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Effect of Different Refrigerant Injection Techniques on Heat Pumpcycle Performance

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ABSTRACT

Refrigerant injection techniques are considered as modifications to vapor compression refrigeration systems to improve the performance of these systems when operating at high or low ambient temperatures. In this study a liquid and vapor refrigerant injections were implemented using heat exchangers arrangement. An investigation to the effects of these techniques on the performance of refrigeration cycle was conducted**.** A decrease in discharge temperature was obtained using hybrid injection cycles from 20% to 19% when the ambient temperature varies from 14°C to 8°C. Also the decrease in pressure ratio varied from 24% at an ambient temperature of 14°C to 18% at 8°C. The enhancement in performance factor varied from 35% at 14 °C to 28% at 8 °C.

Keywords: heat pump, vapour injection, liquid injection.

تأثير حقن مائع التثليج بتقنيات متعددة على اداء مضخة حرارية

الخلاصة:

تعد تقنية حقن مائع التثليج احد انوع التحويرات التي تم اجراءها على منظومة التثليج الانضغاطية، وخاصة تلك التي تعمل عند ظروف جوية قاسية ذات درجات حرارة مرتفعة جدا او منخفضة جدا. استخدمت تقنية حقن سائل او بخار مائع الثليجباستخدام بعض المبادلات الحرارية. وتم اجراء دراسة استقصائية لمعرفة تأثير هذه التقنية على معامل اداء مضخة حرارية. ومن خلال النتائج العملية يمكن القول ان استخدام تقنية الحقن الهجينة (حقن سائل وبخار مائع التثليج في وقت واحد) يمكن ان تقلل درجة حرارة بخار التجهيز بمقدار 19 الى 20% عن تغير درجة حرارة المحيط من 14 الى 18 درجة مئوية. في حين ان انخفاض ضغط الدفع تراوح من 14 الى 18% عند درجة حرارة خارجية تساوي 8 درجات مئوية. وتراوح التحسين في 35% عند درجة حرارة خارجية تساوي 14 درجة مئوية الى 28% عند درجة حرارة خارجية تساوي 8 درجات مئوية.

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INTRODUCTION

The traditional cycle (One-stage vapor-compression systems) usually uses moderate compression ratios but the compression ratio increases when the system operates in severe weather conditions accompanied by a deterioration in the coefficient of performance. Thus for such severe conditions a resort to more advanced cycles is recommended such as liquid and vapor refrigerant injection cycles. The technique of liquid refrigerant injection have rapidly developed in recent years owing to their outstanding potential in enhancing the performance of refrigeration systems at severe weather conditions. It is a very effective method for controlling the compressor discharge temperature and increasing sub cooling effect of a refrigeration system at high ambient temperatures. There are many different methods of liquid injection techniques such as the injection into the hot gas stream in the discharge line, compressor suction line or directly into the sealed compressor pocket. The principle of liquid refrigerant injection into the compressor pocket is not a new concept, a number of patents have existed since 1946 for reciprocating compressors and later for rolling piston compressors (Holtzapple, 1989),and for screw compressors[1].Kang et al.[2]found that the liquid injection coupled with an accumulator exchanger was effective for maintaining adequate sub-cooling and controlling the compressor discharge temperature at high ambient temperatures. The vapour refrigerant injection is more advantages on vapor compression refrigeration cycle via controlling the super heating and increasing the sub cooling effects. Jaehyek et al.[3] measured and analyzed the effects of flash tank vapor injection on the heating performance of a two-stage heat pump with an inverter-driven twin rotary compressor. The COP and heating capacity of the injection cycle were enhanced by 10% and 25%, respectively, at an ambient temperature of -15 ^{o}C.Chul et al.[4]studied a heat pump system having an additional refrigerant injection line into the accumulator and compared its performance with the classic vapor-injection cycle. Colmeket al.[5] presented a study of R22 vapor injection in piston compressor for improving the cooling capacity of the system yet maintaining the compressor temperature in conformity range. As shown in figures (1) and (2),the system incurrent work has two refrigerant injection bleed lines that were taken from the main side of the condenser outlet.

The objective of this work is to investigate the effect of hybrid liquid and vapor refrigerant injections on a heat pump system using R407C refrigerant since it is more appropriate for Iraqi climate than R410 or R32 investigated in other research[6] .

