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NUMERICAL INVESTIGATION ON EJECTOR AS AN EXPANSION DEVICE USING R290 IN RESIDENTIAL AIR CONDITIONER FOR VARIOUS COOLING CAPACITY

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ABSTRACT

Typically, the residential air conditioner uses capillary tube as an expansion device. The friction between refrigerant flow and pipe wall, and also the changing of the velocity along capillary tube cause energy loss during expansion. The pressure drop from the condenser to the evaporator caused by capillary tube is considered isenthalpic process. An ejector as an expansion device can be used to recover energy loss during expansion process. Many researchers reported that the use of an ejector as an expansion device in vapor compression refrigeration cycle (VCRC) may lead to increase in the system performance. In this study, the numerical investigations were carried out on the residential air conditioners using the VCRC for various cooling capacity with R290 as working fluid. At present, the working fluid of R22 is widely used as refrigerant in residential air conditioners. Because R22 has a high global warming potential (GWP), as a result it must be phased out in the near future. Researchers recommended R290 (propane) as a substitute refrigerant for R22. As a natural refrigerant, R290 is abundant and relatively cheaper than that of R22. In addition, many studies reported that retrofit from R22 to R290 in air conditioner may result increase in coefficient of performance (COP). As a result, this study investigates the use of R290 for replacing R22 in residential air conditioner for various cooling capacity, viz. 2.5, 3.8 and 5.0 kW or the compressor capacity of 1, 1.5 and 2 HP. Three equations, i.e., conservation equations of mass, momentum and energy were applied to determine physical properties on each section of the ejector and the performances of the air conditioners. The main geometrics parameter of an ejector is area ratio (AR), which is defined as the ratio between the cross-sectional areas of mixing chamber and motive nozzle. The results showed that the diameter of motive nozzle is constant with the increase in ambient temperature, whereas the mixing chamber diameter slightly increases with the increase in ambient temperature. Meanwhile, the area ratio of ejector decreases with the increase in compressor capacity. In addition, the COP improvements of air conditioners are 4.94, 12.24 and 20.28% for ambient temperature of 30, 35 and 40 ^{o}C, respectively.

Keywords: cooling capacity, residential air conditioner, ejector, COP improvement.

INTRODUCTION

Many researchers have performed investigation both numerically and experimentally that the use of ejector as an expansion device yielded COP improvement on air conditioners [1-5]. The COP improvement depends on the geometric dimensions of an ejector. In other words, the size of an ejector is influenced by the cooling capacity of air conditioner. In the market, to represent the cooling capacity of residential air conditioner is used its compressor capacity, such as 1, 1.5, and 2 HP (0.75, 1.1 and 1.5 kW). In this study, the cooling capacity is represented by the compressor capacity. Furthermore, the geometric dimension of ejector for each capacity also must be different.

Nowadays, at least there are five refrigerants that are available in the market for residential air conditioners, i.e., R22, R410A, R404A, R407C and R290. Working fluid of R22 as a family of HCFCs (hydro-chlorofluorocarbons) is the most widely used as refrigerant in residential air conditioners. Meanwhile, R410A, R404A and R407C as family of HFCs (hydro-fluorocarbons), are projected to replace R22 due to environmental issues. Although both refrigerant families above have zero ozone depletion (ODP), however still have the high of global warming potential (GWP), as shown in Table-1. Because R290 (propane) has zero ODP and very low GWP, as shown in Table-1, this refrigerant is recommended by researchers [4-6] to replace R22 and/or other refrigerants. The aim of the present study is to investigate the geometric dimension changes on the ejector due to the cooling capacity changes on residential air conditioner using R290 as working fluid. In addition, R290 has the lowest GWP, and its NBP (normal boiling point) is also the nearest to the R22, as shown in Table-1.

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Table-1. Environmental properties of the refrigerants.

No	Refrigerant	NBP (°C)	GWP	ODP
1.	R22	-40.8	1700	0.05
2.	R410A	-51.6	1725	0
3.	R404A	-46.6	3800	0
4.	R407C	-43.8	1610	0
5.	R290	-42.1	3	0

EJECTOR AS EXPANSION DEVICE

Most residential air conditioners utilize vapor compression refrigeration cycle (*VCRC*) as its working principle. A simple VCRC has four major components, namely a compressor, a condenser, an expansion device and an evaporator, as shown in Figure-1 (a). The residential air conditioner usually uses a capillary tube as an expansion device. If the expansion device is replaced by an ejector, the cycle of VCRC becomes as shown in Figure-1(b). Furthermore, Figure-1 (c) shows P-h diagram of simple cycle and ejector as an expansion device. It can be seen from Figure-1(c) that the use of ejector as an expansion device decreases the compressor work, viz., from 1a to 2a becomes 1b to 2a, because the enthalpy difference between 1a to 2a is higher than that of 1b to 2a. As a result, it is expected the COP of ejector as an expansion device will be higher than that of simple cycle.

