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THE PERFORMANCES OF A MODIFIED EJECTOR AIR CONDITIONING CYCLE

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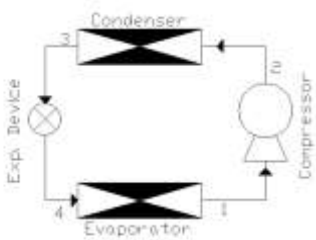
Graphical abstract



Abstract

Residential and commercial air conditioning systems have contributed to high electricity usage and cost in daily living. People nowadays look forward to environmental friendly products, as well as saving operating cost. Air conditioning system using ejector as two phase expansion valve was studied earlier to obtain better performance in terms of energy saving. The purpose of this study was to prove that ejector air conditioning system has better coefficient of performance (COP) than conventional air conditioning system. Two refrigerant cycles, including standard cycle and modified ejector cycle had been studied and their characteristics were investigated. Electrically heated ambient air was used to obtain higher ambient air temperatures. The experiments were run by using R22 and R290. The experiments were carried out by using standard cycle and modified ejector cycle system. On top of that, analyses were conducted on the results obtained from the experiments. Moreover, it had been proved that modified ejector cycle had higher COP than standard refrigeration cycle.

Keywords: Standard refrigeration cycle; standard ejector cycle; modified ejector cycle; coefficient of performance

Abstrak

Kediaman dan komersial sistem penghawa dingin telah menyumbang penggunaan elektrik yang tinggi dan kos dalam kehidupan harian. Orang pada masa kini kelihatan alukan mesra alam produk serta kos operasi penjimatan. Sistem penghawa dingin menggunakan pelenting dua injap pengembangan fasa telah dikaji sebelum ini untuk mendapatkan prestasi yang lebih baik dari segi tenaga menyimpan. Tujuan kajian ini adalah untuk membuktikan bahawa sistem pelenting penyaman udara mempunyai yang lebih baik pekali prestasi (COP) daripada konvensional sistem penghawa dingin. Dua kitaran penyejuk termasuk kitaran standard dan kitaran pelenting diubahsuai telah dikaji dan ciri-ciri mereka telah disiasat. Elektrik udara persekitaran dipanaskan telah digunakan untuk mendapatkan suhu udara ambien yang lebih tinggi. Kajian ini telah dijalankan dengan menggunakan R22 dan R290. Kajian ini telah menjalankan menggunakan kitaran standard dan kitaran pelenting diubahsuai sistem. Analisis telah dijalankan ke atas keputusan eksperimen. Ia membuktikan bahawa diubahsuai kitaran pelenting mempunyai COP lebih tinggi daripada kitaran penyejukan standard.

Kata kunci: Kitaran penyejukan standard; kitaran pelenting standard; diubahsuai kitaran pelenting; pekali prestasi

INTRODUCTION

Typical vapor compression refrigeration cycle (VCRC) or conventional refrigeration cycle uses capillary tube, thermostatic expansion valve, and other throttling devices to reduce refrigerant pressure from condenser to evaporator. Theoretically, the pressure drop is considered as an isenthalpic process, which is constant enthalpy of refrigerant. This isenthalpic causes dropping in cooling capacity in evaporator because energy is lost in the throttling process. To recover this energy loss, ejector plays a vital role in generating isentropic (constant entropy) condition in throttling process. Even so, the ejector refrigeration is still not widely used in commercial air conditioning system, especially split-type air conditioning system, which has been often used in households since it is yet to convince people using it. Hence, more analysis has to be done to prove that ejector refrigeration cycle is more efficient than standard/ conventional cycle.

1.1 Standard Cycle

Standard refrigerant cycle is commonly used in commercial air-conditioning system. It contains four basic components: evaporator, compressor, expansion device, and condenser. Figures 1 and 2 show the schematic diagram and the P-h diagram of standard cycle with two variables; KP and KI. Figure 1 shows the block diagram of a PI controller.