Experimental setup

An R407C heat pump system was installed in an environmentally controlled chamber. Fig (3) shows a schematic diagram of the experimental setup intended to measure the performance of liquid and vapourin jections effects using heat exchangers arrangement. The system consists of ascroll compressor, an indoor and outdoor units, an internal heat exchanger, an oil separator and two thermostatic expansion valves. ACopeland scroll type compressor (model ZR36K1-PFJ-501) was with a heating capacity of 10.5 kW. Finned-tube heat exchangers was used as a condenser and evaporator. The indoor unit is an air cooled condenser, consists of 22 rows and 2 columns with a heat transfer area of 0.435m^2 and tube diameter of (5/16) inch. The evaporator (outdoor unit) consists of 46 rows, 2 columns with heat transfer area of 0.96m^2, and tube diameter of (1/4)inch. A cross flow shell and coil heat exchanger of 2.1 kW capacity is used as an internal heat exchanger (IHE). A 0.25kW tube in tube heat exchanger as an liquid injection heat exchanger (LHE) was installed at the discharge line. The outer and inner diameters of LHE were (25 and16) mm respectively. Two refrigerant injection streams were constructed using bleed lines with two manual valves. A two mass flow- meters (MFMs) model KF500 were installed. The first flow meter was installed at the outlet of indoor heat exchanger (condenser) to measure the total mass flow rate of refrigerant discharged from compressor. The second MFM was installed after the two injection bleeds line to measure the mass flow rate in each bleed line. Pressure transducers and thermocouples were installed as shown in fig. (3).Two Pressure transducers and ten thermocouples were installed in in-stream of the system to measure the refrigerant-side pressures and temperatures respectively. The outdoor unit is located inside an environmental chamber, where temperature and humidity can be controlled. A Watt hour meter model ES-32L was installed to measure the compressor and outdoor fan motor power consumption. All measuring devices are calibrated and corrected according to calibration certification No. 3990,1709P and 1708P in the central organization for standardization and quality control. Finally the system was charged with R407C refrigerant and can be operated in different modes, that is traditional cycle , liquid injection cycle, vapor injection cycle or a hybrid injection cycle.

Test procedure

A set of experimental tests on the heat pump system were conducted according to the following sequence. First, internal and external environmental chambers were operated to create a predetermined environmental conditions. After that, the heat pump system was run until reaching steady state. Then readings of temperatures, pressures, power and flow rate were recorded.

The system were then operated under different modes: closed injection lines (traditional),with liquid injection, with vapor injection and as a hybrid (liquid and vapor) heat pump system. The procedure was repeated for different environmental chambers conditions. The performance factor (PF)is calculated according to:

$$PF = \frac{Q_C}{W_C} = \frac{\dot{m}(h_{ci} - h_{co})}{W_C}$$

Where Q_C is the cycle capacity, h_{ci} and h_{co} are the inlet and outlet enthalpies of condenser calculated corresponding temperature and pressure measurements, $\dot{m}$ and $W_C$are the refrigerant mass flow rate and input power calculated by mass flow meter and Watt hour meter.

