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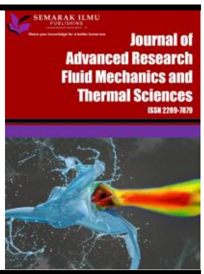

Evaluation of Air Conditioner Performance using Different Methods of Temperature Measurement

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ABSTRACT

Performance evaluation of an air conditioner using R410a has been evaluated by field measurement of pressure and temperature at suction and discharge line. Two methods were used for temperature measurement. First, the sensors were mounted on the outer wall of pipe and second, the sensors were inserted into the refrigerant flow in the pipe. Using the second method, the suction temperature is averagely 5.0°C lower and the discharge temperature is 17.8°C higher than that of the first method. The coefficient of performance and power consumption resulted from the second method is in a good agreement with that of standardized test according to ISO 5151:2017. This indicates that the temperature sensor insertion to the refrigerant flow gives the better accuracy in the evaluation of performance of an air conditioner.

1. Introduction

Performance evaluation of an air conditioner is an important step before launching an air conditioner into the market. The most important parameters to be tested are its power consumption, cooling capacity, and energy efficiency ratio. Apart from these parameters, the operating conditions of an air conditioner are also important to be discussed. The most common operating conditions are suction temperature, evaporating temperature, discharge temperature, condensing temperature, suction pressure, and discharge pressure.

Temperature measurement is one of the most important parameters in air conditioning and refrigeration applications. Considerable accuracy is needed in order to proper analysis of operating conditions and performance of air conditioning and refrigeration systems. Generally, fluid temperature measurements were carried out by mounting a sensor in the outer pipe wall. This leads to the temperature difference among the sensor reading and actual refrigerant temperature. The flow parameters such as Reynolds number, Prandtl number, mean velocity, ambient temperature, density, and pipe diameter are usually considered in temperature measurement of flowing fluid inside a pipe [1]. If the temperature difference between the pipe surface and the fluid is significant,

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the uncertainty of the measurement will increase [2]. The difference of the measurement results could be minimized when the mass flow rate of fluid inside the pipe is higher [3].

The existence of disturbance from the ambient could aggravate the uncertainty. Errors in temperature measurement, especially discharge temperature, can harm a vapor compression refrigeration system. Discharge temperature that is too high and undetected can cause a decrease in the ability of the oil to lubricate the compressor and shorten its service life [4]. In refrigeration and air conditioning application, the discharge temperature should be controlled to prevent it excesses the recommended maximum value. Mota-Babiloni *et al.,* [5] suggested the discharge temperature not more than 380K to prevent carbonization and break down of lubricant. High discharge temperature could be caused by the use of liquid-suction heat-exchanger to transfer heat from liquid line and suction line of refrigeration system [6].

Depending on the type of lubricants and refrigerants, the allowed operating condition limit, especially the discharge temperature, can be different. For instance, the discharge temperature of R513A will be different from that of R134a [7]. Therefore, accurate measurement of this parameter should be carried out to avoid failure in operating refrigeration and air conditioning equipment.

To evaluate the performance of an air conditioner, Park *et al.,* [8] used 40 type T thermocouples made from copper-constantan to measure the temperature of refrigerant along the condenser and evaporator. This method was adopted from Jung *et al.,* [9] and Park and Jung [10]. Other parameters were also measured in this study, including the pressure at the evaporator and condenser inlets and outlets, mass flow rate of refrigerant, temperature at the inlet and outlet of compressor, and the temperature of compressor body.

This paper is aimed to discuss the performance of an air conditioner based on the different method of temperature measurements, i.e., with the sensor mounted on the outer pipe wall and the sensor installed inside the refrigerant pipeline. The results of the measurements were used to calculate the performance of the air conditioner, especially the coefficient of performance (COP).

