

The Effect of Refrigerant Charge and Outdoor Temperature on the Condenser and Evaporator of a Split-Unit Type Air Conditioner Using R22 Refrigerant

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Abstract. To maintain the temperature setup on an air conditioner, the compressor will use more or less energy based on the outdoor temperature. Therefore, there is a need to understand the performance of the air conditioner if the outdoor temperature is varied. In this research, a used small capacity split-unit air conditioner using R-22 refrigerant is used to study the effect of outdoor temperature on the performance of the air conditioner. From the results, it can be understood that lower outdoor temperature requires less work from the compressor. The cooling capacity and coefficient of performance drop as the outdoor temperature increases.

1 Introduction

The air conditioner is commonly used to create a comforting environment inside buildings. For residential, the air conditioner is known to be one of the major electrical energy consuming appliance [1, 2]. In 2008, U.S. Department of Energy reported that 40% of total U.S. energy is consumed in commercial buildings and residential[3]. Among numerous types of the air conditioner, the split-unit type air conditioner is commonly used in residential due to its simplicity and flexibility [4].

In any refrigeration cycle, there are four main components involved: the compressor, condenser, a metering device (expansion device) and evaporator. These components are vital, and each has its own function to ensure the refrigerant completes its cycle to produce the desired cooling effect. Fig. 1 shows a typical refrigeration cycle with all components labelled in the correct sequence and position [5]. Technically, an ideal refrigeration cycle can best be illustrated with a Pressure-Enthalpy (P-h) diagram as per Fig. 2 (a) [5].

However, the ideal refrigeration cycle is a general in nature, but a typical cycle works in slight different behaviour. Fig. 2 (b) shows the typical refrigeration cycle that is always encountered practically in operation [5]. At D (compressor discharge), a pressure drop will typically occur as the refrigerant flows into a condenser, but the enthalpy amount remains.

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The enthalpy in the superheated gas is removed as in D' to E. In E, the refrigerant reaches saturated vapour point and begins to change from pure vapour into liquid and reach pure saturated liquid at A, releasing heat and enthalpy to outdoor along the process. The saturated liquid will further be releasing its enthalpy and further subcooled turns into pure liquid (A to A'). While, the line D' to A, actually is not as straight as in the diagram due to the occurrence of pressure drop as the refrigerant flows into the condensing coil as well as the loss in temperature because of dissipation of heat.

In an ideal cycle, the refrigerant enters the compressor in the saturated vapour state. However, in a typical system, it is normal that the refrigerant leaves the evaporator coil in 'slightly' superheated to ensure no liquid enters the compressor to avoid damage to the component. Another significant pressure drop occurs from C' to S' as the refrigerant flows through the suction line into the compressor, without any change in enthalpy. Similar in D' to A, the B' to C' line is also not straight in actual due to the pressure drop through the evaporator coils, but the losses are considered small.

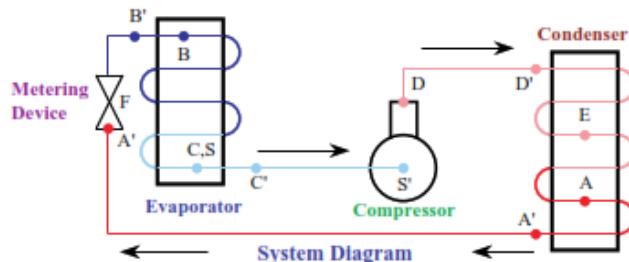


Fig. 1. Schematic diagram of air conditioning system [5].

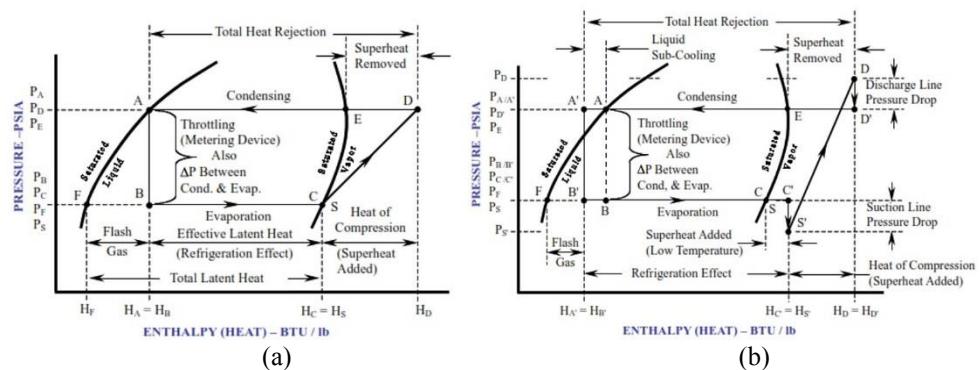


Fig. 2. Pressure-Enthalpy (P-h) diagram of: (a) an ideal refrigeration cycle, (b) a typical refrigeration cycle [5].