Results and discussion

The results include different modes of operation(traditional, liquid injection, vapour injection and hybrid injection cycles)at different ambient temperatures. Figure (4) shows the effect of ambient temperature on heating capacity. The increase in ambient temperature tend to increase the heat pump capacity. The traditional and liquid injected cycles give lower capacity than the hybrid injection cycle. The effect of ambient temperature on the capacity of traditional and liquid injection cycles is prominent for ambient temperatures less than 12^{o}C. As the ambient temperature increases more than 12^{o}C the cycle capacity for both cycles mentioned above tends to be mild(less than 0.1 kW), while the capacities of vapour, and hybrid cycles increase significantly. Figure (5) shows the effect of ambient temperature on pressure ratio. As the outdoor temperature increases the pressure ratio decreases mildly. This could be attributed to that the unit condenser is subjected to constant indoor temperature, leading to nearly constant condensing pressure, as shown in figure (6).On the other hand the evaporator is subjected to outdoor conditions, therefore its pressure is strongly affected. Vapour injection cycle shows significant effect on the cycle pressure ratio, while liquid injection shows less effect. Figure (7) shows that the ambient temperature has insignificant effects on compressor discharge temperatures. the minimum discharge temperature is for hybrid with much less effects for the liquid injection cycle. As the discharge temperature increases the refrigerant vapour specific volume increases thus, less mass will be delivered for a given volume flow rate of refrigerant vapour. Hence, higher discharge temperature of the traditional cycle leads to lower refrigerant mass flow rate, as it is shown in figure (8). As the discharge temperature increases the refrigerant vapour specific volume increases, which means delivering less mass for a given volume flow rate of refrigerant vapour. Figure (9) shows the variation of inlet condenser temperature with the outdoor temperature. The outdoor temperature has insignificant effect on the condenser performance, but liquid, vapour and hybrid injection cycles have low inlet compressor temperature. The discharge temperature of liquid injection cycle is reduced from around 89 ^{o}C, figure (7), to around 83^{o}C figure(9). The effect of liquid injection on condenser inlet temperature is reflected on the hybrid cycle also. Although discharge temperature for both vapour and hybrid cycles are almost the same, the inlet condenser temperatures are not. Figure (10) presents the variation of sub cooling effects of other injection cycles(liquid, vapour and hybrid) that of traditional cycle, i.e. ($T_{sub\ other\ cycle}$- $T_{sub\ traditional}$). The condenser inlet temperature is reflected strongly on the sub cooling effect, since for lower temperatures, less condenser volume will be reserved for the super heat region thus leaving more space for sub cooling. The degree of sub-cooling, for hybrid injection cycle, reduces slightly as the outdoor temperature increases from 8 to 10^{o}C, after which it is affected insignificantly while the vapour injection cycle shows continuous decrease in sub cooled effects since on the contrary to the hybrid cycle it is not assisted by liquid injection to neutralize the increasing evaporation pressure. Figure (11) shows the effect of ambient temperature on the compressor power consumption. The minimum power consumption is for hybrid injection cycle, and the maximum is for traditional cycle. The liquid injection cycle is almost an effects by ambient temperature variation, while other cycles show little variation. Since the compressor power consumption is affected slightly by outdoor temperature variation, and the cycle capacity increases with the increasing ambient temperature, the increase of outdoor temperature improves cycle PF figure (12). The traditional cycle recorded less PF value, while the maximum PF is for the hybrid cycle.

CONCLUSIONS

Injection of refrigerant in the form of liquid or vapour reduces compressor power consumption and increases the heat pump performance factor. The injection of vapour improves cycle PF more than the liquid injection techniques. The liquid injection cycle was better than the traditional cycle, it gives a decreases in pressure ratio of about 11% at ambient temperature 14°C and 2% at 8°C.This cycle also gives lower discharge temperatures by about 2% to 1% when ambient temperatures varies from 14°C to 8°C with higher performance factor of about 13% to 4%. The vapour injection cycle as compared to traditional cycle gives a decreases in pressure ratio of about 23% at ambient temperature of 14°C and 16% at 8°C. It gives a lower discharge temperature of about 19% to 17% when ambient temperature varies from 14°C to 8°C with higher performance factor of about 29% to 6%. The hybrid injection cycle as compared to traditional cycle gives a decrease in pressure ratio by about 24% at ambient temperature of 14°C and 18% at 8°C. It gives lower discharge temperature by about 20% to 19% when ambient temperature varies 14°C to 8°C with higher performance factor of 35% to 28% .

REFERENCES

[1]Xing Xu, Yunho Hwang, ReinhardRadermache"Refrigerant Injection for Heat Pumping/Air Conditioning Systems: Literature Review and Challenges Discussions" International Journal of Refrigeration,34,402-415, 2010.

[2]Hoon Kang, Sunil Lee, YongchanKim"Effects of liquid refrigerant injection on the performance of a refrigeration system with an accumulator heat exchanger" International Journal of Refrigeration,31,883-891, 2008.

[3]JaehyeokHeo, Min Woo Jeong, ChanghyunBaek, Yongchan Kim, "Comparison of The Heating Performance of Air-Source Heat Pumps using Various Types of Refrigerant Injection" International Journal of Refrigeration,34,444-453, 2010.

[4]Chul Woo Roh, Min SooKim"Comparison of The Heating Performance of an Inverter-Driven Heat Pump System using R410A Vapor-Injection into Accumulator and Compressor" International Journal of Refrigeration,35,434-444, 2011.

[5]Sophie Colmekl, Laurent Goderneaux"Gas vapor Injection on refrigerant cycle using piston technology" International Compressor Engineering Conference, July 16-19,2012.

[6]Xing XU, Yunho Hwang, ReinhardRadermacher"Performance Measurement of R32 in Vapor Injection Heat Pump System" International Refrigeration and Air Conditioning Conference,July 16-19, 2012.