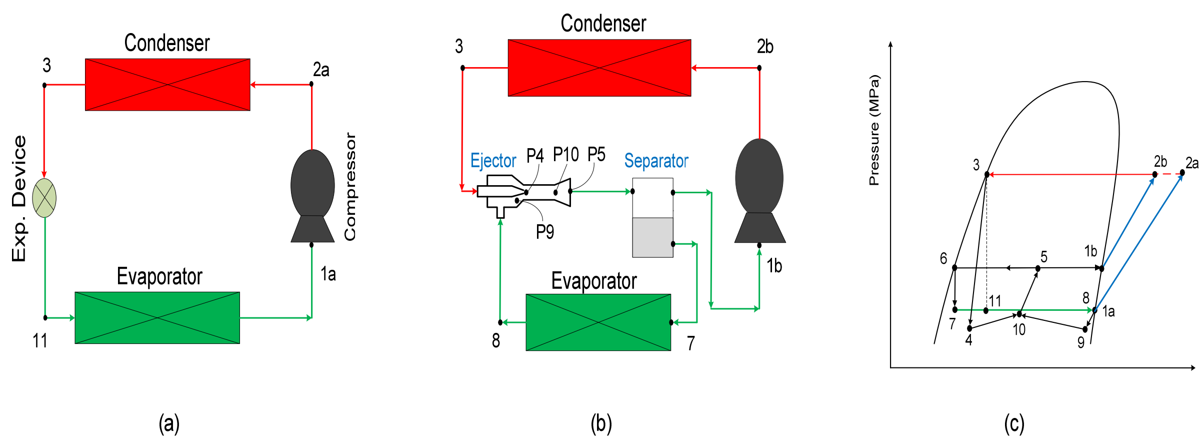

Figure-1. Schematic and P-h diagrams of a simple and an ejector as expansion device of vapor compression refrigeration cycle.

THERMODYNAMIC ANALYSIS

In order to calculate the performance of VCRC using ejector as an expansion device, the properties of refrigerant in each point in the P-h diagram in Figure-1(c) has to be determined. Three equations, viz., conservation of mass, momentum and energy will be applied to determine refrigerant properties in each point in the P-h diagram. The equations of mass, momentum and energy conservations are shown in equations. (1), (2) and (3), respectively [6, 7].

$$\sum \rho_i u_i a_i = \sum \rho_o u_o a_o \tag{1}$$

$$P_i a_i + \sum \dot{m}_i u_i = P_o a_o + \sum \dot{m}_o u_o \tag{2}$$

$$\sum \dot{m}_i (h_i + \frac{u_i^2}{2}) = \sum \dot{m}_o (h_o + \frac{u_o^2}{2}) \tag{3}$$

To apply these equations on the ejector cycle, the assumptions must be defined. The assumptions in this study refer to Sumeru *et al.* [1], i.e.:

a. There is no heat transfer except in the evaporator and condenser;

b. Properties and velocities are constant over the cross-section (one dimensional analysis).

c. The refrigerant condition is in thermodynamic quasi-equilibrium.

d. There is no pressure drop along the evaporator and condenser.

e. There is no wall friction between refrigerant and copper tube.

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f. There is no subcooling and superheating in the system, or in other words, the refrigerant conditions at the outlet of the evaporator and the condenser are saturated.

g. Deviation from adiabatic reversible processes for each section of the ejector is calculated using efficiencies.

Based on manipulation of the equations. (1) – (3) and assumptions, the diameters of motive nozzle (*mn*) and mixing chamber (*mc*) can be calculated using equations. (4) and (5), respectively.

$$D_4 = \sqrt{\frac{4\dot{m}_{cond}}{\Pi \rho_4 u_4}} \tag{4}$$

$$D_{10} = \sqrt{\frac{4(\dot{m}_{cond} + \dot{m}_{evap})}{\Pi \rho_{10} u_{10}}} \tag{5}$$

Meanwhile, area ratio (AR) of an ejector is defined by equation. (6).

$$AR = \frac{A_{mc}}{A_{mn}} = \frac{D_{10}^2}{D_4^2} \tag{6}$$

where A_{mc} and A_{mn} are cross-sectional areas of mixing chamber and motive nozzle, respectively.

Furthermore, the COPs of standard and ejector cycle are determined using equations. (7) and (8), respectively.

$$COP_{std} = \frac{(h_{1a} - h_{11})}{(h_{2a} - h_{1a})} \tag{7}$$

$$COP_{ejc} = \frac{\dot{m}_{evap}}{\dot{m}_{cond}} \frac{(h_8 - h_7)}{(h_{2b} - h_{1b})} \tag{8}$$

where h_{2a} and h_{2b} are determined using equations. (9) and (10), respectively.

$$h_{2a} = h_{1a} + \frac{(h_{2a,is} - h_{1a})}{\eta_{comp}} \tag{9}$$

$$h_{2b} = h_{1b} + \frac{(h_{2b,is} - h_{1b})}{\eta_{comp}} \tag{10}$$

where the compression isentropic efficiency (η_{comp}) is defined by equation. (11) [4].

