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Experimental study of enhancing heating performance of the air-source heat pump by using a novel heat recovery device designed for reusing the energy of the compressor shell

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ABSTRACT

A novel heat recovery device designed to recover the heat that is released from the outer surface of heat pump compressors, and to enhance the performance of heat pumps in cold areas was made and tested in this study. The novel heat recovery device consists of three fundamental units: a heat absorption unit, a heat emission unit and heat pipes. An amount of work focused on recovering the heat of compressors through oil system, but few studies concentrated on the housing. The main advantage of the heat recovery device is no need for extra energy consumption for its only driving force is the temperature difference between the compressor shell and the working fluid inside the suction line. The experimental results were obtained from a series of tests with a R410A air-source heat pump. Effects of the device are analyzed with respect of the suction temperature, temperature distribution among the housing, input power and exergy destruction. Moreover, the impact on the heating capacity is also discussed. Further, direction for improvement is also given based on the analysis.

1. Introduction

Energy savings has become one of the most important subjects as energy shortage is getting worse and the demand for energy is rising rapidly worldwide in recent decades [1]. Space heating and cooling consume approximately 1/3 of the whole building energy consumption which accounts for about 1/5 of the total delivered energy consumption worldwide [2,3]. As it is a more efficient and environmental-friendly way to supply suitable indoor climate compared with that which uses boiler central heating or electrical heating, heat pump earns its position in the air-condition market [4]. Especially in recent years, sever air pollution in north China where the coal-fired boiler heating is used for supplying domestic hot water and residential heating becomes a serious problem the government faces with [5]. Compared with other types of heat pumps, the one with air source is strongly encouraged to be an alternative for the advantage of easy installation. However, the performance of the air-source heat pump deteriorates sharply with the decrease of the ambient temperature especially in sub-zero regions [6]. According to the law of conservation of energy, the indoor heat exchanger (HE) would give out little heat because the outdoor HE hardly absorbs heat from the surrounding. What's more, the refrigerant may not evaporate entirely or not have a sufficient superheat when it flows into the compressor that the risk of liquid compression will rise as a consequence. Liquid slugging is a common and serious problem in compressors that it would consequently damage the compressor valves and have detrimental impacts on reliability and lifetime of the compressor [7]. It might even make the peak pressure of the cylinder ten times higher than the normal value [8]. There are a variety of reasons that can cause this phenomenon [9]: low environment temperatures, cold start of compressors, excessive refrigerant mass flow and so on. To prevent compressors from liquid slugging, manufacturers apply complemental devices such as accumulators, pre-heaters and heat generators before the suction line [10]. But in some sub-zero areas, the ambient temperature is extremely low that the plants mentioned above could not ensure the compression under a completely dry condition.

According to the data of BITZER Software, Fig. 1 illustrates the discharge temperature of a BITZER scroll compressor (GSD80295VA 4, 61.8 m^3/h under frequency of 50 Hz) with the refrigerating capacity of 50 kW which operates in the evaporating temperature of 268.15 K (heating season), superheat of 10 K. As is known, the housing temperature of a compressor with a high pressure side shell is practically identical to its discharge temperature. Because of the large temperature difference (around 340–380 K) between the compressor shell and the ambient air in winter, it is

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Nomenclature

COP	coefficient of performance
NHRD	novel heat recovery device
HAU	heat absorption unit
HEU	heat emission unit
HE	heat exchanger
OSV	opening of subcooled valve
ex	exergy (kJ/kg K)
h	enthalpy (kJ/kg)
P	pressure (MPa)
Q	heat transfer rate (kW)
q	specific heat transfer rate (kJ/kg)
s	entropy (kJ/kg K)
T	temperature (K)
W	work rate (kW)
w	specific work rate (kJ/kg)
η	energy efficiency (dimensionless)
κ	compression pressure ratio

Subscripts

0	the reference state
bot	bottom
c	condensation
com	compressor
d	discharge
des	destruction
e	emission
el	electrical
ent	enthalpy
in	inlet of the condenser
oil	lubricant or cooling oil
out	outlet of the condenser
s	suction
sur	surface
top	top
ts	theoretic isentropic condition