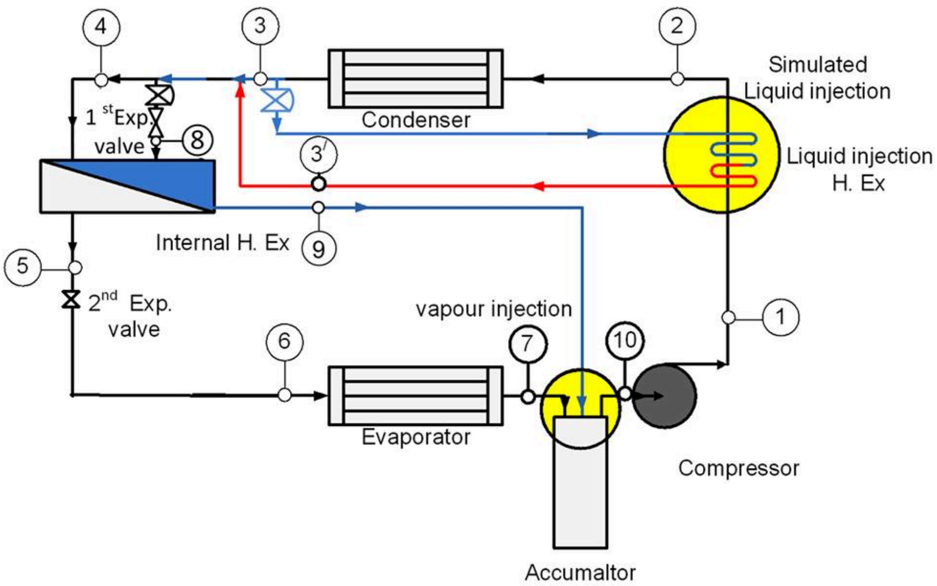

Figure (1) Schematic diagram of hybrid injection cycle.

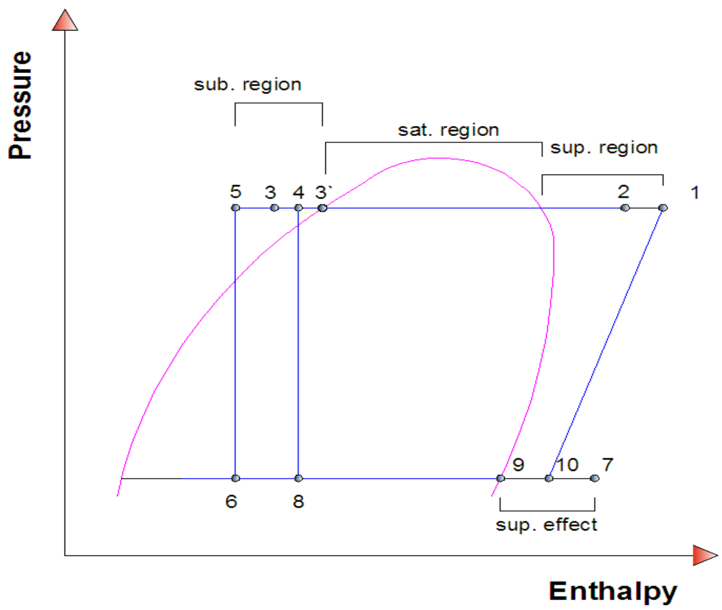

Figure (2) Pressure-enthalpy diagram for the hybrid injection cycle.