$$\eta_{comp} = 0.874 - 0.0135 \frac{P_2}{P_1} \tag{11}$$

Furthermore, COP improvement due to the use of ejector in air conditioner, is determined using equation. (12).

$$COP_{imp} = \frac{COP_{ejt} - COP_{std}}{COP_{std}} \tag{12}$$

RESULT AND DISCUSSIONS

In this study, the values of motive nozzle and mixing chamber efficiencies are 0.9 and 0.8, respectively [5], whereas the evaporating temperature is 5°C. Figure-2 shows the effect of compressor capacity and ambient temperature on diameters of motive nozzle and mixing chamber. The figure shows that the diameters of motive nozzle and mixing chamber increase with increase in compressor capacity. However, the diameter of motive nozzle is constant with the increase in ambient temperature for certain compressor capacity. Meanwhile, the diameter of mixing chamber slightly decreases with the increase in ambient temperature.

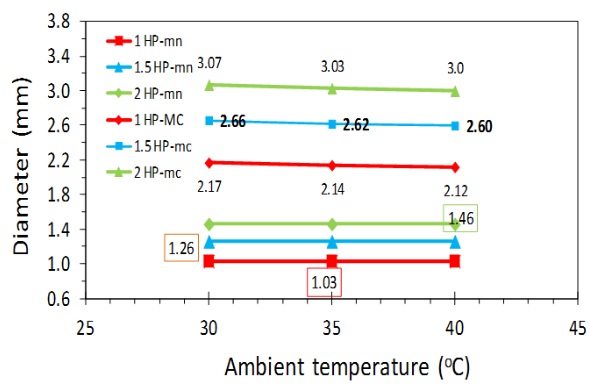

Figure-2. Diameters of motive nozzle and mixing chamber of ejector for various the air conditioners capacity and the ambient temperatures.

Figure-3 shows the area ratio of ejector for various the compressors capacity and the ambient temperatures. The figure shows that the area ratio decreases with the increase in ambient temperature. In addition, the figure illustrates that the area ratio decreases when the compressor capacity increases. It can be seen from Figure-3, the area ratio of 1 HP is higher than that of 2 HP.

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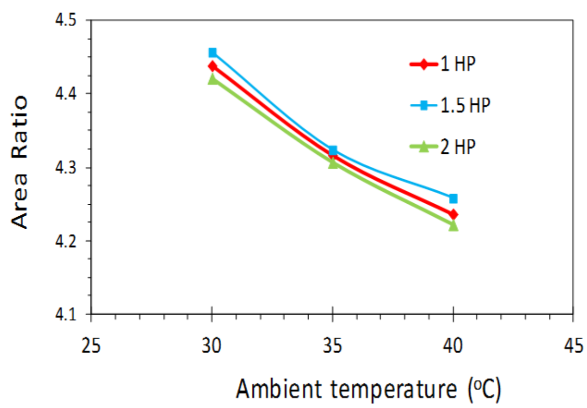

Figure-3. Area ratio of ejector for various the air conditioners capacity and the ambient temperatures.

According to equations. (7), (8) and (12), COP improvement due to the use of ejector as an expansion device is not influenced by the compressor capacity. As a result, the COP improvements for the compressor capacity of 1, 1.5 and 2 HP are the same, as shown in Figure-4. The figure shows that COP ejector is higher than that of standard cycle. The COP improvement increases with the increase in ambient temperature. The results of this study are similar to the numerical results performed by Sarkar [6].

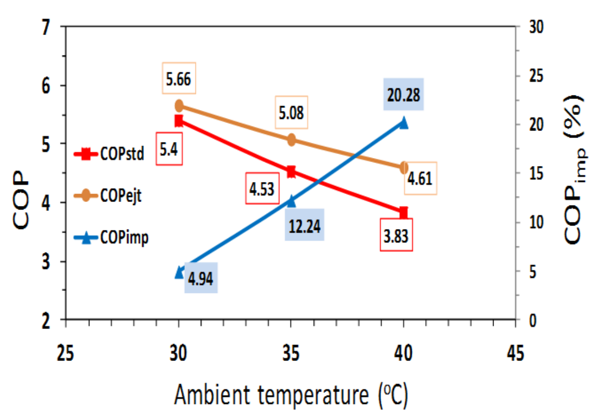

Figure-4. Comparison COP standard versus COP ejector and COP improvement for various ambient temperature.

CONCLUSIONS

Numerical approach on ejector as an expansion device in residential air conditioner for various cooling capacity has been investigated. The following main conclusions emerged from this investigation: 1. the diameter of motive nozzle increased with the increase in the capacity, however it was constant with the increase in ambient temperature; 2. The diameter of mixing chamber slightly decreased with the increase in ambient temperature; 3. The area ratio decreased with the increase in cooling capacity and ambient temperature.

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