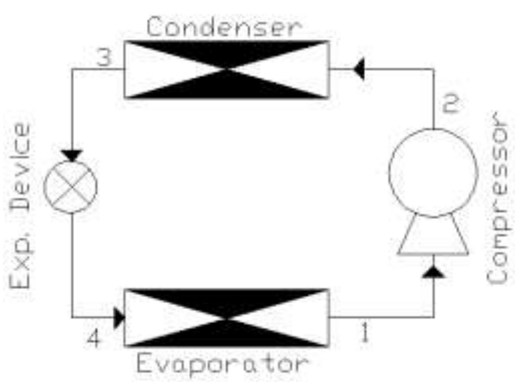


Figure 1 Schematic drawing of standard cycle

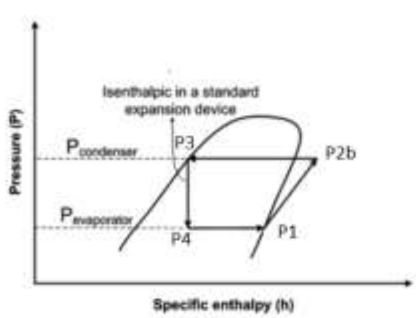


Figure 2 Schematic drawing and P-h diagram of standard cycle

1.2 Standard Ejector Cycle

Standard ejector cycle (SEC) is often used by researchers in improving coefficient of performance (COP). The throttling devices, such as capillary tube, are replaced by the two-phase ejector as an expansion device to reduce the throttling losses. Meanwhile, throttling in the ejector generates isentropic process with no entropy generation. As a result, the COP could be improved. Different from standard refrigeration cycle, standard ejector cycle contains ejector and separator. The ejector has an inlet for primary fluid to go into the ejector, and the secondary fluid is sucked at the suction chamber in the ejector, based on Bernoulli's principle. The mixed fluids from the outlet of the ejector will flow into separator to separate liquid refrigerant and vapor refrigerant. Vapor refrigerant is sucked by compressor at suction line, while liquid refrigerant goes through evaporator for heat exchange with indoor temperature. Figures 3 and 4 show the schematic diagram of standard ejector cycle and the standard ejector cycle on p-h diagram respectively.

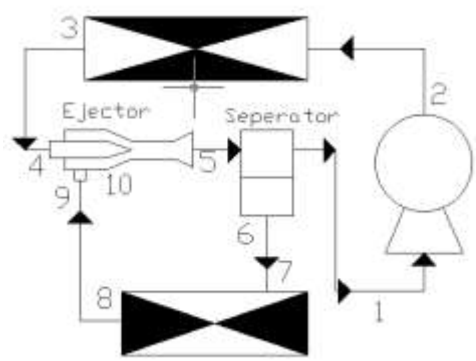


Figure 3 Schematic drawing of standard cycle

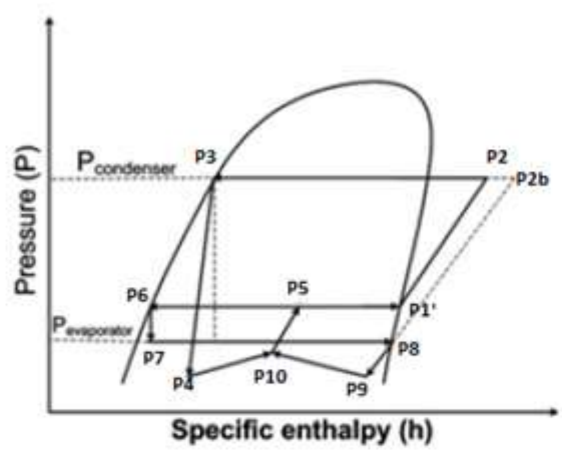


Figure 4 P-h diagram of Standard Ejector Ejector Cycle

1.3 Modified Ejector Cycle

Modified ejector cycle is a modification from the standard ejector cycle, which theoretically has better performance. The difference between modified ejector cycle and standard ejector cycle is in the type of separator used. In the SEC, the separator has an inlet that flows the refrigerant from the ejector, and two outlets that flow out the vapor refrigerant to compressor suction and liquid refrigerant to the evaporator. Meanwhile, the modified ejector cycle has a separator that only has an inlet and one outlet. The outlet is connected to the evaporator, while the refrigerant is sent to suction inlet of ejector and to compressor after exchange of heat in evaporator. Figures 5 and 6 show schematic and P-h diagrams of modified ejector cycle respectively.