2. Methodology

In this study, the indoor unit of a room air conditioner, as usual, was mounted on a wall in a room. The outdoor unit was installed outside the room with a height difference of 1.5 m, in which the indoor unit is located higher than the outdoor unit. R410a was used as a working fluid in this air conditioner with a rated cooling capacity of 2.6 kW. The scheme of refrigeration system for the room air conditioner is sketched in Figure 1. In this system, cold vapor refrigerant from the evaporator is compressed by the compressor to produce a hot and high-pressure refrigerant vapor (process 1-2). The hot vapor is the cooled in the condenser by passing air through the condenser coil (process 2-3). Sensible and latent cooling process take place in the condenser. In the sensible process, the vapor refrigerant from the compressor is cooled until it reaches its saturated vapor temperature. Thereafter, latent cooling occurs where vapor refrigerant condenses until all the vapor turns into liquid at the condenser outlet. This process takes place at constant pressure. The liquid refrigerant is then passed through the expansion device and the expansion process takes place here (3-4). In this process there is a pressure drop at constant enthalpy and some of the liquid refrigerant evaporates into vapor and the rest remains a liquid. The remaining liquid will evaporate along the evaporator and the process of evaporation and a two-phase flow of boiling refrigerant takes place here (4-1) [11,12]. Heat from the surroundings is absorbed to evaporate the liquid refrigerant in the evaporator. Then the refrigerant will be compressed by the compressor and the refrigerant cycle repeats.

In order to evaluate the performance of the air conditioning machine, temperature measurements (T) were carried out at the suction line, discharge line, condenser output, and expansion device output. Pressure measurements (P) on the suction and discharge lines were carried out using refrigerant pressure gauges. The measurements of the electrical current, voltage, and power were accomplished using a power meter.

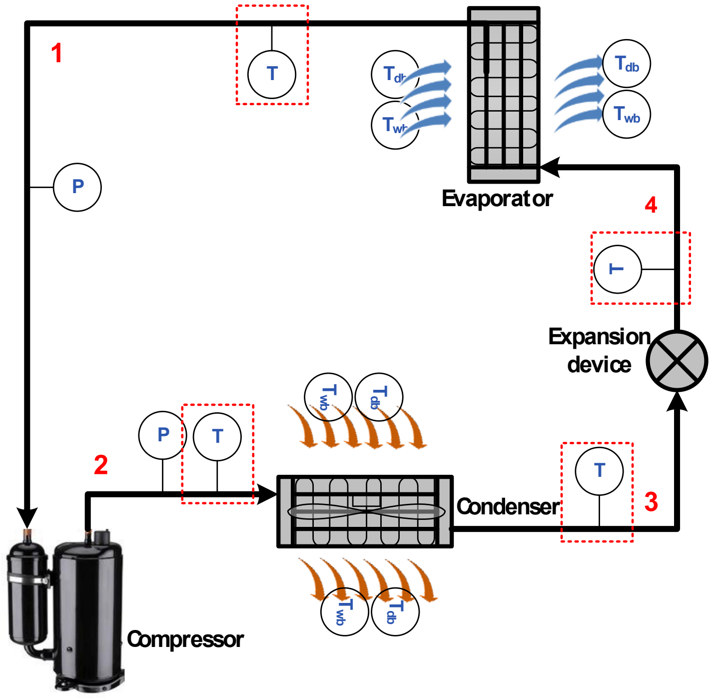

Fig. 1. Sketch of room air conditioner

The pressure measurement was accomplished using pressure gauges and temperature measurement was performed by thermocouples. The dashed lines in Figure 1 show the location of measurement of temperature. Two methods were used for temperature measurement. In the first method, the sensors were mounted on the outer wall of refrigerant pipe at the suction and discharge line (Figure 2(a)). In the second method, the sensors were inserted into the refrigerant flow in the pipe (Figure 2(b)). In the insertion method, the thermocouple wire was installed using a strong and heat-resistant glue to prevent refrigerant leakage.

