INTERNATIONAL JOURNAL OF REFRIGERATION 34 (2011) 402–415

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Review

Refrigerant injection for heat pumping/air conditioning systems: Literature review and challenges discussions

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ARTICLE INFO

Article history:
Received 23 July 2010
Received in revised form
8 September 2010
Accepted 21 September 2010
Available online 2 November 2010

Keywords:
Liquid
Vapor
Separation
Injection
Tank
Heat exchanger

ABSTRACT

This paper reviews the major research on refrigerant injection techniques in detail. Liquid and vapor refrigerant injection techniques are discussed and compared. The current research on refrigerant injection techniques falls into two categories: system level research and component level research. The system level research is focused on low ambient temperature heating, heat pump water heating, high ambient temperature cooling, cycle comparison, and control strategy development. Internal heat exchanger and flash tank cycles are the two typical cycles for refrigerant injection. These two cycles are discussed and compared in detail. The component level research is focused on employing different types of compressors, variable speed compressors, the injection process, and the flash tank. Different types of compressors employing refrigerant injection are presented. Based on the literature study, the potential future research directions are presented and discussed. The flash tank cycle control strategy and refrigerant charge management strategy are worth further research efforts. Compressor design can be improved in order to optimize the performance with refrigerant injection. The appropriate design of flash tanks plays a vital role in achieving appropriate two-phase flow patterns in the flash tank. Computational Fluid Dynamics (CFD) modeling can be a useful tool to facilitate the design of the flash tank.

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Injection du frigorigène dans les systèmes à pompe à chaleur et de conditionnement d'air : passage en revue de la littérature et discussion sur les défis

Mots clés : Liquide ; Vapeur ; Séparation ; Injection ; Réservoir ; Èchangeur de chaleu

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doi:10.1016/j.ijrefrig.2010.09.015

1. Introduction

Refrigerant injection is a technique that involves injecting the refrigerant from the condenser outlet to the suction line, or the sealed compressor pocket, or the condenser inlet in a vapor compression system. It has proven to be effective in ensuring the reliable cycle operation and improving the performance of vapor compression systems. Refrigerant injection can be classified into two types: liquid refrigerant injection and vapor refrigerant injection. The former is commonly used for decreasing the extremely high discharge temperature of the compressor and ensuring the reliable system operation. The latter is used for so-called "economizer cycle" to improve the cooling/heating capacity at the same stroke volume of the compressor.

1.1. *Liquid refrigerant injection*

Liquid refrigerant can be injected to the hot gas before entering the condenser, or into the suction side of the compressor, or directly into the sealed compressor pocket. The principle of liquid injection into the compressor pocket is not a new concept. US patents have existed since 1946 for reciprocating compressors and later for rolling piston compressors (Holtzapple, 1989). Haselden (1976) patented liquid refrigerant injection applied to a screw compressor. The liquid refrigerant was injected to seal the compressor rotor clearance. A number of designs (Kamimura et al., 1999; Cho and Bai, 2003; Fujita and Amo, 2003; Bush et al., 2004; Ignatiev and Caillat, 2008) were also patented with respect to the liquid refrigerant injection technique.

Operating compressors at high compression ratios can result in excessively high discharge temperatures, which can chemically degrade refrigerant oil and lead to mechanical failure. Therefore, employing liquid injection is a good option when high-pressure ratios are reached. Dutta et al. (2001) investigated the influence of liquid refrigerant injection on the performance of a scroll compressor both experimentally and theoretically. The oil temperature was maintained to be constant in the first experiments. It was found that the injection increased the compressor power and decreased the compressor efficiency. Later the system was operated without controlling the compressor oil temperature. Slight improvement was observed for the system performance. This was due to the fact that the liquid injection tended to decrease the oil temperature, which led to improvement in the system performance. Sami and Tulej (2001) and Sami and Aucoin (2002, 2003a, 2003b) did a series of liquid injection testing with different refrigerant mixtures such as R404A, R410A, R407C and R507C, and concluded that the liquid injection was effective in reducing the compressor discharge temperature. Cho et al. (2003) studied an inverter-driven scroll compressor with liquid injection at different compressor frequencies. The liquid injection under high frequency was very effective in attaining prominent performance and reliability of the compressor. Some disadvantages were found with injection at low frequency with respect to the compressor power, capacity and adiabatic efficiency due to high leakage through the gap in the scroll wrap. Kang et al. (2008) studied the effects of liquid refrigerant injection on the performance of a refrigerant system with an accumulator heat exchanger. It was found that the liquid injection coupled with an accumulator exchanger was effective for controlling adequate sub-cooling and the compressor discharge temperature of the compressor at high ambient temperatures. Liu et al. (2008) studied the liquid injection using a rotary compressor for a heat pump water heating system. It was found that the compressor discharge temperature decreased significantly due to the liquid injection. The liquid refrigerant injection mass flow rate was quite small compared to the mass flow rate of the main circuit; therefore the capacity remained almost the same when compared to the case without the injection.

1.2. *Vapor refrigerant injection*

Vapor refrigerant injection typically refers to injecting vapor refrigerant to the intermediate location of the compressor. Compared to liquid refrigerant injection, more benefits were found for the vapor injection technique, and are listed as follows:

(1) Capacity improvement in severe climate (heat pumping at lower than 0 °C and air conditioning of higher than 35 °C of ambient temperature) was significant, which provides alternative heating/cooling method in cold/hot ambient climates. As a result, the design point of vapor injection system can be extended, as shown in Fig. 1.
(2) System capacity can be varied by controlling the injected refrigerant mass flow rate, which permits some energy savings by avoiding intermittent operation of the compressor.
(3) The compressor discharge temperature of a vapor injection cycle is lower than that of a conventional single-stage cycle. Therefore the working envelop of the compressor is improved.

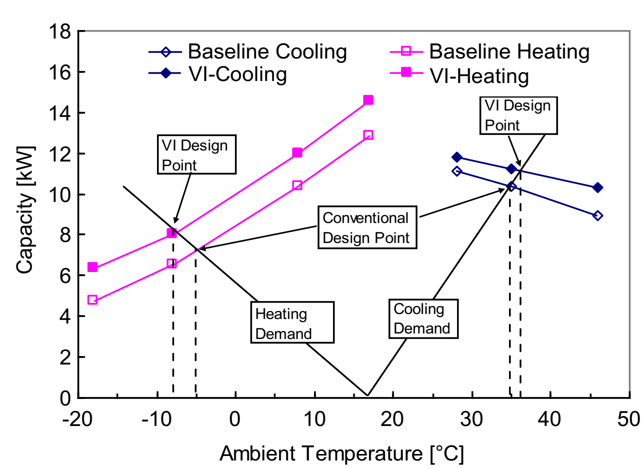

Fig. 1 – Comparison of system design point of conventional system and vapor injection system (Wang et al., 2009c).

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