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Dual port vapor injected compression: In-system testing versus test stand testing, and mapping of results

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ABSTRACT

This paper introduces the differences of in-system testing of a dual-port vapor injected compressor as compared to test stand testing and presents the performance results. Single-port vapor injected compression has been studied previously, typically using scroll compressors. Single-port vapor injection employs one port with a single intermediate injection pressure, while dual-port vapor injection uses two ports at different angular locations, leading to two intermediate pressure levels for the injected vapor. The main differences between in-system testing and test stand testing can be found in suction and injection superheat values, discharge temperature, and range of injection flow rates. Dimensionless PI-type mappings are introduced that can be used for system simulation.

1. Introduction

Air source heat pumps are known to provide up to three times more heat energy to a home than the electricity they consume [9]. In addition, the electricity used to operate air source heat pumps could come from renewable sources. The use of renewables for heating using other technologies is more challenging as pointed out by Ref. [8]. However [5]; points out that it is much more difficult to apply heat pumps in extreme cold conditions because of diminishing heating capacity and efficiency. In fact, a significant amount of auxiliary heat is needed in cold climates, which reduces the overall system efficiency. As a result, the European Union considers heat pumps to be renewable if they produce more heat than they consume in auxiliary energy [10]; point 31). The work described in this paper was carried out as part of a project to develop high performance high pumps for cold climates and focuses on characterizing the performance of a specialized compressor for this purpose.

Compressors are the main power consumer in air source heat pumps and therefore are of primary interest for reducing power consumption and increasing efficiency. The overall isentropic efficiency of the compression process generally decreases with increasing compression ratio. This decreases the coefficient of performance in applications with high pressure ratio, such as cold climate heat pumps (CCHPs). One way to overcome this problem is to use a staged compression process with multiple compressors, implemented in form of a cascade, intercooler, or economizer cycle as shown in Ref. [3].

Ref. [7] introduced a cold climate heat pump with economizer cycle and noted that an oil management system is needed to compensate for oil migration between compressors. In the final field test results [8], it is noted that compressor failure occurred due to oil migration between the compressors. Ref [8] were able to overcome the issue of oil migration by using better controls. However, compressor failure is preprogrammed in case of a failure of these controls. Vapor injected compression circumvents any such oil migration issues by employing only a single compressor. Additionally, the reduced count of components and controls complexity could reduce cost.

Single-port vapor injected compression has been investigated by a number of different researchers (e.g. Refs. [16,20,21]). Ref. [22] provides an extensive literature review, which includes potential applications for vapor injected technology. The common conclusion of different researchers is that single-port vapor injection at low suction pressures leads to an increase in COP, an increase in low temperature heating capacity, and a decrease in discharge

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temperature. For high suction pressures (e.g. CCHP at high ambient temperature), the COP can be lower than the one for the baseline system due to re-expansion losses at the injection ports.

Note that there are different ways to integrate vapor injected compression within the system. Ref. [11] presented flash tank and subcooler cycles, which are the two most common approaches, together with two more complicated system layouts. They experimentally investigated the different cycles and found that the flash tank cycle leads to the highest capacity while the COPs of the different configurations were similar.

Refs. [12–15] conducted simulation studies to investigate the effect of increasing the number of injection ports as well as using two-phase refrigerant rather than saturated vapor for the injection. Ref. [14] showed that two injection ports lead to a 28% improvement in COP if saturated vapor injection is used, with the injection of two phase mixture only leading to an additional 1% improvement. Further increasing the number of ports was shown to lead to additional benefits, with the per-port improvement of performance decreasing with each additional port. From a cost perspective, two ports might be an economic optimum between initial cost and energy savings during system lifetime.

Since two-phase injection is complicated to achieve, experimental work carried out by the same group was limited to using saturated or slightly superheated vapor [2,17–19]. The main result was an increase in heating COP and capacity. This increase generally was larger for lower suction pressures, while a decrease in COP occurred for higher suction pressures.

Ref. [19] introduced a mapping for suction, as well as injection flow-rates, power consumption, and discharge temperature. Their mapping was based on test stand data and was limited to a single value of discharge pressure, compressor speed, and suction superheat and did not show a satisfactory performance for the power consumption ($R^2 < 84\%$).