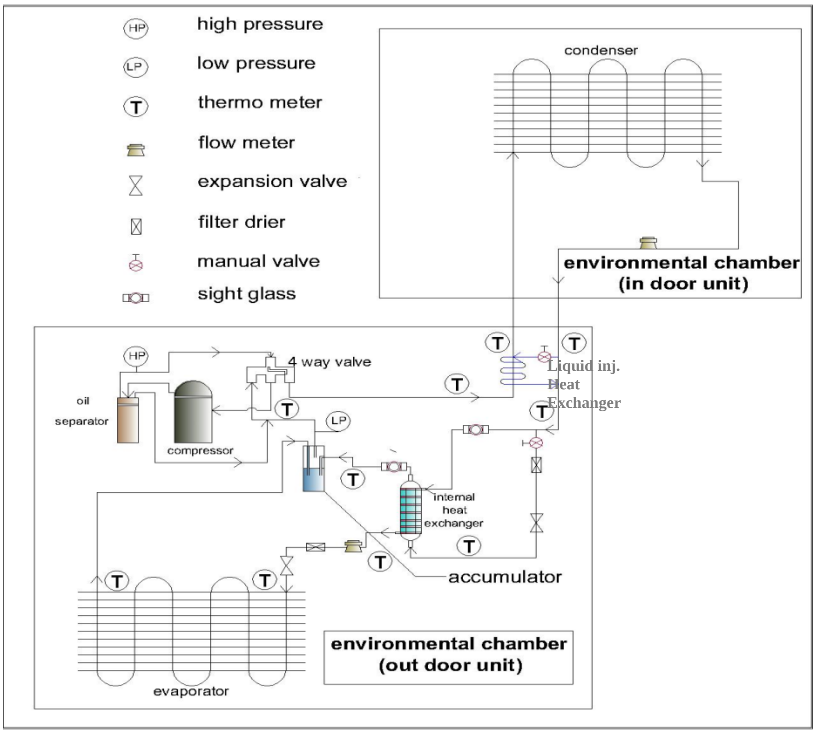

Figure (3) Experimental heat pump system.

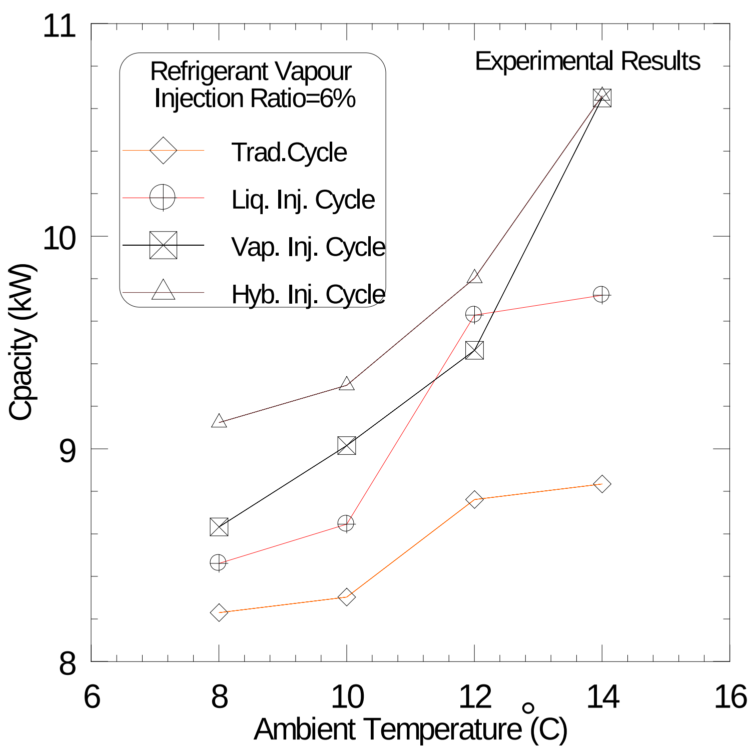

Figure (4) Effect of ambient temperatures on heating capacity.

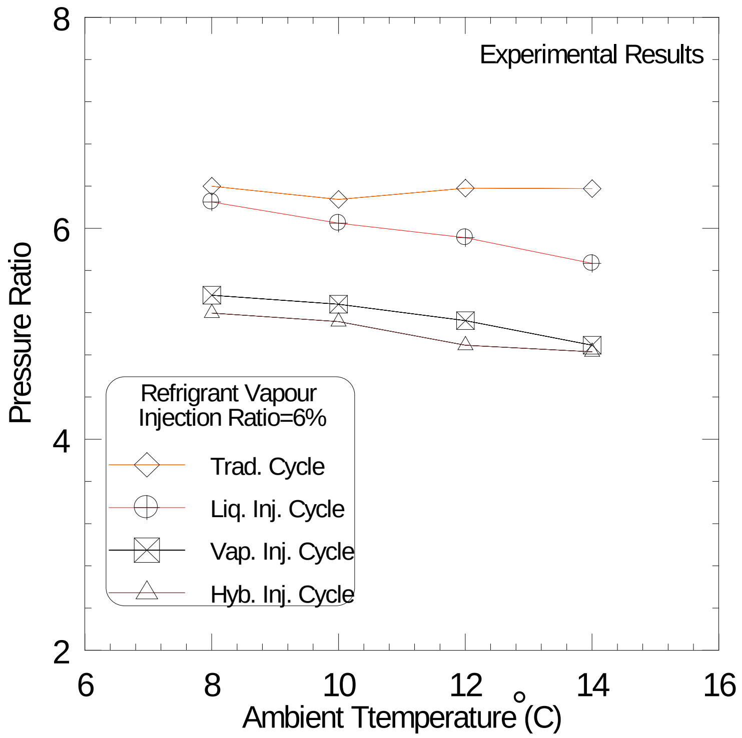

Figure (5) Effect of ambient temperatures on pressure ratio.

