the air velocity is calculated from the differential pressure (DP) value at mouth of the ACU. The calculation percent of blower (air velocity) was calculated by using Equation 1 and 2. DP reading was the value of the ACU to be set at 15%, 30%, 45%, 60%, 75%, and 90%.

$$\text{Air velocity (\%)} = DP_{ref} / (DP_{max} - DP_{min}) \quad (1)$$

$$DP_{read} = DP_{min} + DP_{ref} \quad (2)$$

Compressor work and COP. The actual compressor work was calculated by using Equation 3 followed by using Equation 4 to determine the COP.

$$\text{Compressor work, } W_{in} \text{ (kW)} = (h_2 - h_1) \times m \quad (3)$$

$$COP = (h_2 - h_1) / [(h_2 - h_1) - (h_3 - h_4)] \quad (4)$$

3.0 RESULTS AND DISCUSSION

The enthalpy was measured by determined the temperature at every point starting from point 1 to 4. In order to know the enthalpy, the temperature of every point of ambient temperature (AT) and refrigerant temperature (TT) were recorded.

Table 1 shows the result of the AT and TT. Based on the result, refrigerant increases slightly with the increasing of DP. On the contrary, the AT showed decrement through every point, starting from point 2 to 5. The AT2 and AT3 are the temperature points where they are before and after the pre-heater unit. The AT4 is a temperature point after the evaporator and the AT5 is after the re-heater as illustrate in Fig. 3. These points were located at different point to represent the temperature difference before and after the unit processes occurred. The ambient temperature at point 6 (AT6) only for indicator, which indicated the ambient temperature ranged from 20°C to 24°C, showing only slight increment between AT5 and AT6. Even though there are no slightly difference between AT5 and AT6, it shows that there have a difference in temperature between inside the air conditioning system with the outlet of the system (orifice). This is happened due to the convection and the difference temperature between inside the system and room temperature.

Table 1. Temperatures obtained for each DP applied.

	DP (%)	15	30	45	60	75	90
Refrigerant Temperature (°C)	**TT1**	28.5	29.8	30.1	30.4	30.5	30.7
	TT2	60.1	62.4	62.2	63.3	63.2	63.2
	TT3	38.8	39.7	39.9	40.4	40.2	40.7
	TT4	16.5	17.1	17.7	18.1	18.2	18.3
Ambient Temperature (°C)	**AT1**	28.0	28.4	28.5	28.6	28.7	28.9
	AT2	29.5	30.1	30.0	30.3	30.2	30.2
	AT3	29.2	29.8	29.5	30.0	30.0	30.1
	AT4	21.1	23.1	23.9	24.5	24.6	25.0
	AT5	20.8	22.9	23.6	24.2	24.4	24.7
	AT6	20.0	22.0	23.0	24.0	24.0	24.0

The temperatures obtained were then used to calculate the specific enthalpy (*h*) at every process that shows in Table 2 where *m* is mass flowrate (kg/s) and *V* is volumetric flowrate (m^3/s). These specific enthalpies were obtained from thermodynamics table [4]. Based on the enthalpy, COP can be calculated in order to determine the efficiency of a refrigerator in this unit.

Table 2. Specific enthalpy of refrigerant

	Air flow (m^3/s)	0.021@ DP_{15}	0.042@ DP_{30}	0.063@ DP_{45}	0.084@ DP_{60}	0.105@ DP_{75}	0.126@ DP_{90}
Enthalpy (kJ/kg)	h_1	274.4	275.4	275.5	282.1	282.1	282.3
	h_2	287.9	285.3	289.3	289.9	298.9	289.7
	h_3	106.4	161.1	178.9	217.9	202.1	241.7
	h_4	263.4	263.8	264.2	271.7	271.8	271.9
Refrigerant	V (m^3/s)	0.009	0.007	0.009	0.014	0.012	0.017
	m (kg/s)	0.198	0.233	0.181	0.120	0.139	0.100

From the result, it showed that the lowest outer ambient temperature achieves was at 15% air flow and the highest outer ambient temperature as expected achieves at 90% air flow with temperature 20.8°C and 24.7°C respectively (AT5). The temperature was increase with the increasing of DP. This happen because at DP_{90} the blower gives highest heat transfer between heat rejection from compressor and refrigerant temperature.

Table 2 shows that the mass refrigerant flowrate decrease with increasing air flow. At the beginning of 0.021 m^3/s (15% DP), the mass flowrate obtained was 0.198 kg/s followed by 0.233 kg/s at 0.042 m^3/s (30% DP). Only 15% DP to 30% DP shows the increasing of mass refrigerant flowrate, other than that the mass refrigerant flowrate decrease with increasing of DP percent. At the highest air flow of 0.126 m^3/s (90% DP), the mass flowrate decreased to 0.1 kg/s. Table 2 shows that the mass flowrate (m) of refrigerant through the compressor are dependent on its speed, amount of refrigerant in the system and air flow through the evaporator. The higher the amount of air flow, the lower the mass refrigerant flowrate obtained. This is related to compressor work and COP.

Fig. 4. The actual work of compressor for each point of DP.

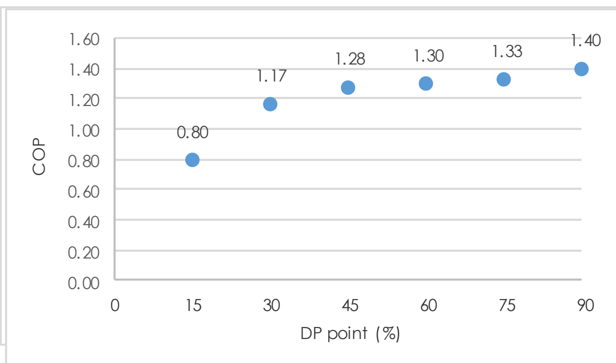

Fig. 5. COP of ACU for every DP point in the system.

Fig. 4 shows the higher air flow gives lower work for compressor. This happen because the temperature of refrigerant itself decreased after the evaporator. It is already high enough for the compressor to compress the refrigerant to decrease the temperature at specific value. The rejection of heat at high pressure will occur at condenser.

Meanwhile, Fig. 5 shows the higher the air flow (DP), the higher the COP for the refrigerant. COP refrigeration define as the ratio of the desired output to the required input, where the desired output is the heat adsorption of refrigerant at the evaporator. Even when COP is higher, the heat transfer is more between the water vapour in air and the surface of the coil. Moreover, in term of temperature drop, the higher air flows the lower dropping of temperature difference from AT1 to AT5. The air does not reject heat efficiently to evaporator but its efficient for dehumidification. As shows in Table 1, the higher air flow causes the higher bypass of the air (V=0.017 m^3/s) thus the exit air slightly higher in temperature difference. It can be concluding that the high in air flow is inefficient way for air cooling.

4.0 CONCLUSION

As a conclusion, the effects on COP with increasing air flow showed that the highest air flow did not give optimum COP of the system, but is efficient to achieve highest cooling power. In daily life, the application of refrigeration system can be seen in car air conditioner, where applying high level of blower will help in increasing the cooling power in the car, but not efficient if it is applied for a long time. Increasing the blower fan will not lower the temperature. Therefore, it can be concluding that the best condition for this refrigeration system is at the air flow of 15%, which give the appropriate COP and temperature.

Acknowledgement

Authors wish to express their gratitude to Mrs Irma Atika Zainal Abidin for her guidance on technical matters related to the work and her support at the site in pilot plant.

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