Generally, the sub-cooling definition is the difference between the saturation temperature (T_s) corresponding to the pressure on the condenser exit and the refrigerant temperature, as shown in Eq. (1). Here, T_s is the saturation temperature of the refrigerant, and T_{cond} is the temperature of the refrigerant exiting the condenser.

$$\text{Subcool} = T_s - T_{cond} \quad [^{\circ}\text{C}] \quad (1)$$

Superheat is defined as the difference between the saturation temperature (T_s) corresponding to the pressure on the evaporator exit and the evaporating temperature, as shown in Eq. (2). Here, T_{eva} is the temperature of the refrigerant exiting the evaporator. Superheat value is crucial to assure that the refrigerant is utterly changed to vapour state.

Otherwise, the existence of liquid would damage the compressor. Therefore, the superheat value must be above 0°C.

$$\text{Superheat} = T_{\text{eva}} - T_s \text{ [°C]} \quad (2)$$

As mentioned above, the refrigerant that leaves the evaporator and enters the compressor must be in saturated vapour or superheated vapour state. Hence, it is important to clarify the effect of refrigerant charge and outdoor temperature on the condenser and evaporator. In this research, the refrigerant charge will be varied from 80% to 120%, while the outdoor temperature will be varied from 30°C to 36°C.

2 Methodology

An experiment setup consists of a split-unit air conditioner, and appropriate measurement tools to measure temperature and pressure was designed and fabricated to clarify the superheat and subcool. Fig. 3 shows the schematic diagram of the experimental setup.

The Air-Conditioning & Refrigeration Institute (ARI) Standard 210/240 has to be applied in any performance testing of unitary air-conditioning equipment [6]. All the tests conducted must be in accordance with the test methods and procedures as described in the standard so that the standard ratings can be verified. However, this study could not be performed to the ARI 210/240 standard due to limitations of this research equipment setup. Therefore, the manufacturer's data sheet is not comparable to the results of this study. However, the results would show a similar trend and able to provide information on the performance of the split-unit air conditioner. In this research, the blower fan was set at the lowest setting to provide more stable air flow, and the air-conditioner was set to 26°C.

In this research, the experiment work utilised a standard 1.5 HP, 3.81 kW cooling (13,000 Btu/hr) rated used split-unit type air conditioner (2012 model). The working refrigerant gas for this unit is an R-22 refrigerant. The setup included sensors in specific locations to measure parameters such as dry-bulb and wet-bulb temperatures, refrigerant pressure (low and high), pipeline temperatures, air flow rate, as well as electrical power input.

To simulate the effect of different outdoor temperature, the temperature on condensing unit was be varied by using three-stage coil heaters with 1.5 kW power input to achieve specific outdoor temperature (see Fig. 4). Ductwork was attached at the unit's outlet with the dimension of 0.635 x 0.084 m cross section to measure the air flow rate of the indoor unit. A modification was done by installing a port for manifold gauge attachment for the purpose of high-pressure side's reading.

The refrigerant charge and outdoor temperature were varied from 80% to 120%, and 30°C to 36°C, respectively.

