ADSORBENTS AND STRATEGIES FOR HIGHER PERFORMANCE ADSORPTION CHILLERS

S SAI SARAN YAGNAMURTHY

DEPARTMENT OF ENERGY SCIENCE AND ENGINEERING

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ADSORBENTS AND STRATEGIES FOR HIGHER PERFORMANCE ADSORPTION CHILLERS

by

S SAI SARAN YAGNAMURTHY

Department of Energy Science and Engineering

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Certificate

This is to certify that the thesis entitled "**Adsorbents and strategies for higher performance adsorption chillers**" being submitted by Mr. S. Sai Saran Yagnamurthy to the Indian Institute of Technology Delhi in fulfillment of the requirements for the award of the degree of 'Doctor of Philosophy' is a record of the original bonafide research work carried out by him under our guidance and supervision at Department of Energy Science and Engineering, Indian Institute of Technology Delhi. The results contained in the thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

(Dr. Dibakar Rakshit)

Associate Professor,

Centre for Energy Studies,

Indian Institute of Technology Delhi,

Hauz Khas New Delhi - 110016

(Dr. Sanjeev Jain)

Professor,

Department of Mechanical Engineering,

Indian Institute of Technology Delhi,

Hauz Khas New Delhi - 110016

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ABSTRACT

Cooling accounts for a significant share of global energy demand, and is expected to grow triple fold by the year 2050. With the major dependency on fossil fuels for energy needs and their depletion over time, the world may experience a cold crunch due to an inability to meet the growing cooling energy demands. In addition to increasing the energy efficiency measures for the cooling technologies and spaces, alternative energy powered cooling technologies are needed to reduce the grid dependency for cooling.

Among the various alternatives explored for cooling needs, adsorption cooling technology has shown potential through its capability to operate with low grade energy sources, along with having lower maintenance issues due to fewer moving parts. However, their bulky system sizes and high cost in comparison to the conventional Vapor Compression Refrigeration (VCR) systems have been the primary setback to the wide scale deployment of this technology. Nevertheless, a significant potential for improvement is possible due to the wide variety of working pairs, design configurations and operational cycles in these systems. The present thesis attempts to further the research on some of these aspects of adsorption cooling systems, through both experimental and numerical studies.

To study the influence of operating cycle parameters and strategies, an experimental facility has been developed for testing a two-bed chiller system with the widely employed silica gel-water pair. Passive heat recovery and two-stage operation strategies have been proposed in this study for the enhancement of performance and operational envelopes through modifications in the chiller’s valves sequencing. An improvement of 22-42% in COP has been observed with an optimized passive heat recovery strategy over the default operation mode of the chiller. Two kinds

of two-stage operations *viz.*, conventional two-stage and reheat two-stage have been explored, which yielded a lowering of minimum desorption temperature to 40℃.

To study the scope of the upcoming low GWP refrigerant of R32, activated carbon composites with H25 graphene nanoplatelets (GNPs), 1-Hexyl-3-methylimidazolium bis(trifluormethylsulfonyl)imide ([HMIM][Tf_2N]) ionic liquid and Polyvinyl alcohol (PVA), have been studied for thermophysical properties and adsorption characteristics. Anisotropic thermal diffusivities have been studied for the GNP based composites, where a large improvement in thermal conductivity of up to 65.6 times has been observed over powdered activated carbon. Further, lumped and distributed parameter modeling studies of the composite-R32 pairs have been carried out for compact heat exchanger design selections.

A comparative assessment between the silicagel-water and activated carbon-R32 (AC-R32) systems has shown that the latter has 17-61% lower COPs over the former. However, since the AC-R32 system has the distinctive advantage of being applicable for sub-zero cooling temperatures, its performance has been studied for an evaporator temperature of (-5)°C where lower COPs (≤0.12) have been observed. A COP improvement up to 3.7 times has been estimated through a suitable cascading strategy between the silica gel-water and AC-R32 systems.