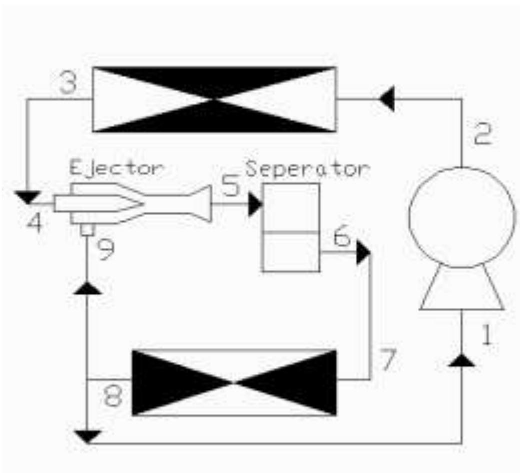


Figure 5 Schematic diagram of a modified

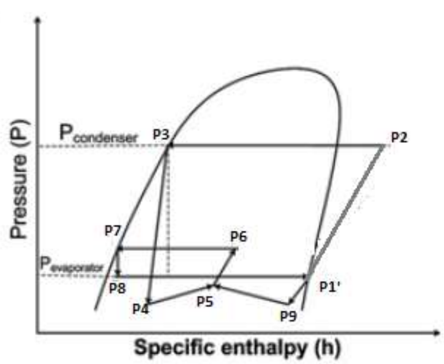


Figure 6 P-h diagram of a modified ejector ejector cycle

2.0 RESEARCH METHODOLOGY

The apparatus was designed in combination of three refrigeration cycles. Experiments were conducted by adjusting the flow of refrigerant by valves. For standard cycle, the valves were shut off to restrict the flow into the ejector. Meanwhile, for standard ejector cycle, the valves were shut off to restrict the flow into capillary tube. For modified ejector cycle, two valves were shut off for flow to capillary tube and flow to compressor after separator. The schematic diagram of apparatus setup is shown in Figure 7.

The schematic diagram shown in Figure 7 consists of thermocouples and pressure gauges. Thermocouples recorded the temperature values, such as discharge temperature (T1), from condenser to inlet of ejector (T2), from evaporator to suction chamber of ejector (T3), after outlet of ejector (T4), before evaporator (T5), and suction temperature (T6). The temperature data were transmitted from thermocouples to Pico data logger, then to computer (Picolog software), while pressure values were measured at discharge line (P2), after condenser (P1), after ejector (P3), and suction line (P4) by using pressure gauges. Besides, precautions were taken while recording the readings to ensure that the flowmeter was stable and the indoor temperature achieved the desired temperature. Moreover, while running experiments from standard cycle to another cycle or vice versa, the system was shut down by using thermostat. After switching the refrigerant path by adjusting the respective valves, the air-conditioner was then re-operated.

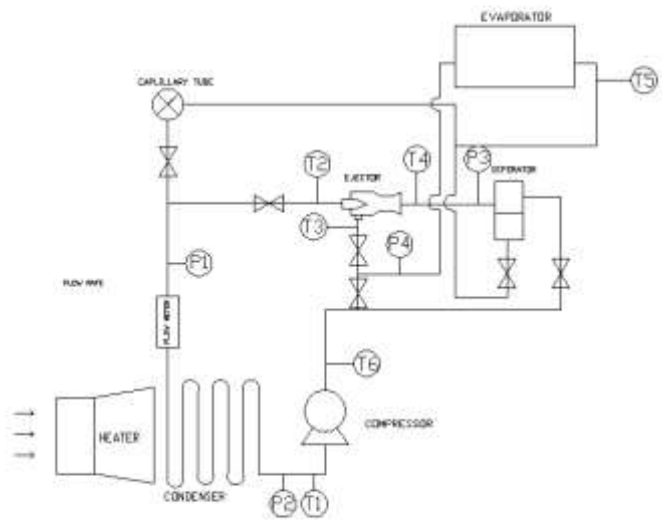


Figure 7 Schematic diagram of the modified ejector refrigeration cycle.

Other than that, in order to obtain different ambient air temperatures as variables, heater air was used. 1000 watt of electrical heater was installed at a hollow box and a duct was connected between the condenser and the heater. The air passed through the heater and was sucked by the condenser fan. In addition, refrigerants R22 and R290 were used in this experiment. Evaluations on refrigerant charge were done before the experiment was conducted.

