Applied Thermal Engineering 131 (2018) 678–685

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Thermodynamic analysis of vapor compression cycle with oil flooding from intermediate pressure port

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HIGHLIGHTS

- Intermediate pressure oil injection port is proposed for oil flooded compression.
- The modification has a beneficial effect on COP_c and cooling capacity.
- Coefficient of oil absorbed heat in the compression process is defined and obtained.
- Performance improvements of the systems are different for R410A and R32.

ARTICLE INFO

Article history:
Received 29 September 2017
Revised 20 November 2017
Accepted 9 December 2017
Available online 11 December 2017

Keywords:
Air conditioning
Injection position
Intermediate pressure port
Oil flooded compression
R32

ABSTRACT

Oil flooded compression is able to improve the performance of vapor compression cycle by approaching a quasi-isothermal compression process. In conventional Oil Flooded Compression Cycle (OFCC), oil is usually injected in the compression chambers just after the compression pockets are sealed off from the suction chambers. In this research, OFCC with intermediate pressure port (OFCC-IPP) is proposed. The performance characteristics of OFCC-IPP with and without regenerator using R410A and R32 working fluids are investigated and compared to conventional OFCC with and without regenerator. Theoretical results show that the improvement of ratios of COPc and cooling capacity in the OFCC-IPP systems can be up to 4.5% an 5.3% respectively compared to the OFCC systems under the operating conditions of 40 °C condensing temperature and evaporating temperature in the range of −25 °C and 5 °C. Besides, the performance improvements of the OFCC and OFCC-IPP systems are different for the R410A and R32 working fluids. The results suggest that OFCC-IPP has huge potential for applications as an alternative to the conventional OFCC.

1. Introduction

The HVAC&R (Heating, Ventilation, Air-Conditioning and Refrigeration) industry plays a major role in modern life. However, it also consumes a large amount of energy used in building [1,2]. Due to the concerns about energy consumption and the corresponding environmental implications [2], vapor compression cycles have received significant attentions to increase the efficiency over the past decades [3]. At present, a number of methods such as variable frequency compression, expansion recovery and vapor injection have been proposed [3]. Consequently, vapor compression systems have seen great improvements. Nevertheless, vapor compression systems need further optimization for the reduction of building energy consumption.

In recent years, an Oil Flooded Compression Cycle (OFCC) has been proposed by Hugenroth et al. [4]. The aim of this cycle was to approach a quasi-isothermal compression by mixing significant amount of oil with the refrigerant in the compression chambers. Thus, the amount of injected oil in the OFCC is significantly larger compared to the amount used for sealing purposes inside the compressor [5,6]. As the injected oil with high specific heat capacity can absorb the heat generated during the compression process of the refrigerant, the temperature of refrigerant is maintained constant during the compression process in the OFCC system. As a result, the specific compression work is reduced and thereby leading to an increase of the coefficient of performance (COP). The experimental results showed the rise of the COP was up to 13% in heating mode [4]. In order to further utilize the benefits of oil

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https://doi.org/10.1016/j.applthermaleng.2017.12.048
1359-4311/

Nomenclature

Variable

C_p	specific heat at constant pressure ($J \cdot kg^{-1} \cdot K^{-1}$)
h	specific enthalpy (J/kg)
$\dot{m}$	mass flow rate (kg/s)
$\dot{Q}$	heat capacity rate (W)
P	pressure (kPa)
T	temperature (K)
$\dot{W}$	power (W)
x	mass fraction (–)
ρ	density (kg/m^3)
η	efficiency (–)

Subscript

c	condenser
e	evaporator
is	isentropic
m	mixture
ref	refrigerant
o	oil
1,2...	state points as shown in Fig. 2