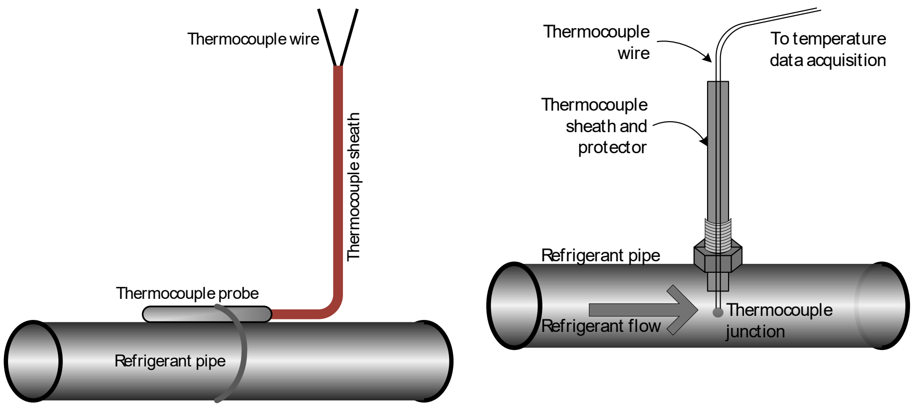

Fig. 2. Two methods of refrigerant temperature measurement, (a) sensor is mounted on the outer wall of pipe, (b) sensor is inserted into refrigerant flow in the pipe

The performance of the air conditioning machine can be expressed in input power, capacity, and efficiency, in term of coefficient of performance (COP). The input power (P_i) can be directly measured using power meter or calculated from the product of current (I) and voltage (V). The cooling capacity (q_e) can be determined using

$$q_e = (h_1 - h_4)\dot{m} \quad (1)$$

Here, h_1 and h_4 represent the enthalpy of refrigerant leaving and entering the evaporator, respectively, which refer to Figure 1. Symbol $\dot{m}$ expresses the mass flow rate of refrigerant flowing in the evaporator pipe. The enthalpy of refrigerant can be determined if its pressure and temperature are known. The mass flow rate of refrigerant can be determined using the product of volumetric flow rate and density, or can be written as

$$\dot{m} = Q\rho \quad (2)$$

The volumetric flow rate can be determined by inspecting the swept volume from the compressor's data sheets and the density of the refrigerant can be determined by using the refrigerant database at the saturated vapor for the given temperature and pressure. Alternatively, the mass flow rate can be calculated using

$$\dot{m} = Q/v \quad (3)$$

where v is the specific volume of refrigerant.

If the capacity of the air conditioner is obtained, the coefficient of performance can be calculated using the ratio of cooling capacity and power consumption

$$COP = \frac{q_e}{P_i} \quad (4)$$

or

$$COP = \frac{q_e}{I \cdot V} \quad (5)$$

3. Results

3.1 Suction and Discharge Pressure

The profile of suction and discharge pressure is pictured in Figure 3. In this experiment, the suction pressure was stable at 9 bar or 130 psi. This corresponds to evaporation temperature of about 7°C. Meanwhile, the discharge pressure was stable at 28 bar or 411 psi, which corresponds to condensation temperature of 48°C.