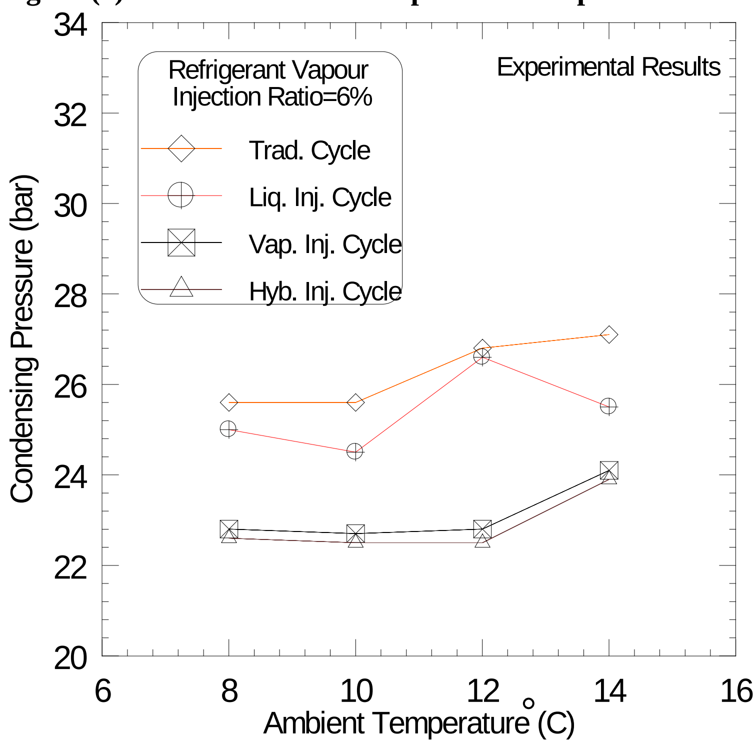

Figure (6) Effect of ambient temperatures on condensing pressure.

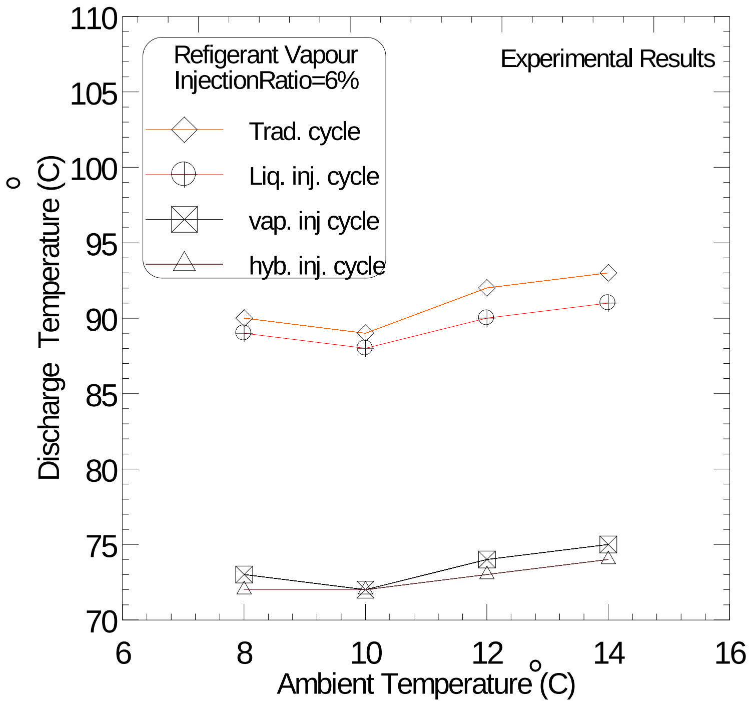

Figure (7) Effect of ambient temperatures on compressor discharge temperature.