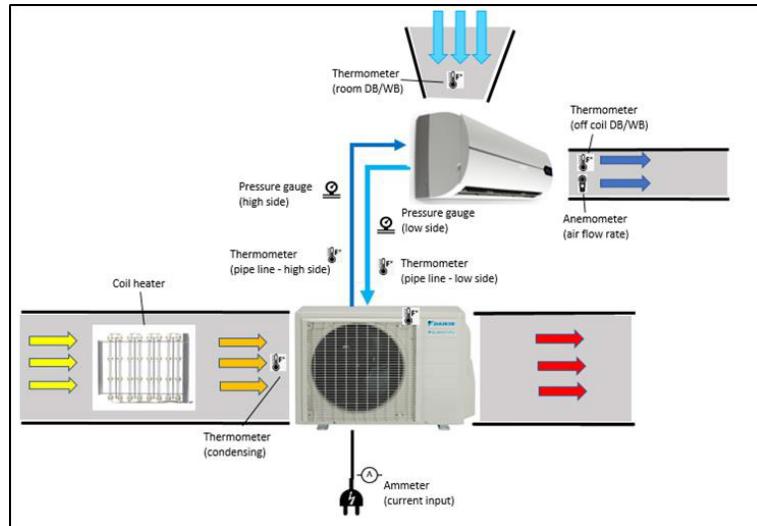


Fig. 3. Schematic diagram of the experiment setup.



Fig. 4. Three stages of coil heater installed in the outdoor unit's ductwork.

3 Results and discussions

Fig. 5 and 6 show the results of superheat as a function of refrigerant charge and outdoor temperature, respectively. As can be seen from these figures, the level of superheat showed a decreasing trend with the increase of refrigerant charge. The superheat levels in this work were highest at 80% charged (18.1 to 19.0°C). The lowest superheat recorded were at 120% charged (1.5 to 2.3°C). As mentioned in Chapter 2.5, superheat is defined as the difference between the saturation temperature (T_s) corresponding to the pressure on the evaporator exit and the evaporating temperature. In this work, evaporating temperature is the pipeline temperature measured after the evaporator coil before entering the compressor.

Superheat level was highest at 80% charge. The level then dropped with the increase of refrigerant charge, recording the lowest value at 120% charge. At a lower refrigerant charge, the superheat level was high because the evaporator was starved of refrigerant. All the refrigerant has evaporated early and completely changed to vapour state long before reaching

the middle part of the evaporator coil. Then the refrigerant continued to superheat and gain temperature, causing the high level of superheat. This condition would cause a loss in the system's capacity. Meanwhile, at a higher refrigerant charge, there was an increase of the refrigerant mass flow rate. The superheat level was getting low because of an excess of refrigerant, overfeed the evaporator. The refrigerant fully evaporated at the end of the evaporator coil and therefore gain only minimal temperature, causing the low level of superheat. The refrigerant must fully transform to vapour prior to entering the compressor to prevent refrigerant flood back to the compressor and damaging the component.

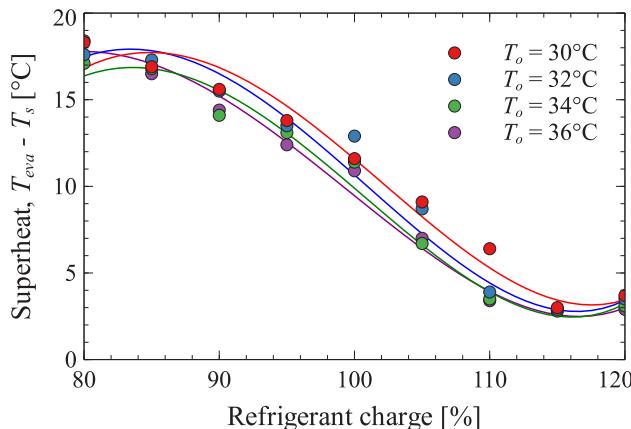


Fig. 5. Superheat, $T_{eva} - T_s$ as a function of refrigerant charge.

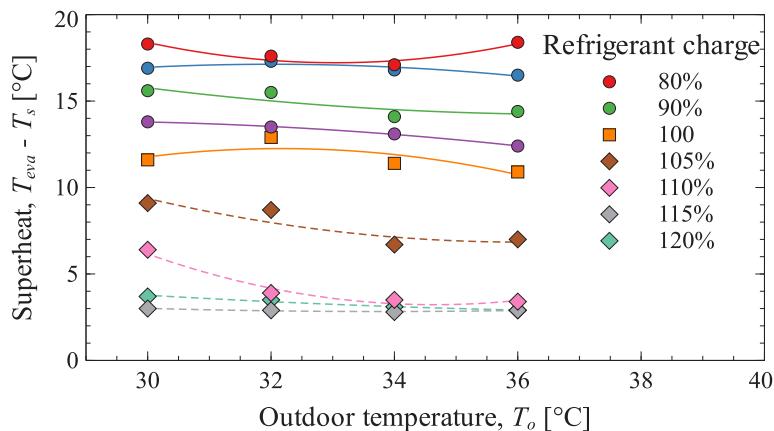


Fig. 6. Superheat, $T_{eva} - T_s$ as a function of outdoor temperature.

