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Research Paper

Study on the performance of compact adsorption chiller with vapor valves

Zhaohong He [a,b], Yu Bai [a,b], Hongyu Huang [a,b,*], Jun Li [c], Huhetaoli [a,b,*], Noriyuki Kobayashi [c], Yugo Osaka [d], Lisheng Deng [a,b]

[a] Key Laboratory of Renewable Energy, Chinese Academy of Sciences, Guangzhou 510640, China
[b] Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, Guangzhou 510640, China
[c] Nagoya University, Nagoya 464-8603, Japan
[d] Kanazawa University, Kanazawa 920-1192, Japan

HIGHLIGHTS

- A compact adsorption chiller applied in the automobile with the vapor valve is proposed.
- The vapor valve is controlled by the pressure difference at both sides.
- The compact adsorption chiller containing vapor valves has a good working performance.
- The maximum output of 1500 W of the prototype is observed at a driving heat source temperature of 368 K.

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ABSTRACT

Adsorption refrigeration is considered a green refrigeration technology that can be driven by a low-grade heat source to generate cooling power. However, the large bulk of adsorption chillers can limit its use especially automobiles. The size of the adsorption chiller is a very important consideration for applying in the automobile. The new type of compact adsorption chiller applied in the automobile was proposed corresponding with the specification of the automobile installation, and was about 40 L by volume in this paper. A vacuum valve was used to increase the adsorption chiller size considerably. Thus, the new adsorption chiller has four pieces of vapor valves instead of vacuum valves, as well as two pieces of adsorbers, an evaporator, and a condenser. The vapor valve was controlled by the pressure difference at both sides. The prototype adsorption chiller was manufactured and evaluated for its cooling power and coefficient of performance by testing the inlet and outlet temperatures of the evaporator, flow rate of chilled water, and cycled time. The maximum cooling power was approximately 1.5 kW at a driving temperature of 368 K and a cycle time of 90 s.

1. Introduction

The waste heat from automobiles is a typical low grade energy and 60–65% of the total fuel energy in an internal combustion engine is considered as waste heat [1]. The temperature of the engine coolant water is about 80–95 °C [2] and the exhaust gas of 150–450 °C comes from the tailpipe [3]. Meanwhile, the energy consumption of vapor compression air conditioning in automobiles is about 20% of the total fuel energy. It is worth using waste engine heat to generate efficient cooling power to reduce the automobile energy consumption.

The adsorption refrigeration is considered a promising technology for enhancing energy efficiency because it can utilize low grade heat, such as waste heat or solar energy to provide cooling energy. An adsorption chiller is also environmentally friendly because it does not emit CFCs.

Interest in adsorption air conditioning in automobiles has increased in recent years. The advantage in adsorption air conditioning is that it can utilize waste heat from automobile engines to generate cooling power to save energy consumption and it reduces emission to protect the environment.

Numerous investigations have already been reported on various automobile adsorption system using engine coolant water or the

* Corresponding authors at: Key Laboratory of Renewable Energy, Chinese Academy of Sciences, Guangzhou 510640, China.
E-mail addresses: huanghy@ms.giec.ac.cn (H. Huang), taoli@ms.giec.ac.cn (Huhetaoli).

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Nomenclature

Ad	adsorber
COP	coefficient of performance
Q	cooling capacity (J)
SCP	specific cooling power (W/kg)
T	temperature (°C)
WCOE	coefficient of waste heat recovery
WCOP	coefficient of waste heat cooling

Subscripts

in	fluid inlet
out	fluid outlet

exhaust gas as the driving heat source of cooling system. An adsorption air conditioning system was proposed for heavy-duty truck application to reduce engine emission and to improve overall energy efficiency [3]. And the lumped parameter model of was built using zeolite-water as the working pair under the driving heat source temperature of 250 °C (exhaust gas as the driving source).

Jiangzhou et al. [4] presented the adsorption air-conditioning system used in an internal combustion engine locomotive driver cabin with the zeolite-water as working pairs. The desorption temperature varied from 200 to 250 °C by oil combustion with a burner to simulate the exhausted gas of the internal combustion engine. The mean cooling capacity of prototype was about 5 kW.

