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Composite adsorbent of $CaCl_2$ and expanded graphite for adsorption ice maker on fishing boats

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Abstract

Adsorption performances and thermal conductivity were tested for three types of adsorbent: Pure $CaCl_2$ powder, simple composite adsorbent and consolidated composite adsorbent. The simple composite adsorbents show better adsorption performance because the additive of expanded graphite in $CaCl_2$ powder has restrained the agglomeration phenomenon in adsorption process and improved the adsorption performance of $CaCl_2$. The consolidated composite adsorbent are suitable to be used as adsorbent for ice maker on fishing boats because they have higher thermal conductivity, larger volumetric cooling capacity, higher SCP values and better anti-sway performance than simple composite adsorbents. Thermal conductivity of the consolidated composite adsorbent is 6.5–9.8 W m^{-1} K^{-1} depending on the molding pressure, ranging from 5 to 15 MPa, which is about 32 times higher than the thermal conductivity of $CaCl_2$ powder. The volumetric cooling capacity of consolidated composite adsorbent is about 52% higher than the best result obtained for $CaCl_2$ at the evaporating temperature of −10 °C. The SCP of the consolidated adsorbent increases of about 353% than $CaCl_2$ powder from simulation results at $T_{ad}=30$ °C and $T_{ev}=-10$ °C. The consolidated composite adsorbents have good anti-sway performance and they are not easy to be scattered out when the fishing boats sway on the sea.

Keywords: Adsorption system; Ice maker; Boat; Trawler; Experiment; Adsorbent; Calcium chloride; Additive; Graphite; Performance

Machine à glace à adsorption utilisée à bord des bateaux de pêche: adsorbant au $CaCl_2$/graphite expansé

Mots clés : Système à adsorption ; Machine à glace ; Navire ; Chalutier ; Expérimentation ; Adsorbant ; Chlorure de calcium ; Additif ; Graphite ; Performance

1. Introduction

Adsorption refrigerator and heat pump have been thought to be environment benign and cost effective when driven by recovered waste heat [1]. In comparison with absorption systems, an adsorption system has no such problems as coolant pollution, crystallization and fractionation, while in comparison with vapor compression refrigerating systems, it has the advantages of simple control, low initial investment and less noise [2].

The composite adsorbent made by $CaCl_2$ and expanded graphite presented in this paper was based on our previous

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Nomenclature

COP	coefficient of performance
EG	expanded graphite
Global conversion	ratio of adsorption capacity and maximum adsorption capacity
h_T	ammonia latent heat of vaporization (kJ kg^{-1})
I	electric current (A)
L	length of the nickel chromium wire (m)
m	mass of adsorbent (kg)
P	molding pressure (MPa)
p/p_0	relative pressure of nitrogen at 77 K
q_{hg}	generation heat for desorption for unit mass adsorbent (J kg^{-1})
q_{ref}	cooling power of unit mass adsorbent (J kg^{-1})
Q_s	volumetric cooling capacity (kJ m^{-3})
r	distance between the hot wire and the measuring thermal couple (m)
r_h	hydraulic radius of pore (Å)
R_1	thermal resistance at interface between heat exchanger tube and adsorbent
R_2	thermal resistance of adsorbent
SCP	specific cooling power (W kg^{-1})
SEM	scanning electron microscope
S_{BET}	specific surface area calculated by the BET method (m^2 g^{-1})
Δt	cycle time (s)
T	temperature (°C)
T_{ad}	adsorption temperature (°C)
T_c	condensing temperature (°C)
T_{ev}	evaporating temperature (°C)
T_{de}	desorption temperature (°C)
θ_1, θ_2	the temperature related to t_1 and t_2 (°C)
t_1, t_2	the measurement time (s)
V	electric voltage (V)
V_a	the volume of the adsorbent (m^3)
V_T	total pore volume calculated from gas volume at S.T.P. (cm^3 g^{-1})
x	refrigerant mass fraction in $CaCl_2$ and in simple composite adsorbent (kg kg^{-1})
x_c	refrigerant mass fraction in consolidated composite adsorbent (kg kg^{-1})
Δx	adsorption capacity (kg kg^{-1})

Greek letters

α_0	heat transfer coefficient at interface between heat exchanger tube and fluid (W m^{-2} K^{-1})
α_i	heat transfer coefficient at interface between heat exchanger tube and adsorbent (W m^{-2} K^{-1})
α	thermal diffusivity (m^2 s^{-1})
λ	thermal conductivity (W m^{-1} K^{-1})
ρ	bulk density of consolidated composite adsorbent (kg m^{-3})

[3] work and mainly designed for the adsorption ice maker on fishing boats. In this paper, we present the experiment results of thermal conductivity, volumetric cooling capacity of five different adsorbent. A simulation is also performed to evaluate the COP and SCP values of these adsorbents.

There are two challenges for the design of adsorption ice maker using calcium chloride: The low heat transfer properties of $CaCl_2$ powder and the occurrence of the agglomeration phenomenon around the $CaCl_2$ particles. Packed bed of granular adsorbents is the most basic design of an adsorber. A major problem with the granular adsorbents of packed bed used in adsorption refrigeration system is their poor thermal conductivity. The adsorbent must be heated (desorption phase) and then cooled (adsorption phase) back to ambient temperature in order to complete a cycle. Each cycle completed results in a specific quantity of heat being pumped between two temperature levels. In order to achieve low capital costs the system must be physically small (special in the fishing boats) and hence the time per cycle must be small. This in turn requires high rates of heat transfer in and out of the adsorbent. The consolidated composite adsorbents of expanded graphite–$CaCl_2$ have higher thermal conductivity and density than the granular adsorbents. The purpose to increase the thermal conductivity of $CaCl_2$ with addition of expanded graphite is to increase the heat transfer rate in and out adsorbent. However, it also decreases the volume of the adsorber and produces more compacter adsorption ice maker which is suitable to be used on the fishing boats.

The second challenge in the design of an adsorption refrigeration system using $CaCl_2$, is the occurrence of the phenomenon of agglomeration of refrigerant around the particles of $CaCl_2$ in the adsorption phase. The first $CaCl_2$ grains that adsorb ammonia stick to the closest grains, which create a large non-porous grain. Any other molecule of ammonia cannot reach the center of this large grain and thus part of the salt cannot react completely. Serious agglomeration phenomenon of the adsorbent leads to the deterioration of adsorption performance. Many researches have been carried out on the composite adsorbent and results show that composite adsorbents can improve the mass transfer performance of chemical adsorbents and can avoid the agglomeration phenomenon. Mikhail Tokarev confined $CaCl_2$ to mesoporous host matrix MCM-41 to improve the mass transfer that caused by agglomeration [4]. Dellero has studied three mixtures of carbon fibers with $MnCl_2$, the sample of GFIC (intercalation of $MnCl_2$ into ex-pitch graphitized carbon fibers P120) not only provide a very fast reaction but also give a complete reaction by avoiding the