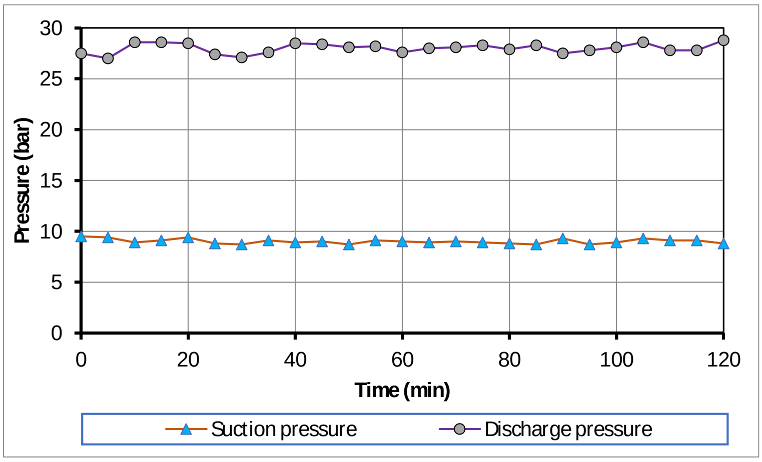

Fig. 3. Suction and discharge pressure

3.2 Suction and Discharge Temperature

The suction temperature measured by mounting sensor on the outer pipe wall (first method) at the suction line is averagely 16.2°C with a fluctuation from 14.3 to 18.1°C. By inserting sensor in the refrigerant flow (second method), the suction temperature was measured at averagely 11.1°C with a fluctuation from 9.8 to 12.5°C. In general, the first method gives the lower reading for suction line temperature. Averagely, a difference of 5.1°C was observed in this experiment. The higher temperature resulted by the first method is possibly caused by two factors: (1) convection from environmental air, and (2) heat conduction from compressor body through the suction pipeline. The outdoor air temperature is higher than that of refrigerant temperature and suction pipe temperature. Therefore, the suction pipe can absorb heat from the ambient air if the insulation is not good. Even if the insulation is good, the suction pipeline can still receive heat by conduction though the pipeline from the compressor which has a higher temperature than that of the suction line. As the experiment was carried out using a small capacity of air conditioner, the influence of heat flow from the ambient and compressor is dominant.

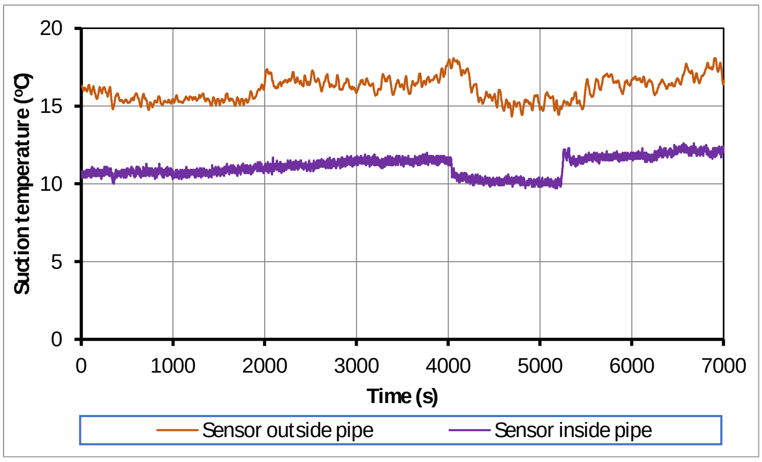

Fig. 4. Suction temperature measurement using sensor mounted on the outer wall pipe and sensor installed inside the pipe

The profile of discharge temperature is pictured in Figure 5. As can be seen, the measurement by sensor insertion to the refrigerant flow provides the higher discharge temperature than that of the mounted sensor on the outside pipe wall. An average of discharge temperature of 87.3°C was obtained when this parameter was measured using temperature sensor installed inside the pipe. When the sensor was clamped on outside pipe wall, the average discharge temperature was recorded at 69.4°C. A temperature difference of about 18°C was noted in this experiment. Again, the difference of the measurement results could be caused by environmental factor and heat conduction through the discharge pipe. The colder condenser causes the temperature of discharge pipe lower than that of refrigerant in the discharge line.

The different reading of temperature outside and inside pipeline has been confirmed by previous studies. Gorman *et al.,* [1] and Gebhardt *et al.,* [13] Using the case of ambient air temperature of 73°F and measurement result of pipe wall of 113.6°F, Gorman *et al.,* [1] calculated a temperature difference of 11.2°F.

The accuracy of the measurement inside the pipe was confirmed by previous publications. Setyawan *et al.,* [14] reported a range of suction temperature from about 9 to 11°C when the air conditioner was operated at outside air temperature from 32 to 38°C. Discharge temperature of about 98°C was reported by Esbrí *et al.,* [15] from their experiment with R134a and IHX at condensing temperature of 40°C and evaporating temperature of -4.7°C. Using R153A, the discharge temperature was found at about 93°C. Jiang *et al.,* [16] reported a range of discharge temperature of 80 to 82°C from an experiment using air conditioner using R410a equipped with condenser heat recovery. At outdoor air temperature of 35°C, Qv *et al.,* [17] reported discharge temperature of about 80, 90 and 98°C for their study using R410a, R22, and R32, respectively. By using evaporation temperature of -7.7°C for R134a and electronic expansion valve opening of 70% Panato *et al.,* [18] reported a discharge temperature up to 116°C. Lower discharge temperature in the range of 76 to 82 was reported by Setyawan [19] when an air conditioner performance was examined at outside wind velocity of 6.5 m/s under different wind direction. Using R410a and a mixture of R32 and R290 in an air conditioner equipped with finned tube condenser, Tian *et al.,* [20] reported average discharge temperature of 77.9 and 82.7°C, respectively. An average discharge temperature of about 79°C has also been reported by Setyawan and Badarudin [21] when an air conditioner was tested at the varied relative humidity from 40 to 70% and constant outdoor air temperature of 35°C.

