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Effects of component performance on overall performance of R410A air conditioner with oil flooding and regeneration

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ABSTRACT

Oil flooded compression with regenerator (OFCR) is one of the possible technologies to improve the performance of air conditioner. The addition of OFCR system to basic vapor compression system adds several components: oil separator, oil cooler and regenerator. These components can lead to a significant increase in performance. In this study, parametric studies of these components performance have been carried out under various operating conditions. Compared with basic vapor compression system, COP of OFCR system with 100% effective regenerator is improved by 0.7–11.8% while COP of OFCR system without regenerator is reduced by 0.6–1.8%. When oil temperature exiting the oil cooler reaches 40 °C and 50 °C, the performance of OFCR system is worse than that of basic system at evaporation temperature T_e = 15 °C and $T_e \geqslant$ 5 °C respectively. COP and cooling capacity of OFCR with solubility are decreased by 6.9% and 14.3% respectively at T_e = 5 °C and 0.4 oil mass fraction. A modification of OFCR system is suggested for reducing the negative effects of solubility. The results of COP and cooling capacity show that the modified OFCR system has a 3–4% performance improvement. Comprehensive effects of regenerator efficiency, oil temperature and solubility are also studied. Taking the solubility into account, the effects of regenerator efficiency and oil temperature are slightly different from that without solubility.

1. Introduction

With the development of economy, comfortable living conditions are greatly demanded. In this situation, the demand of air conditioning system has been increased steadily. Nowadays, vapor compression cycle system is a widespread used air conditioning system. As an electric power driven system, air conditioning system consumes a large portion of total energy (up to 50% in residential sector [1,2]). Without a doubt, the energy consumption of air conditioning system will continue to climb in future. As concerns about energy consumption and the corresponding environmental implications are increasing, the design of high performance air conditioning system is a popular and needed trend [3–6].

As the compressor nearly consumes total power in a vapor compression system, one key approach of achieving better energy efficient air conditioning system is to improve the compressor performance or reduce the compression work. As, nowadays, the motor has reached a high level [7,8], opportunities for significant improvement are changing the compression process [6,9]. One possible approach is isothermal compression that the refrigerant temperature remains constant during the compression process. At present, a number of methods have been proposed to attempt an isothermal compression [6,9–12] while refrigerant injection is the only technique applicable to current commercial compressor. Refrigerant injection, including refrigerant vapor [10] and liquid refrigerant injection [11,12], is injecting some amount of refrigerant to cool the compressor during the compression. When there are a number of injection ports [13], the improvement of COP can be great. However, refrigerant injection is not able to achieve an isothermal compression process. Coney et al. [14] studied an air compressor with water injection and approached a quasi-isothermal compression. As water is not favored in the field of air conditioning and refrigeration, oil flooded compression is proposed and is regarded as a very promising means of achieving isothermal compression [9]. The basic principle of oil flooded compression is injecting significant amounts of oil into the refrigerant at the inlet of compression. Unlike the oil flooding in screw compressor [15], which is used to improve the sealing of the compressor, the oil mass fraction proposed here are significantly larger than that for better sealing. As injected oil absorbs part of the heat generated during the compression process, the temperature of refrigerant can be constant during the compression process in an oil flooded compression with regenerator (OFCR) system. As a result, the performance of air conditioner can be improved by reducing the compression work.

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Nomenclature

Variable		*Subscript*	
COP	coefficient of performance	*c*	condenser
h	enthalpy	*e*	evaporator
$\dot{m}$	mass flow rate	*is*	isentropic
P	pressure	*m*	mixture
s	entropy	*ref*	refrigerant
T	temperature	*ref_s*	dissolved refrigerant in oil
W	work	*o*	oil
ρ	density	*oc*	oil cooler
υ	specific volume	1,2,. . .,7	state points shown in Fig. 2
η	efficiency	3′	state point shown in Fig. 1

Hugenroth [16] studied the performance of Ericsson cycle with liquid flooding and concluded that water was the ideal flooding liquid due to its high specific heat capacity and low specific volume. Hugenroth et al. [17] also studied the performance of vapor compression cycle with liquid flooding. The experimental results showed a possible increase of the COP of up to 13% in heating mode and 9% in cooling mode. Bell et al. [9] developed a detailed model for OFCR system. It was found that the efficiency of OFCR was significantly improved compared with basic vapor compression system. Ramaraj [18] experimentally investigated the performance of oil flooded compressor. Based on a simplified system analysis, an increase of the COP of up to 25% was found in heating mode. Yang et al. [19] studied experimentally a 5-ton R410A packaged heat pump with OFCR. It was found that up to 8% system COP improvement was observed compared to the baseline system for all ambient temperatures. Bell et al. [20] and Ramaraj et al. [21] investigated the effects of oil flooding on the performance of scroll compressor. It was found that the experimental isentropic efficiency was improved at optimal oil mass fraction.

