



THE UNIVERSITY
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**STUDY OF ACTIVATED CARBON/METHANOL
ADSORPTION REFRIGERATION TUBE
AND SYSTEM INTEGRATION**

BY

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Abstract

Solid adsorption refrigeration systems are attracting much research interest because they have numerous advantages, such as using low grade thermal energy and being environment friendly. In recent decades many efforts have been put into developing various prototypes. The adsorption refrigeration tube (ART) is one such development. Through better system integration, a module consisting of a number of individually working ARTs can achieve significant refrigeration capacity, which may solve the vacuum leaking problem that besets large adsorption systems.

In order to propose a feasible ART, this thesis undertakes a study of adsorptive properties of three types of activated carbon/methanol working pairs and modelling of the adsorption refrigeration cycle.

In this examination of adsorptive properties, three activated carbon samples, Calgon 207C, 207EA and WS-480, were used to test and determine their pressure-temperature-concentration ($P-T-x$) relationship with methanol as the adsorbate. Based on the experimental data, three adsorption state equations, Langmuir equation, Freundlich equation and Dubinin-Astakov (D-A) equation, were compared in terms of their agreement with experimental data and their format impact on calculating coefficient of performance (COP) and refrigeration output (Q_r), if one of the formats was used for presenting experimental data. Moreover, a sensitivity analysis was conducted to reveal the parameters' sensitivity to calculation of COP and Q_r . It was found in this study that the D-A equation is the best state equation for presenting the adsorptive properties of the tested activated carbon/methanol working pairs in terms of the best agreement of $P-T-x$ correlation and least sensitivities to parameters' errors.

A1-D dynamic model was established and validated experimentally, in which a local non-equilibrium treatment and dynamic boundary condition were introduced to the mathematical model. Regarding thermal non-equilibrium treatment, the temperatures of the local solid phase (activated carbon and adsorbed methanol) and local fluid phase were treated separately. Due to this non-equilibrium treatment, i.e. a two temperature treatment, convective heat transfer within the transport pores of activated carbon can be considered in the mathematical model. Moreover, a mathematically defined function was introduced to present the transient pressure process at the beginning of an adsorption process. Using this function, the temperature jump phenomenon can be well predicted by the mathematical model.

After the mathematical model had been established and validated, a parametric analysis was conducted using the mathematical model. The effects of the cylindrical activated carbon column's diameter and evaporating temperature on cycle time, COP and specific cooling power (SCP) were examined. Furthermore, a case study of cycle time optimisation was conducted.

Finally, based on the parametric analysis, a practical solution using integrated groups of individual ART was proposed for home or domestic application. A preliminary economics analysis was also conducted to evaluate the potential of this application.

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Nomenclature

Abbreviation

D-A	Dubinin-Astakhov
ART	Adsorption Refrigeration Tube
ARTs	Adsorption Refrigeration Tubes
COP	Coefficient of Performance
SCP	Specific Cooling Power
H-R	Heat Recovery
M-R	Mass Recovery
WBA	Water Bath A
WBB	Water Bath B

Notation

A_0	Specific surface area of adsorbent	1/m
C	Gas density	mol/m ³
D	Parameter in D-A equation	
D_{eb}	Effective diffusion coefficient of adsorbent bed	m ² /s
d_h	Hydraulic diameter of transport pores	m
h_0	Specific enthalpy	J/kg
h	Heat transfer coefficient	W/m ² K
H	Enthalpy	J
L_0	Latent heat of vaporation	kJ/kg
L	Physical length of component	m

M_0	Molar mass	kg/mol
M	Mass	kg
P	Pressure	bar
Q	Heat flow	W
Q_{st}	Adsorption heat, a constant in Langmuir	J/kg
R_i	Inside radius of carbon column	m
R_o	Outside radius of carbon column	m
R	Universal gas constant	J/mol K
R_0	Specific gas constant of methanol	J/kg K
T	Temperature	K or °C
t	Time	s
x	Adsorbate concentration	kg/kg
x_0	A constant in D-A equation or Freundlich	kg/kg
n	A constant in D-A equation or Freundlich	
K_0'	The adsorption constant in Langmuir equation	
K	Permeability of porous adsorbent bed	m ²
c	Specific heat capacity	J/kg K

Greek Symbols

ρ	Density	Kg/m ³
λ	Thermal conductivity	W/m K
ε	Effective porosity	
μ	Dynamic viscosity	Pa s
α	Coefficient reflecting the transient pressure	1/s

Subscripts

<i>s</i>	Solid phase
<i>f</i>	Fluid phase
<i>g</i>	Gas phase
<i>l</i>	Liquid phase
<i>hw</i>	Hot water (simulated heat source)
<i>cw</i>	Cool water(simulated heat sink)
<i>e</i>	Evaporating status or evaporator
<i>c</i>	Condensing status or condenser
<i>sat</i>	Saturation status
<i>tra</i>	Transient process
<i>ini</i>	Initial status
<i>in</i>	Internal
<i>ex</i>	External
<i>eq</i>	Equilibrium status
<i>ge</i>	Generator
<i>r</i>	Refrigeration or refrigerant (methanol)
<i>ac</i>	Activated carbon
max	Maximum value
min	Minimum value
1,2,3,4,3',4'	Status of relevant processes