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Experimental investigation on cold startup characteristics of a rotary compressor in the R290 air-conditioning system under cooling condition

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ABSTRACT

R290 is one of the most alternative refrigerants for the air-conditionings for its negligible environmental impact and high efficiency. This experimental study investigated the cold startup characteristics of the rotary compressor in a R290 air-conditioning system under cooling condition. The characteristics include the pressures and temperatures in the system and the rotary compressor respectively, the mixture of oil and refrigerant viscosity and oil level of the oil sump. The measurements showed that the startup time for the pressures and the temperatures were much longer than that of R410A and R22 systems. A slight liquid slugging happened in the cylinder at the initial time of startup for the pressure during the later exhaust process increasing rapidly to 2.21 MPa in 1.3 seconds. After startup of the system, both the mixture of oil and refrigerant viscosity and oil level of the oil sump in the compressor were within a proper range to guarantee a steady startup of the air-conditioning system.

Etude expérimentale des caractéristiques de démarrage à froid d'un compresseur rotatif dans le système de conditionnement d'air au R290 sous condition de refroidissement

Mots clés : R290 ; Caractéristiques de démarrage ; Compresseur rotatif ; Etude expérimentale ; Système de conditionnement d'air

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1. Introduction

With the increasing attention to environmental problems such as global warming, ozone depletion and atmospheric pollution, a large number of studies related to the selection of environmentally friendly refrigerants as working fluids were conducted in the air-conditioning industry in recent years. Most of CFCs and HCFCs as short-term alternative refrigerants, more or less, do harm to the environment or have thermophysical properties. For example, the alternative refrigerant R410A and R32 have high global warming potential. Current research and industry trends show that HCFCs and HFCs will gradually be replaced by natural refrigerants such as CO_2, R290, NH_3 and so on. R290 as the working fluid used in small heat pumps, room air-conditionings and other commercial refrigeration equipment is considered as one of excellent long-term alternative refrigerants owing to its negligible environmental impact and excellent thermosphysical properties; what is more, it can help to reduce the electric energy consumption of the system (Joudi and Al-Amir, 2014; Palm, 2008; Zhou and Zhang, 2010).

Owing to the flammability of R290, it is necessary to control the refrigerant charge amount in the air-conditioning system (Padalkar et al., 2014). A number of studies have been conducted on the R290 charge amount in room air-conditionings in recent years. Fernando et al. (2004) designed a system to minimize the charge of R290 mainly by use of mini-channel aluminum heat exchangers. And the results showed that the system could be run with 200 g of propane at typical Swedish operating conditions without reduction of the COP compared to a traditional design. Hrnjak and Hoehne (2004) found that it is possible to create a system that can use less than 150 g of charge and produce between 1 kW and 2 kW of cooling capacity by using microchannel heat exchanger technology. Li et al. (2015) experimentally investigated the R290 mass distributions in a split type air condition by the liquid nitrogen method (LNM). Much research on the performances of R290 systems has also been carried out. Devotta et al. (2005) experimentally studied an original R22 window air-conditioning with R290 as refrigerant, and they found that the COP of the R290 system was 7.9% higher under the lower operating conditions and 2.8% higher under the higher operating conditions. Wu et al. (2012) experimentally study the performance of a small wall room air-conditioning retrofitted with R290. The results showed that, with the decrease of the outdoor temperature, alternative systems have higher increase rate and greater increment in both cooling capacity and EER than the original R22 system. Tian et al. (2015) theoretically and experimentally investigated the performance of the air conditioners working with both R32/R290 and R410A. Experimental results show that the refrigerant charge amount of R32/R290 is reduced by 30.0% to 35.0%; the cooling and heating capacities are increased by 14.0% to 23.7%. Cai et al. (2015) explored the leakage characteristics of R290 in rolling piston type rotary compressor. And the results showed that, to obtain relatively high efficiency, smaller radial clearance was required for R290 compressor comparing to that of R22 and R410A compressors under the same condition.

As well known, to keep the temperature in the rooms unchanged, a great many of air-conditionings have to turn on and off frequently, which will lead the air-conditionings working in the unstable state. Therefore, Startup characteristics of air-conditioning systems are very important and have been investigated by many researchers. Yanagisawa et al. (1990) develops a mathematical model of a rotary compressor which can predict its transient behavior and can be easily integrated into a simulation program of a heat pump cycle. For the transient characteristics during speed up of inverter heat pump, Hwang and Kim (1998) carried out that the transient cycle migration of the liquid state refrigerant caused significant dynamic change in system. Kim and Bullard's (2001) experiment studied the dynamic characteristics of a single speed R410A split air-conditioning system during shut-down and start-up. Kapadia et al. (2009) studied the transient characteristics of split air-conditionings that use R22 and R410A as refrigerants by simulation methods, and measured and published experimental data were used to validated the program. Andrade and Negrão (2013) proposed a semi-empirical model applied to domestic refrigeration systems for devising real time predictions of test results. The results showed that the model can predict fairly well the results within the calibration period and that the model accuracy increases with the calibration time.

The liquid slugging consequently threaten the reliability of the compressor as the cylinder pressure could shoot to very high value (Singh et al., 1986), which often occurs when liquid refrigerant enters the compressor or during the cold startup process. Thus the liquid slugging in the compressors has been studied by many investigators. Palm (2008) and Tadashi et al. (1985) experimentally examined liquid compression characteristics at starting in a sliding vane type rotary compressor. Liu and Soedel (1994) presented a mathematical model to simulate the compression processes of two-phase saturated refrigerant mixture and analyzed the factors leading to slugging. Dutta et al. (2001) and Park et al. (2002) investigated the performance of a scroll compressor under liquid refrigerant injection. To identify slugging-induced overpressures in reciprocating compressors, Laughman et al. (2008) proposed a method by analyzing the electrical power flowing into the compressor motor.

Though much research has been devoted to the performances of R290 air-conditioning systems and dynamic characteristics and liquid slugging of the rotary compressor (Devotta et al., 2005; Kapadia et al., 2009; Kim and Bullard, 2001; Liu and Soedel, 1994; Tadashi et al., 1985; Tian et al., 2015), little attention has been paid to the startup characteristics of the rotary compressor in R290 air-conditioning systems. As the saturated vapor line of R290 was closed to the line of compression process in the P-h graph, the liquid slugging is likely to happen during the compression process. Especially, during the cold startup process, the temperature of the cylinder is so low as to make the vapor refrigerant in the cylinder into liquid by transferring heat from refrigerant to cylinder or exhaust valve. In this study, an experimental investigation was done to characterize the cold startup behaviors of a rotary compressor in a R290 air-conditioning system. This study aims to present the variations of temperatures and pressures in the R290 air-conditioning system and the rotary compressor under standard cooling conditions to identify the happening of the liquid slugging. Meanwhile, the mixture of oil and refrigerant viscosity and the oil level of the oil sump during startup of the system were studied as to confirm if the lubrication of the rotary