सार

शीतलन वैश्विक ऊर्जा की मांग का एक महत्वपूर्ण हिस्सा है, और वर्ष 2050 तक इसके तीन गुना बढ़ने की उम्मीद है। ऊर्जा की जरूरतों के लिए जीवाश्म ईंधन पर प्रमुख निर्भरता और समय के साथ इसकी कमी के साथ, दुनिया में शीतलन के प्रयोग में तीव्र कमी का अनुभव हो सकता है। बढ़ती शीतलन ऊर्जा की मांगों को पूरा करने के लिए शीतलन प्रौद्योगिकियों और रिक्त स्थान के लिए ऊर्जा की दक्षता के उपायों को बढ़ाने के अलावा, शीतलन के लिए ग्रिड निर्भरता को कम करने के लिए वैकल्पिक ऊर्जा से संचालित शीतलन प्रौद्योगिकियों की आवश्यकता है।

शीतलन आवश्यकताओं के लिए खोजे गए विभिन्न विकल्पों में, आडसोर्प्शन शीतलन तकनीक ने कम गति वाले भागों के कारण कम रखरखाव के मुद्दों के साथ-साथ निम्न ग्रेड ऊर्जा स्रोतों के साथ काम करने की क्षमता दिखाई है। हालांकि, पारंपरिक वाष्प संपीड़न प्रशीतन (VCR) प्रणालियों की तुलना में उनके भारी सिस्टम के आकार और उच्च लागत की इस तकनीक के व्यापक पैमाने पर लागू करने के लिए प्राथमिक अवरोध आ रहे हैं। फिर भी, इन प्रणालियों में काम करने वाली सामग्री, डिजाइन और परिचालन चक्रों की विस्तृत विविधता के कारण एक महत्वपूर्ण सुधार की संभावना है। वर्तमान में थीसिस, प्रयोगात्मक और संख्यात्मक दोनों अध्ययनों के माध्यम से आडसोर्प्शन शीतलन प्रणाली के इन पहलुओं में से कुछ पर शोध को आगे बढ़ाने का प्रयास करती है।

ऑपरेटिंग चक्र मापदंडों और रणनीतियों के प्रभाव का अध्ययन करने के लिए, व्यापक रूप से नियोजित सिलिका जेल-वाटर जोड़ी के साथ दो-बेड चिलर सिस्टम के परीक्षण के लिए एक प्रयोगात्मक सुविधा विकसित की गई है। इस अध्ययन में चिलर के वाल्व के अनुक्रमण में संशोधनों के माध्यम से उत्पादन और परिचालन आवरण को बढ़ाने के लिए निष्क्रिय गर्मी की वसूली (passive heat recovery) और दो-चरण (2 stage) संचालन रणनीतियों का प्रस्ताव दिया गया है। चिलर के डिफ़ॉल्ट ऑपरेशन मोड पर एक अनुकूलित निष्क्रिय गर्मी की वसूली की रणनीति के साथ COP में 22-42% का सुधार देखा गया है। दो प्रकार के दो-चरण

के संचालन, “conventional” और “reheat” का अध्ययन हुआ है, जिससे न्यूनतम desorption तापमान 40 °C तक कम हो गया।

निम्न GWP रेफ्रिजरेंट R32 का अध्ययन करने के लिए, H25 ग्राफीन नैनोप्लेटलेट्स (GNPs), 1-हेक्सिल-3-मिथाइलिमिडाज़ोलियम बीआईएस (ट्राइफ्लोरोमेथाइलसल्फ़ोनिल) इमाइड ([HMIM] [Tf2N]) आयनिक तरल और पॉलीविनाइल अल्कोहल (PVA) से बने एक्टिवेटिड कार्बन कंपोजिट्स को थर्मोफिजिकल गुणों और आडसोर्प्शन विशेषताओं के लिए अध्ययन किया गया है। जीएनपी आधारित कंपोजिट के लिए अनिसोट्रोपिक थर्मल डिफ्यूसिविटी का अध्ययन किया गया है, जहां पाउडर एक्टिवेटिड कार्बन की थर्मल कंडक्टिविटी पर 65.6 गुना तक का एक बड़ा सुधार देखा गया है। इसके अलावा, कॉम्पैक्ट हीट एक्सचेंजर डिजाइन चयन के लिए समग्र-R32 जोड़े के लम्प्ड और डिस्ट्रिब्यूटेड पैरामीटर मॉडलिंग अध्ययन किए गए हैं।