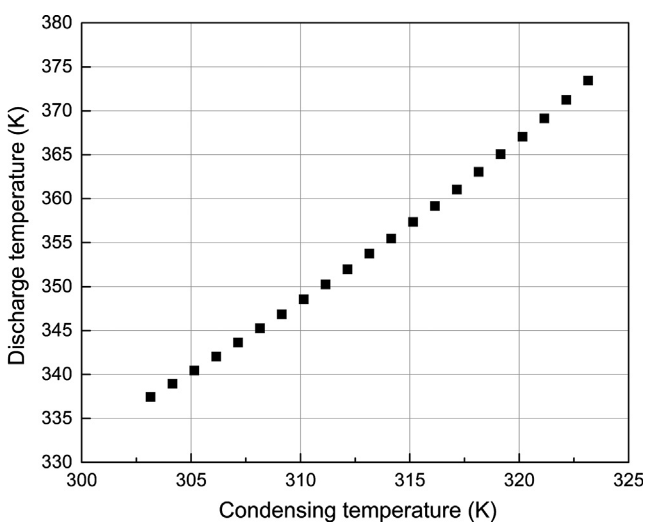

Fig. 1. Discharge temperature of BITZER GSD80295VA 4.

significant to recycle this heat energy which is usually "dumped" into the surrounding, and make use of it [11].

Heat pipe is a simple, flexible device having high thermal conductivity but without requiring any power input [12,13]. Therefore, it has been widely used in heat recovery application to save energy and mitigate global warming [14,15]. Byrne et al. [16] designed an air-source heat pump assisted with two-phase thermosiphons (gravity heat pipes) to implement simultaneous heating and cooling. Noie-Baghban et al. [17] constructed a heat pipe heat exchanger for the purpose of heat recovery in hospitals and laboratories where more fresh air and greater frequency of ventilation are needed.

The study here proposes a novel heat recovery device (NHRD) which reuses the heat of compressor shell to avoid liquid slugging and supplement a certain amount of heat into the system in the environment of low temperature. Aiming at energy conservation and easy installation, heat pipes were made the key components of NHRD. Thus, NHRD has the advantages of power-free and easy-remove. As described at length in the next part, NHRD is much different from the aforementioned technique for it uses heat pipes as its core and doesn't need to connect to another system to get heat source as a consequence. Furthermore, there is no need to change the original structure of the heat pump.

This study focuses on if it is feasible to preheat the refrigerant by NHRD with the energy that is recovered from the compressor, to what extent will it work and how can it affects the compressor. The results were analyzed after series of experiments. Advices for further improvements are also given.

2. Experimental setup

The experiment was conducted with an air-source heat pump of which schematic diagram of heating mode is illustrated in Fig. 2. Main characteristics of the heat pump and its components which were crucial in the experiment are given in Table 1. Considered the difficulties of manufacturing and installation, the heat recovery system (NHRD) was designed to transfer the heat from the compressor shell to the Y-tee so that to preheat the refrigerant before it is sucked into the suction line as shown in Fig. 2.

NHRD comprises of three parts: (i) a heat absorption unit (HAU), (ii) a heat emission unit (HEU) and (iii) 6 heat pipes with the diameter of 8 mm as shown in Fig. 3 where the concrete structure is presented. As seen in Fig. 3(a), HAU and HEU have the following elements in common: aluminum shells, which cover the outer surface of the compressor (HAU) or Y-tee (HEU) and contact with them seamlessly assisting by thermal silicone grease; pressure strips, which press heat pipes to aluminum shells; screw holes; and mounting holes where heat pipes are embedded. Heat and mass flow (indicated with red and blue arrows respectively) within the heat recovery system is marked on Fig. 3(b). It can be seen that the heat which comes from the compressor outer surface is transferred through heat pipes to the Y-tee where refrigerant converges. Each heat pipe has its specific bending angle and length in order to fit the associated components of the heat pump outdoor unit and other parts of NHRD. By the phase transition of the working fluid in evaporator section (evaporation) and condenser section (condensation), the heat can be transferred from the compressor housing to the refrigerant inside the Y-tee.

Fig. 4 shows the theoretical effects of NHRD on a pressure-enthalpy diagram where the subscript "1" stands for the normal condition and the subscript "2" refers to the condition with NHRD. Evaporation and condensation pressures depend mainly on outdoor and indoor temperatures which remain unchanged in the