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Experimental investigation on the performance of NH_3/CO_2 cascade refrigeration system with twin-screw compressor

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ABSTRACT

This paper describes the experiment carried out to analyze the performance of a refrigeration system in cascade with ammonia and carbon dioxide as working fluids. The effect of operation parameters, such as the evaporating temperature of the low temperature cycle, the condensing temperature of low temperature cycle, temperature difference in cascade heat exchanger and superheat degree, on the system performance was investigated. Performance of the cascade system with NH_3/CO_2 was compared with that of two-stage NH_3 system and single-stage NH_3 system with or without economizer. It was found that the COP of the cascade system is the best among all the systems, when the evaporating temperature is below −40 °C. Also, the cascade system performance is greatly affected by evaporating temperature, condensing temperature of low temperature cycle, temperature difference in cascade heat exchanger and is only slightly sensitive to superheat degree. All the experimental results indicate that the NH_3/CO_2 cascade system is very competitive in low temperature applications.

Etude expérimentale sur la performance d'un système frigorifique au NH_3/CO_2 en cascade muni d'un compresseur à deux vis

Mots clés : Système frigorifique ; Système à compression ; Système en cascade ; Ammoniac ; Dioxyde de carbone ; Compresseur à vis ; Expérimentation ; Performance

1. Introduction

The natural refrigerants such as air, water, ammonia, carbon dioxide and hydrocarbons, have recently received increased attention due to the environmental concerns of global warming and emerging regulations. It was shown that carbon dioxide is the most promising natural refrigerant across a broad spectrum of automotive,

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Nomenclature

COP	coefficient of performance
h	specific enthalpy (kJ kg^{-1})
m	mass flow for refrigerant (kg s^{-1})
Q	cooling capacity (kW)
R	dependent variable
ΔS	entropy increase (kJ K^{-1})
T	temperature (°C or K)
ΔT	temperature difference (°C or K)
W	power consumption (kW)
w	uncertainty
x	independent variable which affects the dependent variable R
ε	COP of reverse Carnot cycle

Subscripts

c	condenser
cas	cascade heat exchanger
e	evaporator
H	high temperature cycle
i	inlet
L	low temperature cycle
max	maximum
o	outlet
sub	subcooling degree
sup	superheat degree

domestic, commercial and industrial refrigeration and air-conditioning systems (Pearson, 2005; Pettersen, 1999). Lorentzen (1994) recommended that transcritical cycle and cascade system may be two applications specially suitable for CO_2. Groll and Kim (2007) reviewed the latest research activities regarding to transcritical CO_2 cycle technology as an alternative for the fluorocarbon-based vapor-compression technology for heat pump, air-conditioning and refrigeration applications, while Bansal and Jain (2007) discussed cascade refrigeration systems and suggested NH_3/CO_2 cycle may be the potential selection in low temperature applications.

Many studies have been conducted on the NH_3/CO_2 cascade refrigeration system to investigate its performance. Getu and Bansal (2008) presented a thermodynamic analysis of the system to optimize its design and operating parameters. Dopazo et al. (2007) reported an analysis of the design and operation parameters and their influence on the COP of the system. Lee et al. (2006) analyzed the optimum condensing temperature of cascade-condenser in CO_2/NH_3 cascade refrigeration systems. Ma et al. (2005) studied the performance of NH_3/CO_2 cascade refrigeration cycle making use of expander to replace the throttling valve. Belozerov et al. (2007) examined the effect of CO_2 evaporating temperature on the system COP based on the actual NH_3/CO_2 cycle. Sawalha et al. (2007) and Likitthammanit (2007) designed and built an NH_3/CO_2 cascade refrigeration system experimental rig for a medium size supermarket application to evaluate an energy efficient system in Sweden. They investigated the transient behavior of system parameters and different cascade-condenser arrangements affecting the system performance.

From these previous studies, it can be seen that the majority of them are theoretical analysis and only a few are related to experimental investigations. In this paper, extensive experimental investigation on the performance of the NH_3/CO_2 cascade refrigeration system is carried out for large industrial refrigeration applications. A test rig of the NH_3/CO_2 cascade refrigeration system was built with fully instrumented to evaluate its performance. The main focus of the study reported here was making on a comprehensive investigation experimentally about the effect of the operation conditions on the system performance.

2. Test rig and performance calculation

2.1. Test rig

The sketch of the NH_3/CO_2 cascade refrigeration system that was built in the present study is shown in Fig. 1. This test rig is consisted mainly of two parts, one was the high temperature cycle with NH_3 as the working fluid, and the other was the low temperature cycle with CO_2 as the working fluid. They were connected with each other by the cascade heat exchanger. The compressor unit was composed of an open type compressor, a motor, an oil cooler and a gas-oil separator. Both of the compressor units were twin screw types, and their swept volumes were 598 m^3/h and 152 m^3/h, respectively. The condenser, cascade heat exchanger and evaporator were all shell and tube types. The cascade heat exchanger had a heat exchange area of 59.02 m^2 and its maximum working pressure was 4.8 MPa.

As shown in Fig. 1, the temperatures and pressures of the refrigerant were measured at various locations in the test rig, such as the inlet and outlet of the compressor, and so on. Platinum resistance temperature sensor with an accuracy of 0.1 °C was installed to measure the temperature of refrigerant. All the temperature sensors were well calibrated in a controlled temperature bath using standard precision mercury glass thermometers. The error of the pressure transducer was less than ±1% FS (6 MPa).

Two methods for measuring the cooling capacity were used when the cascade system operates in a steady state. The primary method was measuring refrigerant side capacity by one vortex flow meter located upstream of the compressor, together with platinum resistance temperature sensor and pressure transducer. The supplementary method was measuring the brine side capacity with the mass flow rate and the brine temperature difference. The deviation of the cooling capacity measured with the two methods was less than ±5%. Compressor power meter showed error in ±0.1 kW for power measurement. The errors of volume flow rate of CO_2 and NH_3 measured by the vortex flow meter were less than ±1% FS (193 m^3/h) and ±1% FS (794 m^3/h), respectively, located upstream of the compressor, while that of the brine was less than ±1% FS (80 m^3/h).