Wu et al. [5] proposed the engineering truck adsorption cooling module driven by engine waste heat and their results indicate that the cooling power came with 2.0–10.5 kW under different evaporating temperatures.

Zhang and Wang [6] developed the lumped parameter non-equilibrium model of an adsorption cooling system for automobile waste heat recovery. It was shown that the SCP is more sensitive to parameter changes than COP, WCOP, and WCOE. Later, an experimental adsorption cooling system utilizing the waste heat of a diesel engine, with zeolite-water as the working pair, was discussed. The COP of the system was 0.38 and the SCP was 25.7 W/kg [7]. Other researcher also focused on the automobile adsorption system under the high driving heat source temperature [8,9].

Meanwhile a large number of studies on the low driving heat source temperature in automobile adsorption system were presented. Using zeolite and water as the working pair, Verde [10,11] proposed a waste-heat driven adsorption system prototype for automotive air-conditioning with a total weight of 86 kg. The adsorption chiller generates an average cooling capacity of about 2.1 kW with a COP of 0.35 at the driving heat source temperature of 90 °C. The performance testing operated in full constant driving was discussed. The average cooling capacity and COP were 925 W and 0.4, respectively, under a cabin temperature of 17.5 °C.

And M. Verde et al. proposed a novel adsorption system for the air conditioning of a truck cabin which integrated the vehicle, engine and cooling as one model. Zeolite and water were considered the working pair of cooling system and the experiment using the engine coolant loop of a truck as the lab-scale adsorption chiller driving heat source (80–90 °C) was discussed. It resulted that the adsorption chiller had the 5 kW of peak cooling power at 10 °C and a COP of 0.6 [12]. A innovative adsorption cooling system including exhaust heat recovery system of automobile engine was presented, which employed an effective lumped parameter model to simulate the kinetic performance [13]. It was found that the exhaust energy of a six cylinder 3000 cc car was able to generate nearly 3 kW of cooling power. Wang et al. [14] modified an activated carbon-methanol working pair for fishing boat adsorption cooling systems to make ice using the exhaust heat from diesel engines.

Sharafian et al. [15] used the AQSOA FAM-Z02 as the adsorbent of the vehicle adsorption cooling system under adsorption and desorption temperatures of 30 and 90 °C by experiment. It showed that the adsorber bed with AQSOA FAM-Z02 had good performance of a SCP of 112.9 W/kg and a COP of 0.34 at cycle time of 10 min. Table 1 shows the variety of researches on automobile adsorption system.

However, there is no automobile adsorption air conditioning system currently available commercially because of low efficiency, large size, and weight. Most studies were carried out on enhancing the heat and mass transfer of the system and advancing the cooling cycle to improve the performance of the adsorption chiller system. These include increasing the adsorbent coefficient of heat transfer [17–19], changing the heat exchanger structure [20], and using a multi-stage system [21] among others.

The size of the adsorption chiller is a very important consideration for applying in the automobile. Downsizing the adsorption cooling system is one of the useful measures to improve its applicability, particularly for automobiles. The large bulk and high cost of vacuum valves with a large diameter generally causes an

Table 1
Different automobile adsorption system description.

Adsorbent-refrigerant pair	System details	System performance
Silica gel + water [13]	Driving heat source temperature	Adsorbent mass for 3 kW cooling power
$CaCl_2$ in silica gel + water	85	15
AQSOA Z01 + water	80	8
AQSOA Z02 + water	70	18
	90	13
AQSOA Z02 [15]	90	0.62 kg – SCP between 23.8 W/kg and 29.3 W/kg under the experimental condition 1.5 kg – SCP between 63.2 W/kg and 112.9 W/kg under the experimental condition
Silica gel-water [10,11]	90	COP 0.35, cooling power 2.1 kW
CPO-27(Ni)-water [16]	130	SCP 440 W/kg COP
Zeolite-water [3]	250	COP 0.23–0.498
Zeolite-water [8]	400	COP 0.2–0.3, Cooling power of 5 kW
Activated carbon-methanol [9]	200	COP 0.25, Cooling power of 0.65 kW, SCP of 400 W/kg