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Performance analysis on a novel sorption air conditioner for electric vehicles

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ABSTRACT

A novel sorption air conditioner for electric vehicles is presented, which is expected to reduce electricity consumption of on-board battery with a longer cruising mileage. This technology may be an alternative solution to conventional vapor compression air conditioner for current electric vehicles. Expanded natural graphite is selected in the development of composite sorbent. Performance of novel sorption air conditioner is analyzed based on sorption characteristic of composite sorbent, and a model electric car is chosen for detailed evaluation. It is indicated that sorption technology is able to be applied into electric vehicles. Energy density in winter and in summer ranges from 757 $kJ \cdot kg^{-1}$ to 1980 $kJ \cdot kg^{-1}$ and 387 $kJ \cdot kg^{-1}$ to 990 $kJ \cdot kg^{-1}$ whereas energy efficiency ranges from 0.34 to 0.82 and from 0.19 to 0.42. Also worth noting that the extra mass of sorption air conditioner system will have limited influence on cruising mileage of electric vehicles, which results in a reduction less than 4.3%. In winter, the highest saved cruising mileage by using novel sorption air conditioner is close to 100 km. Even the lowest saved mileage in summer is still able to reach 21 km, which is about 7.5% of the maximum mileage.

1. Introduction

Energy specifically that from fossil fuels, is becoming increasingly scarce and expensive. It is extensively acknowledged that urban gasoline vehicles (GVs) have become a major source of energy consumption and pollution. To deal with this issue, electric vehicles (EVs) are considered as an alternative solution with few emission by using one or more electric motors for propulsion [1]. A long cruising mileage is expected as a ultimate goal for EVs in driving process with less consumption of on-board battery [2].

For GVs, a compressor driven by the engine is performed to realize air cooling in summer. In winter waste combustion heat diverted from engine cooling circuit could supply the heat to cabin inside. Different from internal combustion engines, considerable energy is consumed to heat the interior of EVs, which inevitably requires extra electricity up to 65% from vehicles' battery in term of various operating conditions [3]. Although part of the heat could be harvested from electric motor and battery, there remains to be a large demand of heating power supplied from on-board battery, which will decrease the overall driving range by up to 60% under typical standard heating conditions [4,5]. In order to reduce the impact of air conditioner (AC) on battery in winter, current methods mainly lie in positive temperature coefficient (PTC) heating [6], semiconductor heating [7] and vapor compression heat pump [8]. Although PTC heating has been commonly applied in commercial EVs, a large amount of electricity is consumed due to its relatively low energy efficiency, which sometimes results in lack of motivation. Considering semiconductor heating for EVs, there are several shortcomings e.g. low coefficient of thermoelectric materials and poor ideal cooling performance. Also worth noting that thermoelectric reactor production is limited by the production of thermoelectric elements. Comparably, vapor compression heat pump is more inclined to be selected for EVs due to its high heating efficiency. It seems to be flexibly adapted to different types of EVs with few modification, which was once regarded as a future developing trend of AC for EVs [9]. But in the case of low ambient temperature i.e. below −10 °C, heating performance of vapor compression heat pump will be remarkably attenuated, which cannot meet heating requirements of EVs since evaporation temperature of refrigerant is too low [10,11]. When evaporator frosts in winter, heating performance will be further reduced with extra energy for defrosting, which also leads to safety problems in driving process [12]. In fact, vapor compression heat pump technology for EVs still needs to consume the electricity of on-board battery. Besides, most of the current researches of EVs focus on technology innovation to improve the capacity and efficiency of battery since battery is considered as the only energy resource. Nonetheless, it is admitted that heat and electricity load are often mutually independent, and electricity has a higher energy grade than heat. If electricity and heat can be charged and discharged respectively, vast potential working performance i.e. cruising

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Nomenclature

AC	air conditioner
CD	cold density (kJ·kg^{-1})
COP	coefficient of performance
D	power density (kW·kg^{-1})
ENG	expanded natural graphite
EVs	electric vehicles
F	driving resistance
GWP	global warming potential
GVs	gasoline vehicles
HD	heat density (kJ·kg^{-1})
M	mass (kg)
ODP	ozone depletion potential
P	pressure (Pa)
PTC	positive temperature coefficient
Q	heat (J)
R	gas constant (J·mol^{-1}·K^{-1})
S	cruising mileage (km)
T	temperature (°C)

Greek letters

ΔH	reaction enthalpy of sorbent (J·mol^{-1})
ΔS	reaction entropy of sorbent (J·mol^{-1}·K^{-1})
η	efficiency

Subscripts

a	ambient
am	ammonia
b	battery
c	cold
con	condensation
eq	equilibrium
eva	evaporation
H	high
h	heat
in	input
L	low
max	maximum
mc	mechanical and control
out	output
q	discharge of battery
R	reaction
sorb	sorbent
T	transmission

mileage of EVs will be further explored. It is quite desirable to seek for an alternative method which could supply heat and cold without extra electricity consumption.

