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Comparison of different kinds of heat recoveries applied in adsorption refrigeration system

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ABSTRACT

Heat recovery is an effective way to improve adsorption refrigeration system performance due to its easy realization and obvious improvement. Three kinds of heat recoveries (circular heat recovery is complete type and serial and passive heat recoveries are part type) have been applied in recent adsorption refrigerators. Theoretical analysis of three heat recovery methods has been done and results show that serial and passive heat recoveries (part type) are more optimal than circular heat recovery (complete type) when manufacture and cost are considered. Furthermore, a CFD model of a fin-tube type adsorber has been established and simulations of serial and passive heat recoveries have been done. The simulation results show that recovery time of passive heat recovery has an effective range whose value is approximately double of optimum recovery time. Thus, serial heat recovery is more reliable than passive heat recovery. Besides, Optimum recovery time of both serial and passive heat recoveries is approximately equal to the ratio of tube length to heating/cooling flow rate. Contribution distribution of recovered heat has also been analyzed. And the results show that contributions of fluid and tube regions are respectively 89%~94% and 5%~10% while contributions of adsorbent and fin regions are negligible.

Comparaison de différentes techniques de récupérations de chaleur appliquées dans un système frigorifique à adsorption

Mots clés : Simulation ; Système à adsorption ; Recupération de chaleur de type partiel ; Condition optimale

1. Introduction

Refrigeration is necessary in modern human life but the large-scale application of it poses numerous problems. The main refrigeration technology—vapor compression refrigeration consumes large amount of electric power, contributing peak load of grid in summer. CFC/HCFC, refrigerant of vapor compression refrigerator, gives rise to ozone depletion. Thermally driven refrigeration can overcome the shortcomings of vapor compression refrigeration since it can be driven

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Nomenclature

A	Coefficient
B	Coefficient
COP	Coefficient of performance
c	Specific heat capacity, J kg^{-1} K^{-1}
D	Diameter, m
F	Volume force, m s^{-2}
J	Mass flux, kg s^{-1}
L	Length, m
m	Mass, kg
P	Pressure, Pa
Q	Heat quantity, J
q	Heat flux, W
r	Radius, m
SCP	Specific cooling power, W kg^{-1}
T	Temperature, °C
t	Time, s
u	Velocity in the axis direction, m s^{-1}
v	Velocity in the radial direction, m s^{-1}
V	Flow rate, m s^{-1}
x	Adsorption capacity, kg kg^{-1}
z	Axial length, m

Greek letters

γ	Ratio
δ	Thickness, m
λ	Thermal conductivity, J m^{-1} K^{-1}
υ	Kinematic viscosity, m^2 s^{-1}
ρ	Density, kg m^{-3}

Subscript

a	Adsorbent
c	Condensation
cf	Cooling fluid
e	Evaporation
f	Fin
h	Heating
hc	Half cycle
hf	Heating fluid
hr	Heat recovery
in	Inlet
o	Outlet
t	Tube

Abbreviations

HAT	High temperature adsorber
LTA	Low temperature adsorber

by waste heat or solar energy and use natural refrigerant. Hence, thermally driven refrigeration is paid more and more attention by researchers in recent years (Cho et al., 2009; Wang et al., 2010).

Adsorption refrigeration is a promising refrigeration technology since it can be driven by low-grade heat (60 °C~150 °C) and employ natural refrigerants, such as water, methanol or ammonia (Wang et al., 2011). In addition, it has advantages of simple control, low operating cost and less vibration (Lu et al., 2007). However adsorption refrigeration system has not been widely applied due to its low efficiency and large system size. In order to overcome these shortcomings of adsorption refrigeration, adsorbers with high heat and mass transfer performance and advanced adsorption refrigeration cycles were developed. Several different structural forms of adsorbers (Wang et al., 1998) (like shell and fin-tube type, plate-fin type and spiral plate type) were adopted to intensify the heat transfer performance by extending heat transfer surface. Meanwhile, a number of advanced adsorption refrigeration cycles (Akahira et al., 2004; Douss et al., 1988; Pons, 1997; Shelton et al., 1989, 1990; Taylan et al., 2012; Wang, 2001) (like heat recovery cycle, thermal wave cycle, mass recovery cycle, etc.) were proposed and studied. Thermal wave cycle can exceedingly improve system performance via recovering the adsorption heat to reduce energy input. The simulation results obtained by Pons (1997) showed that the coefficient of performance (COP) of thermal wave cycle could reach 1.18. But due to the great difficulty of fulfillment in practical machine, thermal wave cycle is still in the theoretical stage. On the contrary, heat recovery and mass recovery cycles have been successfully adopted in practical application. In two adsorbers system, heat recovery cycle is used to recover heat from the hot adsorber to the cool adsorber when adsorption/desorption switches, thus the reduction of energy input contribute to the improvement of cycle COP. Mass recovery cycle can intensify the adsorption and desorption reaction via balancing the adsorption and desorption pressures at the end of adsorption/desorption phase. So the circulated quantity of refrigerant enlarges, meaning that cooling capacity increases and cycle COP rises. The simulation done by Wang (2001) showed that the COPs of heat and mass recovery cycles could be increased by 25% and 10%, respectively. The remarkable improvement in performance and easy realization makes heat recovery and mass recovery cycles be extensively applied in recent adsorption refrigeration prototypes (Chen et al., 2010; Gong et al., 2012; Liu et al., 2005; Lu and Wang, 2013; Lu et al., 2007; Wang et al., 2005a, 2005b).

As one of the most effective cycles, mass recovery cycle has been adequately studied in theory and experiment when it is applied in different adsorption refrigeration system structure, like two adsorbers, multi adsorbers, two evaporators, etc (Khan et al., 2007; Lu and Wang, 2013; Pan et al., 2014; Uyun et al., 2009). However, researches on heat recovery cycle is concentrated in complete type heat recovery (Lu et al., 2007; Neveu and Castaing, 1993; Teng et al., 1997; van Benthem et al., 1995; Wang et al., 1998). Teng et al. (1997) computed the maximum recovered heat of an active carbon-methanol adsorption system and analyzed the improvement of the complete type heat recovery cycle when compared with an basic cycle. Test unit (Wang et al., 1998) and refrigerator (Lu et al., 2007) using complete type heat recovery cycle have also been experimentally studied. However, the internal heat is almost impossible to recover completely in actual situation. Thus part type heat recovery cycle with more easier and simpler fulfillment leads to the common use in adsorption refrigeration prototypes (Chen et al., 2010; Gong et al., 2012;