Calculation of COP for each cycle was different. For standard cycle, ratio of cooling capacity was applied to work for compressor to get the COP, while ejector refrigeration cycle had to include entrainment ration into the calculation. For standard cycle,

$$COP_{st} = \frac{h_1 - h_4}{h_2 - h_1} \tag{1}$$

For COP of standard ejector cycle, mass flow rate of primary fluid and secondary fluid were determined to obtain the entrainment ratio,

$$entrainment\ ratio, \prod = \frac{\dot{m}_2}{\dot{m}_1} \quad (2)$$

$$COP_{ej} = \frac{(h_1 - h_{7'})}{(h_2 - h_1)} \times \prod \quad = \frac{(h_1 - h_{7'})\dot{m}_2}{(h_2 - h_1)\dot{m}_1} \quad (3)$$

ulation f entrainment ratio was different because the mixture in separator went through the evaporator, and then, it was sucked by a compressor and the remaining became secondary fluid.

$$COP_{ej} = \frac{(h_1 - h_{7'})\dot{m}_1 + \dot{m}_2}{(h_2 - h_1)\dot{m}_1} \quad (4)$$

COP improvement could be calculated to obtain the improvement of standard cycle to ejector cycle.

$$COP_i = \frac{COP_{ej} - COP_{st}}{COP_{st}} \quad (5)$$

3.0 RESULTS AND DISCUSSION

During the experiments, it had been discovered that standard ejector cycle for the air conditioning system was a failure. This was because there was freezing on the surface of copper piping around the suction line, after ejector and separator. The situation was considered as malfunction of the system and it was shut off immediately. It had been assumed that it was caused by the strong compressor that sucked the entire refrigerant (either vapor or liquid state) in the separator while there was low liquid refrigerant passing through the evaporator only. It means that the refrigerant mostly flowed in the compressor, condenser, ejector, and separator. Figure 8 shows what actually happened in refrigeration cycle of the standard ejector cycle.

3.1 Coefficient of Performance (COP) versus Time Taken

The COP values were calculated based on data obtained at stable condition during the experiments based on different refrigerants (R22 and R290) and different ambient temperatures (31°C and 36°C). Figure 9 shows COP versus time taken for refrigerant R22 in different ambient temperatures.

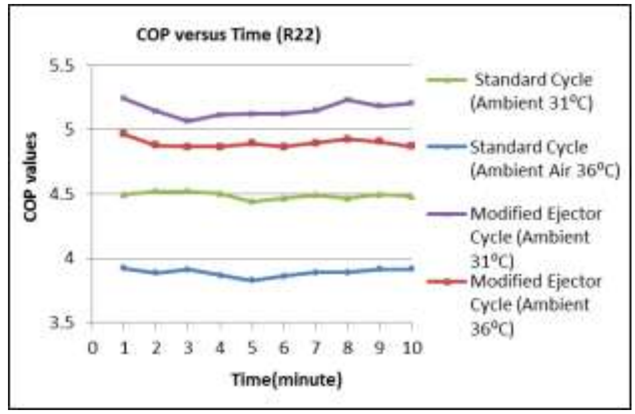


Figure 8 The actual refrigeration cycle in the standard ejector cycle

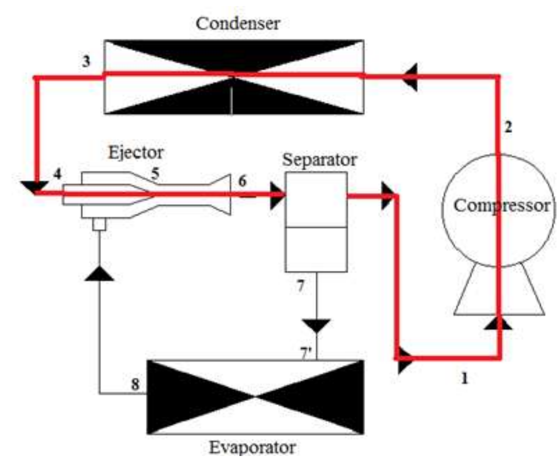


Figure 9 COP versus time taken for refrigerant R22

From Figure 9, it is clear that the COP values dropped when the experiments ran on higher ambient temperature even for standard cycle and modified ejector cycle. It can be explained based on thermal efficiency of Carnot's theorem,

$$COP_{carnot} = \frac{T_L}{T_H - T_L} \quad (6)$$

Note that all temperatures are expressed in Kelvin. From the equation, when the ambient temperature increased, the COP decreased when the indoor temperature remained the same. On the other hand, from Figure 10, the COP of modified ejector cycle was always higher than standard cycle for similar ambient temperatures when using refrigerant R22. Figure 10 shows COP versus time taken for refrigerant R290 in different ambient temperatures.