Sorption technology has been generally recognized as a prospective energy conversion method, which demonstrates various functions of refrigeration [13], heat pump [14], energy storage [15], carbon dioxide capture [16] and electricity generation [17]. Actually sorption refrigeration in GVs has been investigated theoretically and experimentally [18]. The core concept is to supply cooling power for vehicles through sorption systems driven by the exhaust heat of engine since waste combustion heat of GVs still has a high temperature [19]. Comparably, this could be completely different scenario for EVs, i.e. both heat and cold should be supplied with non-simultaneous heat input. Also no waste heat could be recovered to drive sorption system. To effectively overcome these difficulties, chemisorption AC could be a suitable candidate for EVs, which could flexibly adjusted to external conditions by using different metal halides due to its monovariant reaction process [20]. The intermittent operating mode and performance of heat and cold cogeneration [21] also meet the requirements, which simultaneously has a capability of energy storage [22]. Interaction between ammonia and metal halides is able to provide a remarkable energy potential in exothermic process. It is worth noting that heat e.g. electric heat could be charged through sorption reaction when battery charges the electricity. The discharging processes of electricity and heat are also independent. Advantages of chemisorption AC such as high energy density, long-term storage with little heat loss, time and space discrepancy adjustment happens to overcome the problems of AC for EVs [23]. High energy density is consistent with lightweight concept of EVs while time and space discrepancy adjustment with little heat loss provides more flexibilities for AC. Compared with conventional vapor compression AC for EVs, a main modification is that compressor is replaced with sorption reactor, and other equipment are remained. Various researchers have investigated working pairs for various types of sorption reactors [24]. One remarkable fact is that granular metal halides usually have low sorption and desorption capacity due to the fact that heat and mass transfer performance will be attenuated by swelling and agglomeration in working processes [25]. Small sorption and desorption capacity increase the required mass of sorbent, which will inevitably result in excessive loads for EVs. Composite sorbent is usually considered as a common solution to overcome drawbacks of granular metal halides by using various porous matrices [26], which provides the possibility of EVs' air conditioner for real applications [27].

Our previous research has initially verified the feasibility of such type AC for EVs by using sorption and desorption characteristics of multi-salt chemisorption working pairs. The research is to present and compare the possible heat and cold output for EVs without considering metal part of reactor [28]. Since rare related researches are reported in terms of sorption AC for EVs, this paper aims to investigate working performance of novel sorption AC for EVs in terms of theoretical thermodynamics and practical factors i.e. metal ratio, mileage, etc. Sorption and desorption characteristics of composite sorbent are also used for detailed analysis.

2. Working principle of AC cycles for EVs

For better elaboration of sorption AC, conventional vapor compression AC for EVs is first introduced briefly as shown in Fig. 1, which is mainly composed of a compressor, an evaporator, a condenser, a liquid receiver, and an expansion valve. Working process of conventional vapor compression AC is illustrated as follow: After expansion process of expansion valve, the refrigerant is evaporated in the evaporator,

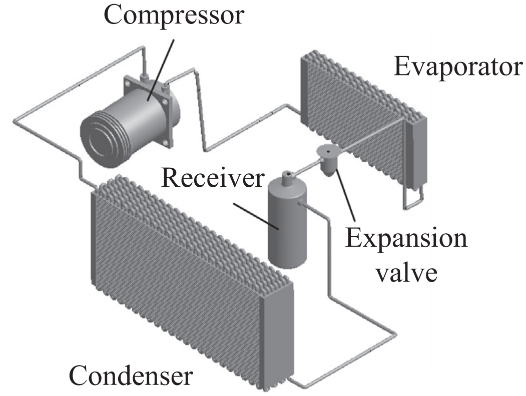

Fig. 1. Conventional vapor compression AC for EVs.