सिलिकजेल-वाटर और एक्टिवेटिड कार्बन-R32 (AC-R32) सिस्टम के बीच एक तुलनात्मक मूल्यांकन से पता चला है कि बाद वाले में पूर्व की तुलना में 17-61% कम COP हैं। हालांकि, AC-R32 प्रणाली में उप-शून्य शीतलन तापमान के लिए लागू होने का विशिष्ट लाभ है। इसके उत्पादन का अध्ययन (-5) डिग्री सेल्सियस के ऐवपोरटर तापमान के लिए किया गया है जहां कम COP (≤ 0.12) देखा गया है। सिलिका जेल-वाटर और AC-R32 सिस्टम के बीच उपयुक्त कैस्केडिंग रणनीति के माध्यम से 3.7 गुना तक COP सुधार का अनुमान लगाया गया है।

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Nomenclature

A : Area (m^2)

b_0 : Pre-exponential constant (kPa^{-1})

C_p : Specific heat capacity (kJ/kg.K)

CHTC : Contact heat transfer coefficient ($W/m^2.K$)

D : Pore diameter (m)

Ds : Diffusion coefficient (m^2/s)

E : Adsorption characteristics parameter (kJ/kg)

E_a : Activation energy (kJ/kg)

F_s : shape factor of adsorbent particle (-)

f : Fugacity of refrigerant (Pa)

H : Henry's constant (-)

$F_s\ D_o/r_p^2$: Preexponential diffusion constant (s^{-1})

h_{fg} : Enthalpy of vaporisation (kJ/kg)

K_o : Pre exponential Toth's constant (Pa^{-1})

M : Mass (kg)

$\dot{m}$: mass flow rate (kg/s)

n : Heterogeneity/Toth's parameter (-)

ns : No. of stages

P : Pressure (kPa)

Q_{st} : Heat of adsorption (kJ/kg)

r : Radius (m)

R : Gas constant (kJ/kg.K)

T : Temperature (K)

t : Time (s)

UA : Overall heat transfer coefficient (kW/K)

V : Volume (m^3)

W : Mass of adsorbate per unit mass of adsorbent (kg/kg)

X : Annular fin pitch (m)

x : Thickness (m)

Z : Partial molar volume of solute in solvent (m^3)

z : Mole fraction

α : Thermal diffusivity (m^2/s)

ε : Porosity

λ : Permeability (m^2)

ρ : Density (kg/m^3)

μ : Viscosity (Pa.s)

θ : Longitudinal fin pitch (radians)

Φ : Fractional uptake (-)

Subscripts

ads : adsorber

annular : annular configuration

BET : total monolayer or BET surface area

bed : adsorbent bed

C : Critical

Cin : Cooling source inlet

CHin : Chilled fluid inlet

cond : condenser

cycle : cycle time

des : desorber

e : equalization

eq : equilibrium

eva : evaporator

fin : Heat exchanger fin

flow : Heat transfer fluid

Hin : Heat source inlet

hex : Heat exchanger metal

in : inlet

initial : initial value

l : refrigerant liquid

longi : longitudinal configuration

max : maximum pore diameter

min : minimum pore diameter

o : maximum uptake

out : outlet

p : particle

sample : composite sample

sat : saturated

sk : skeletal volume

tube : Heat exchanger tube

vapor : refrigerant vapor

Abbreviations

COP : Coefficient of Performance
CHW : Chilled Water
CW : Cooling Water
HW : Hot water
LMTD : Logarithmic Mean Temperature Difference
LPM : Litres per minute
LPH : Litres per hour