These studies mainly focused on the feasibility of energy savings of OFCR. The general conclusion was that thermodynamic efficiency of OFCR was greatly improved compared with basic vapor compression system. However, the literature on the details of additional components (oil separator, oil cooler and regenerator) performance on overall performance of OFCR system is quite limited. Only Bell et al. [9,22] investigated the effects of regenerator efficiency on COP for CO_2 (T_{sink} = 28 °C) [9] and carried out a simplified thermodynamic analysis of CO_2 solubility in oil [22]. It was found that oil flooded compression without regenerator deteriorated the performance of system and no improvement in system COP existed at a refrigerant solubility of 20% compared with basic vapor compression system. Thus, the performance of additional components is important for achieving the potential of oil flooding. However, the work is not enough to reveal the effects of additional components.

In this study, a model of OFCR was developed. First, the effects of regenerator efficiency on system COP, demanded lowest regenerator efficiency, optimal oil mass fraction and cooling capacity were investigated in detail. Second, the effects of oil temperature on system COP and optimal oil mass fraction were analyzed. Third, the effects of solubility on system COP and cooling capacity were studied. Unlike the solubility varied in the range of 0–0.3 at a fixed oil mass fraction [22], the solubility is determined by oil temperature and oil pressure. Thus, the effects of solubility in this paper are closer to a practical system. In order to reduce the negative effects of solubility, a modification of OFCR system is suggested and investigated. Finally, comprehensive effects of regenerator efficiency, oil temperature and solubility are also studied.

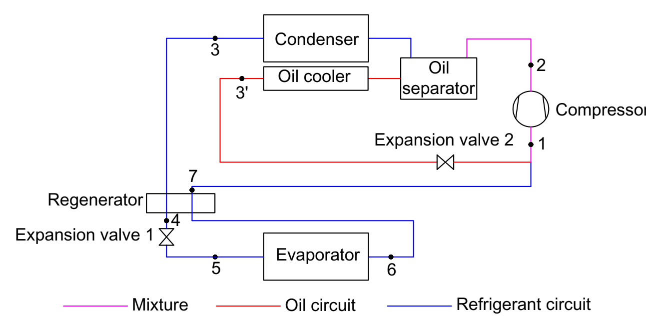

Fig. 1. Schematic diagram of OFCR air conditioner.

2. Principles of the OFCR air conditioner

2.1. Description of OFCR air conditioner

The OFCR air conditioner is based on basic vapor compression system (as given in Fig. 1). The addition of OFCR adds four components: oil separator, oil cooler, regenerator and expansion valve 2.

In the configuration, there are two circuits: refrigerant circuit and oil circuit.

The refrigerant circuit consists of compressor, oil separator, condenser, regenerator, expansion valve 1 and evaporator. In oil separator, the mixture of refrigerant vapor and oil from the compressor is separated into refrigerant vapor, dissolved refrigerant in oil and oil. The refrigerant vapor is condensed in condenser. After exchanging heat with the refrigerant vapor from the evaporator, the slightly subcooled liquid refrigerant is largely subcooled in regenerator. Through expansion valve 1, the refrigerant is expanded and evaporated in evaporator by absorbing heat from the ambient. Then the refrigerant vapor passes through the regenerator and mixes with the oil and the dissolved refrigerant in oil from the oil circuit. Finally, the mixture is compressed and discharged in compressor.

The oil circuit consists of compressor, oil separator, oil cooler and expansion valve 2. The oil and the dissolved refrigerant in oil from the oil separator are cooled closely to heat sink temperature in oil cooler. After expansion, the oil and the dissolved refrigerant in oil, together with the refrigerant vapor from the evaporator, flow into the compressor and are compressed together in compressor.

2.2. Model of OFCR air conditioner

The pressure-enthalpy diagram of refrigerant cycle in OFCR system is given (see Fig. 2) in relation to basic vapor compression