The purpose of this paper is to obtain a more accurate mapping, which includes different compressor speeds, discharge pressures and a range of suction superheat values, and furthermore compare test stand data against in-system data. Accurate mappings will be useful for system simulation, while a general understanding of the difference between test stand and in-system data will be useful to understand the limitations of the resulting data.

1.1. Scroll compressor with dual port vapor injection

Fig. 1 shows a cross-section of the scroll compression mechanism of the scroll compressor used to obtain data for this paper. It is composed of an orbiting scroll and a stationary scroll. The stationary scroll has two injection ports, which are connected to external ports at the compressor shell. The low pressure vapor injection port is located at an angular position that opens up directly after the outside suction pocket is closed. The high pressure injection port is located further away from the point at which the inside suction pocket is closed. The angular position between seal-off point and injection port determines the optimum pressure for the injection ports. The injection ports were not equipped with check-valves, but the passage to the port can be plugged inside of the stationary scroll for single-stage operating mode. The displacement of the compressor is 4 cubic inches (65.5 cm^3), with an inbuilt volume ratio of 3.29. More details on this compressor can be found in Ref. [18].

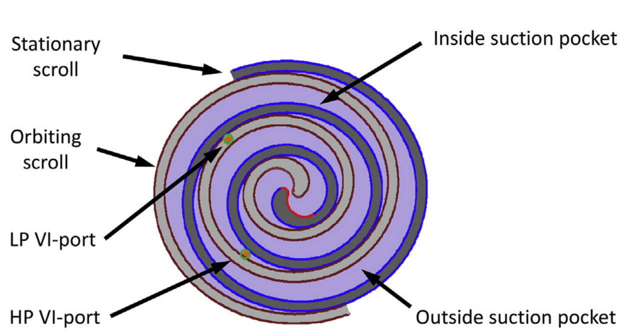

Fig. 1. Employed dual port VI scroll [18]; modified.

2. Test setups and test plans

The data used for the development of the correlation was obtained using three different test setups:

1. A modified calorimeter test stand ("calorimeter") that allows for adjustment of the injection flow rates.
2. A hot-gas bypass test stand ("HGB test stand") with two brazed plate type heat exchangers used for the generation of vapor for injection.
3. A cold climate vapor injected heat pump (CCHP, "in-system testing") modified for vapor injection by using two vapor separators.

Each of the setups led to a different range of injection flow rates, condensing and evaporating pressures and compressor ambient temperature. While the compressor was directly exposed to the ambient air in the test stands, it was insulated for the in-system testing.

2.1. Modified calorimeter

A calorimeter was modified by the compressor manufacturer to allow for vapor injected compression as shown in Fig. 2. Part of the refrigerant exiting the compressor is cooled by a desuperheater, while the remaining refrigerant enters the calorimeter. The refrigerant exiting the desuperheater is expanded using two expansion valves and injected at a high and low pressure level into the injection ports of the compressor. Temperature and pressure is measured at both injection ports as well as at the suction and discharge of the compressor. Compressor motor power consumption as well as internal motor shaft speed were measured. The environment of the compressor was maintained at 95 °F (35 °C), and the compressor was not insulated.

2.2. Modified hot-gas bypass test stand

An existing hot-gas bypass test stand was modified for vapor injection by implementing two desuperheaters with control valves

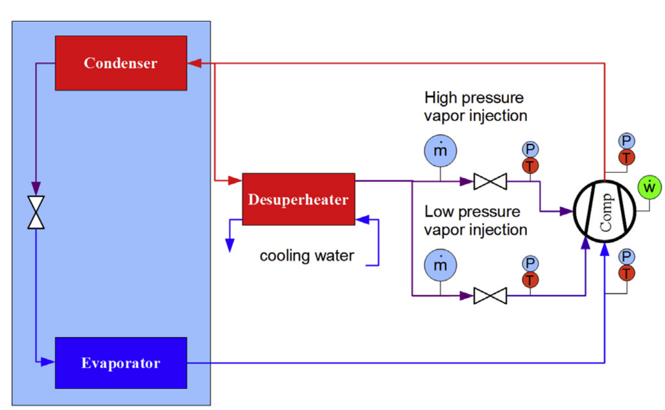

Fig. 2. Calorimeter modified for vapor injection.