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Performance investigation of vapor and liquid injection on a refrigeration system operating at high compression ratio

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ABSTRACT

In this study, the performance of an R22 refrigeration system of 9.6 kW cooling capacity injecting vapor and liquid refrigerant to compressor inlet through accumulator is analyzed at high compression ratio experimentally. Results obtained in this study are compared and discussed for better performance of refrigeration system with respect to the injection type and ratio. In vapor injection, the COP decreased with increasing injection ratio while in the liquid injection, the COP increased up to 10% of injection ratio and decreased beyond that. Thus, the liquid injection up to 10% is recommended at high compression ratio in order to minimize the performance decrease and extend operating range of a refrigeration system. In addition, the subcooling for liquid injection could be considered as a proper parameter to control the injection for the reliable operation in the liquid injection case.

Etude de la performance d'injection de vapeur et de liquide dans un système frigorifique fonctionnant à forts taux de compression

Mots clés : réfrigération ; Injection de vapeur ; Injection de liquide ; Vitesse de compression élevée ; Compresseur à spirale

1. Introduction

Nowadays, people are looking forward to improve the quality of a life in accordance with the higher economic and culture level. On this situation, the demand of refrigeration system has been increased at tropical region with annual high ambient temperature such as Africa and Middle East (JARN, 2011). However, as ambient temperature increases, condensing pressure in air-conditioning system is increased because average temperature difference between air and

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Nomenclature

COP	coefficient of performance
EEV	electric expansion valve
Evap.	evaporator
EWT	entering water temperature, °C
ε_s	isentropic efficiency
ε_v	volumetric efficiency
ID HEX	indoor heat exchanger
$\dot{m}$	mass flow rate, kg s^{-1}
OD HEX	outdoor heat exchanger
ρ	vapour density, kg m^{-3}
υ	compressor speed, r min^{-1}
$\dot{\upsilon}_d$	compressor displacement, m^3 h^{-1}
w	specific shaft power, kJ kg^{-1}
w_s	isentropic compression work, kJ kg^{-1}
WFR	water flow rate, m^3/h

refrigerant decreases. Thus, the refrigeration system operates in high compression ratio for efficient condensation in tropical region. Since the compressor discharge temperature is very high, it may result in breakdown of the lubricating oil causing excessive wear and reduced life of the compressor valves (Stoecker, 1958). Therefore, it is highly important to overcome constraints such as excessive compressor discharge temperature and performance degradation for stable operation on a refrigeration system in tropical region. Recently, the development of injection type compressor with supplementary injection port has raised the potential of the operating range extension and performance improvement for refrigeration system.

Dutta et al. (2001) investigated theoretical and experimental influence of liquid refrigerant injection on performance of an R22 refrigerant scroll compressor. their study showed the performance improvement of compressor due to the decrease in the oil and cylinder temperature by the injection under the practical operating condition without controlling the oil temperature. Winandy and Lebrun (2002) presented an experimental analysis of different hermetic scroll compressor using different methods of injection. Results showed how the vapor injection permits one to increase slightly the cooling capacity of the compressor keeping a quite constant coefficient of performance. Guoyuan and Hui-Xia (2008) analyzed the performance of a heat pump system of 8.15 kW capacity with a flash-tank and with a subcooler. They reported that the heat pump with a flash tank is more efficient than the system with a subcooler at low ambient temperature. This agreed with the result reported by Wang et al. (2009a). Guoyuan et al. (2003) proposed a new subcooling system of approximately 5.5 kW heating capacity employing a scroll compressor with a supplementary inlet. Results showed that the heating capacity and power input of the heat pump increased, where the increase in the heating capacity was larger than that of the power input, so the heating EER was improved. Wang et al. (2009b) developed a model of the 5HP refrigeration system with a gas injected scroll compressor and investigated the effects of gas injection on the system and component parameter. It was shown that the maximum cooling capacity could be achieved when the injection pressure and specific enthalpy are adjusted to minimize the refrigerant enthalpy at the inlet of the evaporator for cooling capacity. Feng et al. (2009b) presented the experimental study of a heat pump of 12.16 kW heating capacity with water heater (HPWH) using economizer vapor injection system for varying mass ratio of R22/R600a and R22. It was demonstrated that the heating capacity and energy efficiency ratio (EER) of the unit increased, and the discharge temperature of compressor decreased for using the vapor injection and mixing refrigerants of R22/R600a. Cho et al. (2003) tested the performance of an inverter-driven scroll compressor of a displacement of 14.5 cm^3 with liquid refrigerant injection. They reported that the liquid injection under high frequency was very effective at attaining higher performance and reliability of the compressor, but injection under low frequency showed some disadvantage with respect to compressor power, capacity, and adiabatic efficiency due to high leakage through the gap in the scroll wrap.

The above literature review reveals the injection benefits using injection type compressor briefly as: Firstly, capacity improvement in severe climate was significant. Secondly, system capacity can be varied by controlling the injected refrigerant mass flow rate. Finally, the compressor discharge temperature can be lower than that of a conventional single stage cycle.

However, the system is more expensive since the refrigeration cycle requires additional components such as a special compressor with supplementary port. In the real application, the refrigerant injection for suction port is a simple and practical method for adoption to improve reliability of compressor and it is thus recommended as a relatively inexpensive solution of system for compressors adopting injection.

Some researchers have tried the liquid refrigerant injecting method through compressor suction port (compressor inlet) to improve performance and extend operating range for refrigerator system in high compression ratio. Dutta et al. (1996) investigated a compression characteristics of vapor–liquid R22 two phase mixture. The results indicated that the evaporation of the liquid refrigerant in the compressor cylinder decreased not only the vapor temperature but also decreased the compression pressure rise under liquid suctioning.

Feng et al. (2009a) studied on the performance of a heat pump with water heater using suction stream liquid injection. They found that the suction liquid injection explicitly lowered the discharge temperature of compressor and heating capacity of the unit, but the power consumption increased with the COP decreases. Kang et al. (2008) investigated the effect of liquid refrigerant injection on the performance of 9 kW refrigeration system with an accumulator heat exchanger. Their results showed that the subcooling at inner heat exchanger outlet increased and the superheat at the accumulator outlet decreased with the increase of the liquid injection rate. However undesirable results such as the increase of compressor discharge pressure and decrease of the system performance were also observed. Very recently, Roh et al.