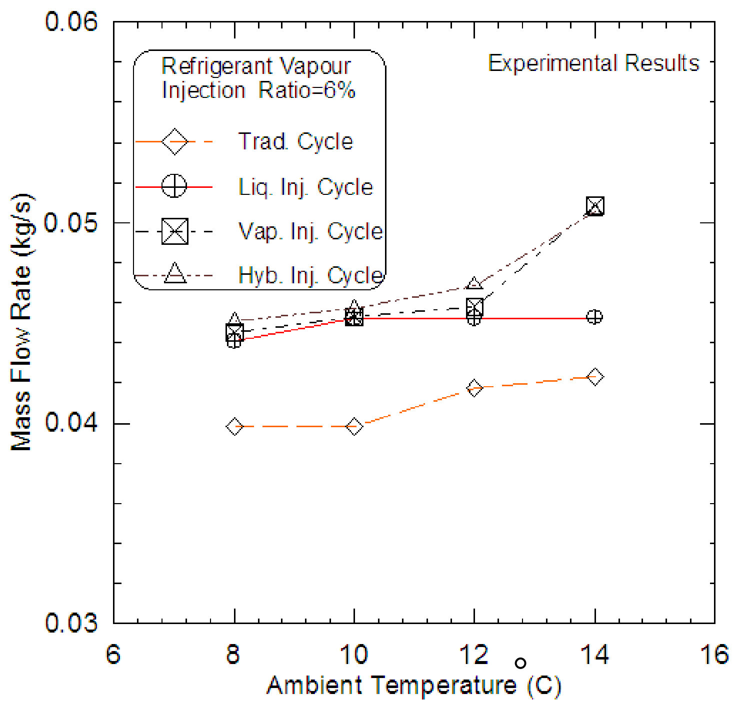

Figure (8) Effect of ambient temperatures on mass flow rate.

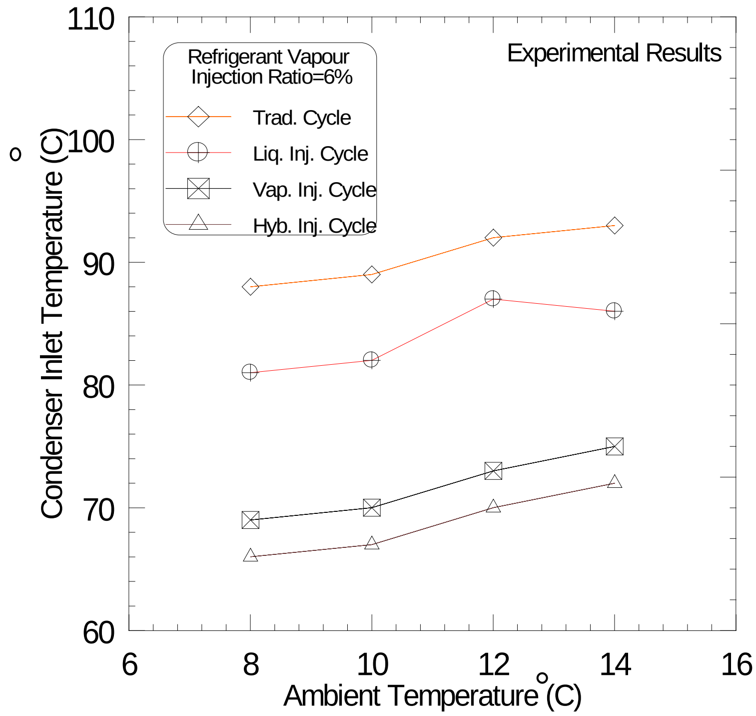

Figure (9) Effect of ambient temperatures on condenser inlet temperature.