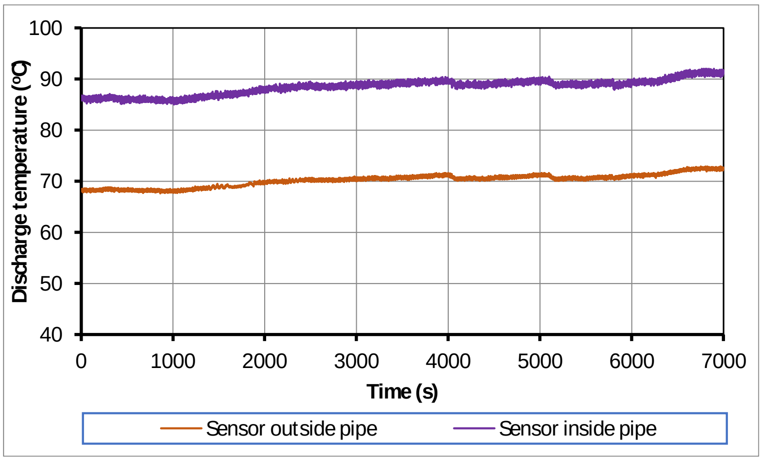

Fig. 5. Discharge temperature measurement using sensor mounted on the outer wall pipe and sensor installed inside the pipe

3.3 Power

In this experiment, the measured current was almost with a relatively small fluctuation from 3.9 to 4.1 A. The voltage was also recorded at almost constant value at 216 V. As a result, the input power to the air conditioner was obtained in the range of 830 to 874 Watts with an average of 853.2 Watts. The measured input power is presented in Figure 6.

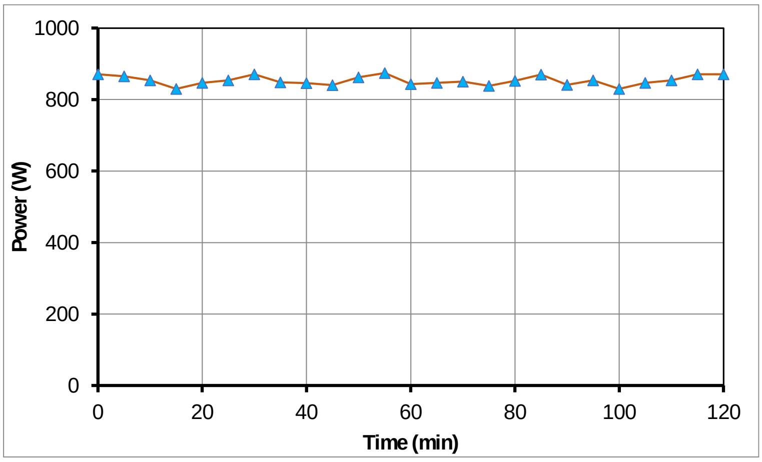

Fig. 6. Input power

If the first method of temperature measurement is used and the refrigeration cycle is analyzed using pressure-enthalpy diagram, the compressor work (W_k) can be calculated as

$$W_k = (h_2 - h_1)\dot{m} \tag{6}$$

where h_2 and h_1 are the enthalpy of refrigerant entering and leaving the compressor, respectively, according to Figure 1. The refrigerant enthalpy for Eq. (6) are

h_2 = 458.806 kJ/kg
h_1 = 427.485 kJ/kg

The swept volume of the compressor is

Q = 1.6513 m^3/h = 0.00046 m^3/s

The specific volume (v) and density (ρ) can be found in the pressure-enthalpy diagram, from which the mass flow rate can be calculated. The compressor work is then calculated to be 0.538 kW or 538 Watts.