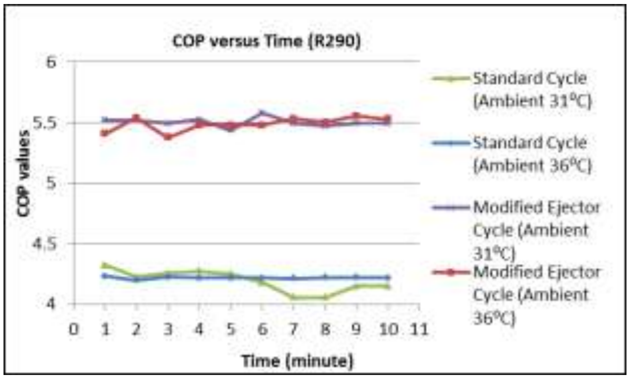


Figure 10 COP versus time in minute taken for refrigerant R290.

Figure 10 shows the experiments ran by using refrigerant R290 and it shows that COP of modified ejector was always higher than standard cycle since isenthalpic process or throttling process at capillary tube caused energy losses. The ambient temperatures do not have much effect on the COP of two cycles compared to the experiments that used R22. It might due to strong thermal properties of R290. Figure 11 shows the COP improvement for standard cycle and modified ejector cycle at different ambient temperatures.

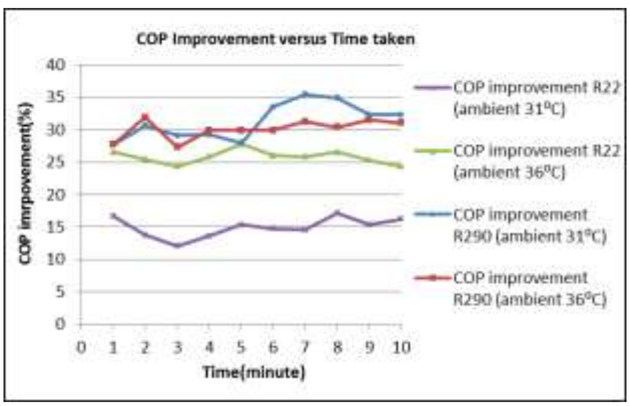


Figure 11 COP Improvement versus time taken for refrigerants (R22 and R290), and ambient temperatures (31°C and 36°C).

From graph shown in Figure 11, the overall COP improved from standard cycle to modified ejector cycle. COP Improvement ranged from 12% to 35%.

3.2 Coefficient of Performances (COP) Versus Ambient Temperature

Figures 12 and 13 show performances versus ambient temperatures with different refrigerants in standard cycle and modified ejector cycle.

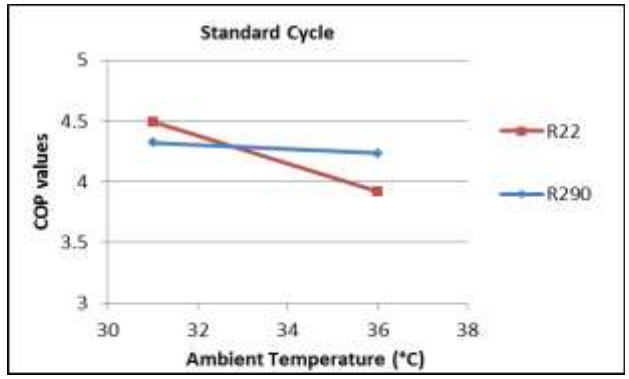


Figure 12 COP versus ambient temperature with different refrigerants in standard cycle

