UNIVERSITI PUTRA MALAYSIA

ADSORPTION PROPERTIES OF MALAYSIAN ACTIVATED CARBON FOR USE IN SOLAR REFRIGERATOR

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Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

PROPERTIES OF MALAYSIAN ACTIVATED CARBON USE IN SOLAR ADSORPTION REFRIGERATOR

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August 2002

Chairman: Professor Mohd. Yusof Sulaiman, Ph.D.

Faculty: Science and Environmental Studies

Detail experiments and analyses have been made on the solar refrigerator using activated charcoal and methanol adsorption cycle. A test rig was designed to study adsorption and desorption capability of activated carbon. A comparison has been made between adsorbability of six Malaysian commercial activated carbons. To improve the adsorbability of the carbon a simple method was tested.

Base on Dubinin equation, some thermodynamic properties of adsorbent/ adsorbate necessary for refrigeration calculation had been obtained. In this experiment methanol is used as the refrigerant medium. The amount of methanol adsorbed by the activated carbon was measured as a function of temperature of the activated carbon. During the experiment, the temperature of the unadsorbed methanol was kept constant. From Dubinin-Astakhov equation, parameters of adsorption data were determined using graphical analysis. A Claperyon P-T-X (pressure, temperature and concentration) diagram was then constructed.

The Coefficient of Performance (COP) of the activated carbon was then calculated as a function of maximum collector temperature for different condenser and evaporator temperatures. From these results of the Coefficient of Performance of ideal adsorption refrigeration cycles applicable in solar heated adsorption refrigerators are calculated. The results of the COP calculation for collector temperature of 100°C, condenser temperature 30°C and evaporator temperature of -10°C are as follows:

Activated carbon Type	2030	4050	5060	6070	7080	5060(4x8)
COP	0.2566	0.2494	0.2563	0.2656	0.2768	0.2535

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SIFAT-SIFAT BUATAN MALAYSIA KARBON TERAKTIF BAGI PENJERAPAN SURIA KE ATUS PETI SEJUK

Oleh

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Ujikaji terperinci dan analisis telah dilaksanakan ke atas alat penyejuk yang menggunakan kitar penjerapan karbon teraktif dan metanol. Suatu rig mengujian telah direka bentuk untuk mengkaji kebolehan karbon teraktif menjerap dan menyahjerap. Perbandingan telah dibuat terhadap sifat penjerapan enam jenis karbon teraktif komersial buatan Malaysia. Untuk memperbaiki sifat penjerapan karbon, suatu kaedah mudah telah diuji.

Berpandukan ke atas persamaan Dubinin, beberapa sifat termodinamik penjerap bahan terjerap yang diperlukan untuk pengiraan penyejukan telah diperolehi. Dalam ujikaji ini metanol digunakan sebagai media pendingin. Amaun metanol yang dijerap oleh karbon terakdit telah diukur terhdap perubahan suhu karbon teraktif. Semasa ujikaji, suhu metanol yang tak terserap ditetapkan. Dari persamaan Dubinin-Astakhov, parameter data penjerapan ditentukan menggunakan analisis grad. Rajih Claperyon P-T-X (tekanan, suhu dan depadatan) kemudiannya dibentuk.

Pekali prestasi (COP) karbon teraktif dikira menurut fungsi suhu pengumpul untuk suhu kondenser dan penyejat yan berbeza. Dari hasil pengiraan ini prestasi kitar penyejuk penjerapan unggul yang terpakai kepada alat penyenjuk penjerapan yang padankyu menggunakan teuga suria dapat dikira. Hasil pengiraan COP untuk suhu pengumpul 100 °C, suhu kondenser 30 °C dan suhu dan penyerat –10 °C adalah seperti berikut.