If the results of the second method of temperature measurement are used, the parameters used in Eq. (6) are

h_2 = 477.707 kJ/kg
h_1 = 427.485 kJ/kg
Q = 1.6513 m^3/h = 0.00046 m^3/s
v = 0.0267 m^3/kg
ρ = 37.45 kg/m^3
$\dot{m}$ = 0.01718 kg/m^3

From which the work of compressor can be calculated to be 0.863 kW or 863 Watts.

The result of the second method of temperature measurement is more accurate than that of the first method. Standardized test based on ISO 5151: 2017 measured the input power to operate the similar capacity of air conditioner at averagely 920 Watt and 912 W [14,22]. It should be noted that the last two publications included power for operating the condenser and evaporator fans that consumed about 50 Watts.

3.4 Refrigerating Capacity

The refrigerating capacity of this experiment was calculated based on the measurement of pressure and temperature of suction and discharge line. From the measurements, the discharge pressure was averagely 29 bar absolute, which is equivalent to 426 psia. The suction pressure was averagely 10 bar absolute or 147 psia, which corresponds to evaporating temperature of 7.3°C. As discussed in Section 3.2, the average discharge temperature is 69.4°C when the sensor was mounted at the outer pipe wall and 87.3°C when the sensor was installed inside the pipe. To calculate the refrigeration capacity, Eq. (1) to Eq. (3) were employed.

In the experiment using sensor mounted on the outside pipe wall, if the ideal cycle is used, the following parameters of Eq. (1) to Eq. (3) will be obtained

h_1 = 427.485 kJ/kg
h_4 = 284.124 kJ/kg
Q = 1.6513 m^3/h = 0.00046 m^3/s
v = 0.0267 m^3/kg
ρ = 37.45 kg/m^3
$\dot{m}$ = 0.01718 kg/m^3

From Eq. (1), the refrigeration capacity is

q_e = 2.463 kW

When the sensor was installed inside the pipe, the parameter h_{out} remains constant while h_{in} slightly increases to 287.576 kJ/kg. Therefore, the enthalpy difference between the outlet and inlet of evaporator decreases from 143.36 kJ/kg to 139.91 kJ/kg. This gives the refrigeration capacity of the evaporator to 2.404 kW. It means that the capacity is lower when the second method of temperature measurement is used.

3.5 COP

The COP is calculated using Eq. (5). As the input power and cooling capacity have been obtained, the COP can be calculated. Based on the first method of temperature measurement, the COP of the air conditioner is 4.47. If the data from the second method is used, the COP is 2.79. The latest result is in a good agreement with the previous data. Setyawan *et al.,* [14] reported a COP of about 2.81 when the similar air conditioner was evaluated under standardized test at 34°C dry bulb temperature and 22°C wet bulb temperature of outdoor air. Different COP of 2.99 for an air conditioner with R410a and 2.78 for air conditioner with a mixture of R290 and R23 were reported by Tian *et al.,* [20]. Meanwhile, Mitrakusuma *et al.,* [22] reported a COP of about 2.62 from an air conditioner test at outside air dry-bulb temperature of 34°C and moisture content of 11.8 g water vapor/kg of dry-air.

4. Conclusions

An experiment to evaluate the performance of an air conditioner has been accomplished using two methods of temperature measurements, i.e., by mounting sensors on the outer pipe wall and by inserting sensor inside the pipe in the refrigerant flow. Important findings were obtained in this experiment.

In general, the suction temperature is lower when the sensor is installed inside the pipe than that of sensor is installed on the outer wall of pipeline. A difference of about 5°C was found from the two methods of temperature measurement.

In discharge temperature measurement, the temperature difference of the measurement using the first and second method reaches 18°C, in which the second method gives the higher result and better accuracy than that of the first. Consequently, the analysis of coefficient of performance (COP) using the second method gives the better result. The accuracy of the second method has been confirmed by the previous publications.

Two possible factors affecting the reading of temperature are environmental factor and heat conduction through the pipeline. Therefore, it is recommended that the two factor should be minimized when temperature measurements are carried out at the pipe outer wall.

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