The results of subcooling as a function of refrigerant charge and outdoor temperature are shown in Fig. 7 and 8, respectively. From these figures, it is clear that the value of subcooling increased with the increase of refrigerant charge. As mentioned in section 1, subcooling is defined as the difference between the saturation temperature (T_s) corresponding to the pressure on the condenser exit and the refrigerant temperature. In this work, condensing temperature is the pipeline temperature measured after the condenser coil just before entering the expansion valve.

The subcool level was lowest at 80% charge (5.9°C). Then the value increased with the increase of refrigerant charge and recorded the highest value of 14.9°C at 120% charge. At a lower refrigerant charge, the low subcooling was due to the low amount of refrigerant spend so little time in the condenser, and the condenser did not receive enough refrigerant vapour to condense to liquid. Meanwhile, at a higher refrigerant charge, the subcooling was high due to excess of refrigerant accumulated in the condenser. The refrigerant remained longer in the condenser and continued to lose temperature and therefore increasing the subcooling.

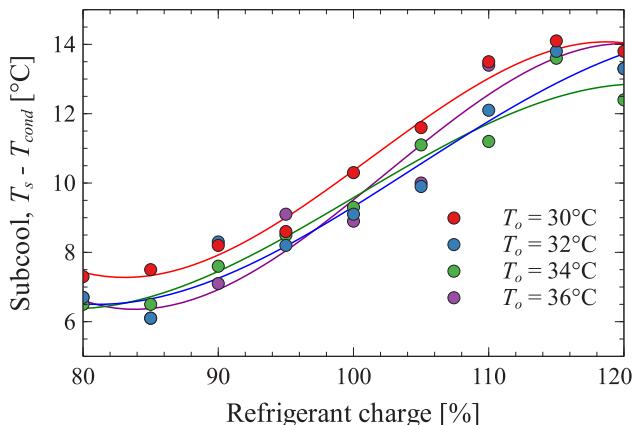


Fig. 7. Subcool, $T_s - T_{cond}$ as a function refrigerant charge.

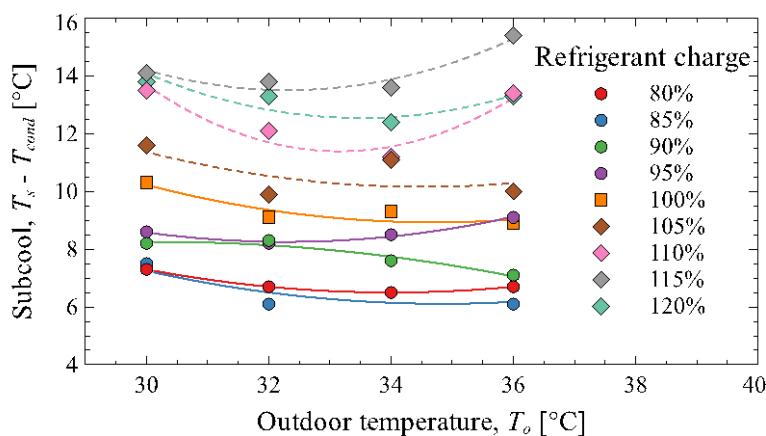


Fig. 8. Subcool, $T_s - T_{cond}$ as a function outdoor temperature.

4 Conclusion

An experiment was conducted to determine the effect of refrigerant charge and outdoor temperature on the condenser and evaporator. As previously mentioned in section 3, since the experiment work was not conducted in accordance with the ARI 210/240 standard, the results could not be compared directly to the manufacturer's data. However, it provides information on how the system performs and react with an improper refrigerant charge and changes of outdoor temperature. The conclusions are as follows:

1. For all outdoor temperatures, the superheat maxed at 80% refrigerant charge and lowest at 120% charge. The refrigerant temperature is above saturation temperature before entering compressor, which indicates the refrigerant is totally in the superheated vapour state.
2. The subcool level was lowest at 80% charge (5.9°C). Then the value increased with the increase of refrigerant charge and recorded the highest value of 14.9°C at 120% charge.

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