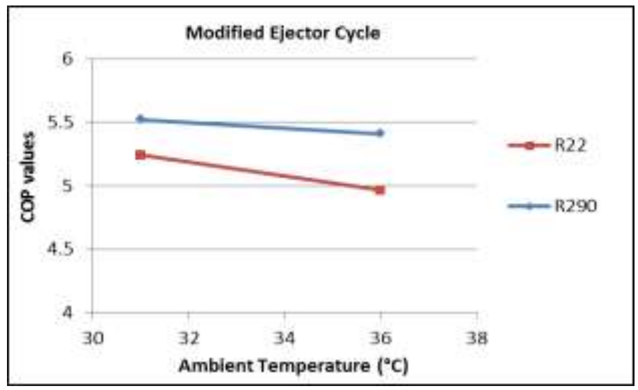


Figure 13 COP versus ambient temperature with different refrigerants in Modified Ejector Cycle

From the above figures, the COP was reduced at higher ambient temperature at 36°C for both refrigerant, either in standard cycle or modified ejector cycle.

Meanwhile, Figures 14 and 15 show performance versus ambient temperature in different refrigeration cycles by using refrigerants R22 and R290 simultaneously.

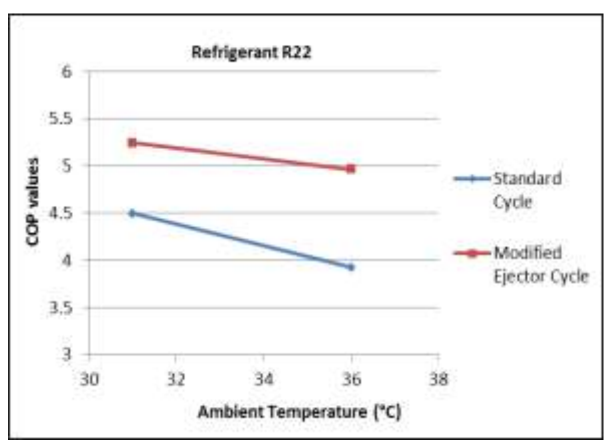


Figure 14 COP versus ambient temperature in different refrigeration cycles by using refrigerant R22

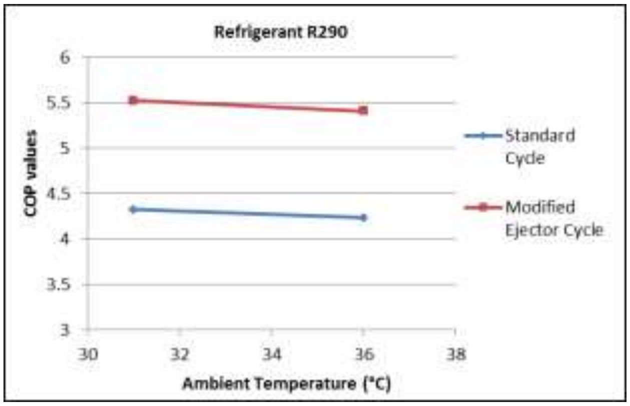


Figure 15 Performance versus ambient temperature in different refrigeration cycles using refrigerant R290

However, the COP did not reduce significantly when the system used R290 as compared to R22. This could be explained with the molecular size of R290 (44.1g/mole), which was smaller than R22 (86.5g/mole). Small molecular size directly leads to high specific heat, whereas higher ambient temperature at 36^{0}C did affect much during the stage of refrigerant cooling at condenser since the refrigerant with high specific heat could cool at a normal rate.

4.0 CONCLUSION

As a conclusion, the results showed that the modified ejector cycle displayed more efficiency than conventional cycle. More variables and factors, such as ambient temperature and refrigerants, were added in the experiments to prove that COP of modified ejector cycle was higher than the conventional cycle. This experiment also revealed that refrigerant R290 was better than R22 since COP with R290 was higher than R22. It also showed that at higher ambient air temperatures, the COP of the cycle decreased.

Meanwhile, the standard ejector cycle failed in running this system. More researches and studies need to be carried out to identify the reasons. Lastly, more studies and researches have to be conducted on this system so that it could be applied widely in the industry and contribute to the society. Moreover, the society is more concerned about global warming and green house issues, as they demand and welcome environmental friendly products. Anyway, this is a step towards greater contribution.

Acknowledgement

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