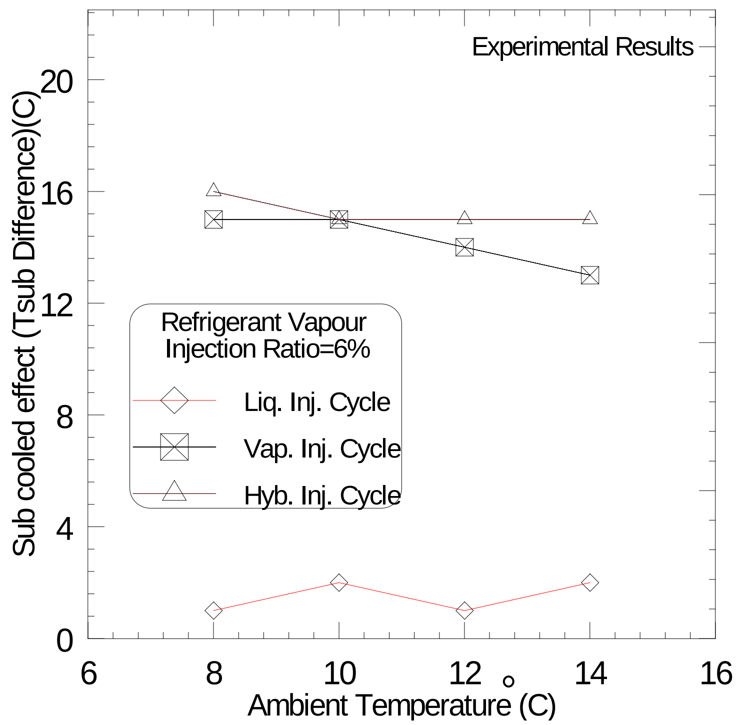

Figure (10) Effect of ambient temperatures on sub cooled effect.

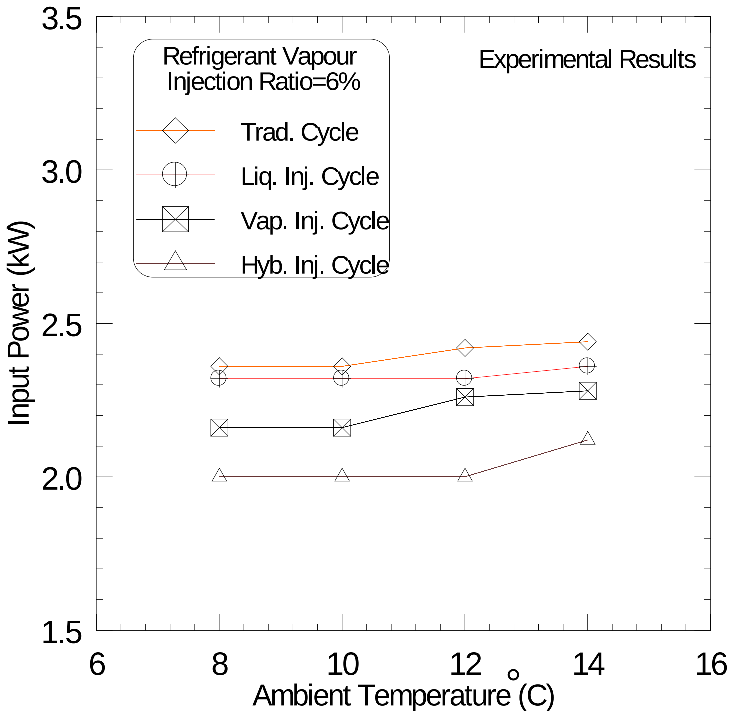

Figure (11) Effect of ambient temperatures on input power.

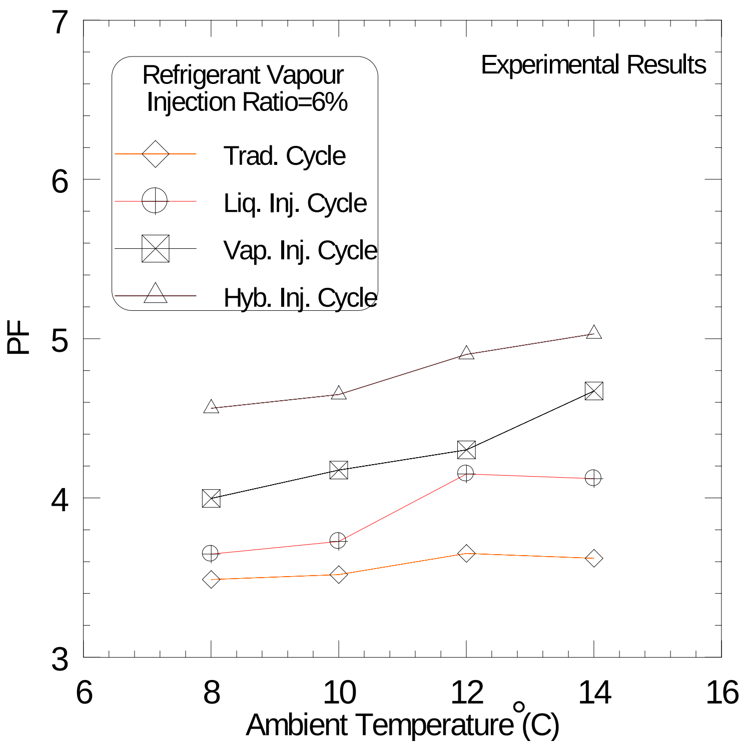

Figure (12) Effect of ambient temperatures on PF.