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New characterization methodology for vapor-injection scroll compressors

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ABSTRACT

This paper presents a characterization methodology for vapor-injection scroll compressors (SCVI). An SCVI was characterized in a modified calorimetric test bench, which is able to control the intermediate pressure and the injection superheat independently. Based on the characterization results, the injection mass flow rate was correlated with the intermediate pressure through a linear expression, and a modified AHRI polynomial was proposed to estimate the compressor power input. The correlations were used in a simple model to predict the intermediate conditions of the SCVI installed in a heat pump prototype with an economizer. The deviations obtained for the evaporator mass flow rate, injection mass flow rate, intermediate pressure, and compressor power input were lower than 5% in all cases. The proposed methodology allows evaluating SCVI in a wide range of operating conditions, being only dependent on compressor characteristics and totally independent of the system in which it is installed.

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Nouvelle méthodologie de caractérisation des compresseurs à spirale à injection de vapeur

Mots clés : Caractérisation ; Injection de vapeur ; Compresseur à spirale ; Banc calorimétrique

1. Introduction

In Europe, manufacturers characterize single-stage compressors based on the Standard EN 13771-1 (2003). The standard proposes several procedures for testing compressors, which require the definition of three external conditions: evaporating pressure, condensing pressure and superheat at the compressor inlet. In these conditions, the mass flow rate and the power consumption have to be measured.

Based on that, compressor manufacturers provided AHRI polynomials for single-stage compressors in order to estimate the mass flow rate and the power input of the compressors when they operate in different conditions of the catalog data (AHRI Standard 540, 2015).

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Nomenclature

CV	control valve
$\dot{E}$	compressor power input (W)
EEV	electronic expansion valve
EV	expansion valve
h	enthalpy (J kg^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
P	pressure (Pa)
P_r	pressure ratio
$\dot{Q}$	capacity (W)
SCVI	scroll compressor with vapor-injection
SH	superheat
T	temperature (°C)
$\dot{V}$	swept volume (m^3 h^{-1})

Greek symbols

ρ	density (kg m^{-3})
η_c	compressor efficiency
η_v	volumetric efficiency

Subscripts

c	condenser
dew	dew point
eco	economizer
e	evaporator
inj	injection
int	intermediate
s	isentropic
tra	transfer
1	compressor inlet
4	compressor discharge
5	condenser outlet
8	injection port inlet
9	evaporator inlet

$$X = C_1 + C_2S + C_3D + C_4S^2 + C_5SD + C_6D^2 + C_7S^3 + C_8S^2D + C_9SD^2 + C_{10}D^3 \quad (1)$$

Equation (1) represents the AHRI polynomial, where C_1 to C_{10} are the regression coefficients provided by the manufacturer. X represents the individual published ratings (power input, refrigerant mass flow rate, cooling capacity and the like). S represents the suction dew point temperature; D represents the discharge dew point temperature. The AHRI polynomial is used to determine the compressor performance independently of the system design for any working point within the compressor working envelope.

The characterization of vapor-injection compressors is more complex because there are two additional degrees of freedom: the intermediate pressure, and the injection temperature. For a given test matrix, when including the two additional parameters in the system, the number of experimental points increases considerably because the intermediate pressure can take several values for each operating point (T_e, T_c, SH). Moreover, a full characterization of these compressors requires the measurement of the injection mass flow rate.

To our best knowledge, there are no published standards for characterization of vapor-injection compressors. However, some studies have been published about vapor-injection compressors, most of them mainly focused on the experimental study of the heat pump system with economizer (Fig. 1(a)) using vapor-injection scroll compressors (Bertsch and Groll, 2008; Ding et al., 2004; Feng et al., 2009; Ma and Chai, 2004; Ma et al., 2003; Roh and Kim, 2011, 2012; Wang et al., 2009a; Xu and Ma, 2011). Other authors have used in their experimental studies a vapor-injection cycle with flash tank (Fig. 1(b)) (Ma and Zhao, 2008; Qiao et al., 2015a, 2015b; Wang et al., 2009b; Xu and Ma, 2011; Xu et al., 2011, 2013), or liquid injection (Cho et al., 2003; Dutta et al., 2001; Winandy and Lebrun, 2002).

Nevertheless, a correct characterization of the vapor-injection compressor should provide the necessary information to evaluate the compressor performance in any working point, with any intermediate conditions (intermediate pressure and inlet injection temperature). However, nowadays the user is not able to know the behavior of the compressor regardless of the system design. Manufacturers characterize the vapor-injection compressors in such a way that their behavior is restricted to how the system is designed internally, for example considering a temperature approach of 5 K in the economizer according to EN 12900 (2014). Consequently, the intermediate conditions depend on the way in which the injection is performed (economizer, flash tank, liquid injection, etc.) and the control algorithm. Therefore, this characterization is not general and is not intrinsic of the compressor, as it is for single-stage compressors.

Fig. 1 shows two typical vapor-injection cycles. The system of Fig. 1(a) uses a heat exchanger (economizer) to vaporize the injection mass flow rate. The intermediate conditions are set from the economizer size (UA) and the chosen mechanism of control, which is usually a thermostatic expansion valve. In this configuration, for each compressor size, a determined heat exchanger size has to be selected to define the different operating points of the compressor, which means having a set of heat exchangers (economizers) to characterize the compressor, hence the costs of the test bench increase dramatically.

In vapor-injection cycles with an economizer, for a given compressor size, the intermediate pressure is defined by the heat transfer in the economizer once the injection superheat is supplied. Therefore, for a given pressure ratio and an economizer size (UA), the intermediate pressure and the injection mass flow rate are fixed.

Some studies define the economizer size by setting the temperature approach in the economizer (T_6 –T_7 in Fig. 1(a)). For all operating points, this temperature approach is assumed to be constant (5 K) (Moesch et al., 2016). Basing on this consideration, manufacturers provide correlations for estimating the intermediate pressure in which the compressor have to work (equation (2)). This equation shows a correlation between the dew point temperature at the intermediate pressure and the dew points temperature at the evaporating and condensing pressures (Emerson Climate Technologies, 2015).

$$T_{dew,inj} = 0.8T_{dew,e} + 0.5T_{dew,c} - \frac{19}{3}K \quad (2)$$

Nevertheless, this consideration does not correspond to any real physical system because the temperature approach varies

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