flooding, Bell et al. [7] proposed an OFCC system with regenerator. The theoretical results showed that the COP increase of OFCC was over 40% for supermarket refrigeration applications. Yang et al. [8] investigated experimentally a 5-ton R410A packaged OFCC heat pump and up to 8% system COP improvement was found for the OFCC over basic vapor compression system or baseline system at the conditions of indoor temperature (21.11 °C) and ambient temperatures (8.33 °C, 8.33 °C and 17 °C). Ramaraj et al. [9] also investigated the performance of the OFCC in cold climate heat pump and found that the heating COP of the OFCC was approximately 13% higher than the baseline cycle at −10 °C ambient temperature. Furthermore, the performance of compressor in the OFCC can be improved [10–15]. Bell et al. [10–12] carried out theoretical and experimental studies on a scroll compressor in the OFCC. The results showed that the isentropic efficiency was improved by nearly 6% at optimal oil mass fraction. Ramaraj et al. [13] also carried out similar experiments and reported an over 10% isentropic efficiency increase at an evaporating temperature of 30 °C and condensing temperature of 43.3 °C. Luo [15] investigated the effects of internal superheat and heat loss and found that the isentropic efficiency of compressor benefited from less internal superheat and heat loss. The overall isentropic efficiency of compressor in the OFCC was improved by up to 7.3% at an evaporating temperature of 25 °C and condensing temperature of 45 °C. Therefore, it can be concluded that the OFCC can significantly improve the COP from cycle-level and component-level. Moreover, the OFCC can be integrated into vapor injection cycle and ejector cycle to enhance the performance. Luo [16] proposed a cycle with a combination of vapor injection and oil flooded compression. The theoretical results showed that the oil flooded compression enhanced vapor injection cycle could raise the COP by up to 17.2% over the vapor injection cycle. Luo [17] also proposed a cycle with a combination of ejector and oil flooded compression. The theoretical results showed that the oil flooded compression enhanced ejector cycle could raise the COP by up to 8.5%. Therefore, the OFCC has huge potential for applications in vapor compression systems.

Currently, the oil is injected in the compression chambers just after the compression pockets are sealed off from the suction chambers [4,7–9,16,17] (as shown in Fig. 1). However, there are a few problems caused by such design:

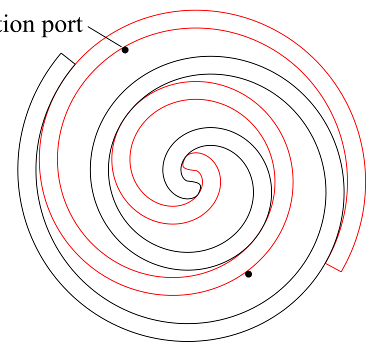

Fig. 1. Schematic location of dual oil injection port in the scroll compressor.

(i) A high efficient regenerator or a low oil temperature is required [18]. When a low efficient regenerator or a high oil temperature is employed, the oil temperature is higher than the temperature of sucked refrigerant. Assumed that the oil and the refrigerant are compressed separately in the compression chamber and the heat can be transferred between the oil and the refrigerant, the oil cannot absorb the compression heat of refrigerant until the refrigerant reaches the oil temperature. Thus, the work for the oil compression has little benefit before the refrigerant reaches the oil temperature and thereby leading to the degradation of COP.

(ii) The benefit of integrating the OFCC into vapor injection cycle and ejector cycle is reduced. As discussed above, a high efficient regenerator is essential in the OFCC. However, the high efficient regenerator will also result in the reduction of expansion work recovery in the cycles with expansion work recovery devices [17]. Thus, little COP improvement is obtained for the integration of OFCC into these cycles [17]. Moreover, although a high efficient regenerator can be employed in the cycle with a combination of vapor injection and oil flooded compression [16], the refrigerant temperature before mixing cannot be approaching the condensing temperature. Thus, compared to the OFCC, it can be hypothesized that a low efficient regenerator is employed. As a result, less COP improvement is obtained for the integration of OFCC into vapor injection cycle [16]. Furthermore, the design increases the cost and the complexity of the compressor for integration into vapor injection cycle, which demands injection ports for the oil and vapor injections separately [16].

Therefore, it is very necessary to further improve the OFCC to make it more viable. In this paper, an OFCC with intermediate pressure ports (OFCC-IPP) is proposed. The modification presents the following potential benefits: (i) a low efficient regenerator or a high oil temperature can be tolerated, and even the regenerator could be removed because the temperature of the injected oil will be guaranteed to be lower than the temperature of the pre-mixing refrigerant by designing the appropriate location of the oil injection ports opening into the compression chamber; (ii) the COP increase could be larger when the OFCC is integrated into other cycles; (iii) the oil injection port could be used for vapor injection