Jensi karbon teraktif	2030	4050	5060	6070	7080	5060(4x8)
COP	0.2566	0.2494	0.2563	0.2656	0.2768	0.2535

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I certify that an Examination Committee met on 12th August 2002 to conduct the final examination of Nyein Chan Win @ Mohd. Ali on his Master of Science thesis entitled "Adsorption Properties of Malaysian Activated Carbon for Use in Solar Refrigerator" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follow:

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master Science. The members of the Supervisory Committee as follow:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NYEIN CHAN WIN @ MOHD. ALI

Date: 7. 10. 2002

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Abbreviation		Unit
COP	Coefficient of Performance	
D-A	Dubinin-Astakhov	
D-R	Dubinin-Radushkevich	
TIM	Transparent Insulation Material	
A	Area	m^2
C	Specific heat	J/kgK
D	Parameter in D-R or D-A equations	
F	Function	
H	Enthalpy	J
L	Latent heat of vaporization	kJ/kg
M	Molecular weight	kg/kmol
P	Pressure	bar
Ps	Saturation vapor pressure	bar
Q	Heat flow	W
R	Universal gas constant	J/kmolK
Tc	Temperature of the Condenser	^oK or ^oC
Teva	Temperature of the evaporator	^oK or ^oC
Tm	Temperature of methanol	^oK or ^oC
V	Volume	m^3
W	Volume filled by the adsorbate in adsorbent	L/kg
W_o	Maximum volume available for adsorbate in adsorbent	L/kg
Xmix	Maximum Concentration	g/g/
Xmin	Minimum Concentration	
X	Concentration	g/g
ρ	Density	kg/m^3

CHAPTER 1

INTRODUCTION

The limited availability of fossil energy carriers and the environmental impact of energy consumption demand mid- and long-term strategies both for the rational use of energy and for increased renewable energy utilization. Concepts of renewable energy conversion have been proposed and implemented during recent decades all over the world and then remarkable potential has been demonstrated. However, large scales implementation in the context of the requirements above has not yet taken place.

Unlike non-renewable energy (fossil fuels), the supply of renewable energy (solar, wind, waves, etc) is 'infinite'. Moreover the net impact of renewable energy conversion on the environment is considerably lower than the impact of traditional energy, which is a current concern for the whole world. As a result of the energy crisis, attention has been focused on the need, not only to conserve conventional sources of energy, but also to explore non-conventional sources of energy such as solar radiation, wind, biomass, tides, geothermal sources etc. There is no reason why these important natural resources should not be exploited for the benefit of the developing countries, particularly solar radiation, which is relatively abundant in most places.

During the last few decades, an increasing interest, based on research and development has been concentrated on utilization of non-conventional energy sources, namely solar energy, wind energy, tidal waves, biogas, geothermal energy, hydropower, hydrogen energy, etc. Among these sources, solar energy, which is an energy source for cooling applications, is a highly popular source due to the following facts: direct and easy usability, renewable and continuity maintaining the same quality, being safe, being free, being environment friendly and not being under the monopoly of anyone.

As a future reseıve of fossil fuel becomes depleted, scientists and engineers are responsible to develop new technologies to exploit renewable energy resources. The sun is the major sources of renewable energy on the earth. Solar energy is one of vital research target in the future. It is hoped that with the further improvements in this technology, solar energy will supply not only the needs of industry but also the everyday needs of the population in the rural and remote areas.

Some of the earliest experiments on refrigeration for preservation date back to the fifth century (Warren, 1979). Since then, there has been a continuous search for cheap methods of providing could be for these purposes. At present, the most common means of producing cold for storage purposes is by the use of vapour compression units powered by electricity. In rural areas, this method of cold production is not easily available because of the non-availability of electricity. This has been affecting their standard of living. Acquisition of the appropriate capability to produce cold in these areas, therefore, will assist significantly in improving their standard of living. Four main options may be considered for this purpose (Critoph, 1990)

(i) extension of grid connected electricity to power refrigerators,

(ii) access road for use of on board refrigerated transport,

(iii) use of photovoltaic refrigerators and

(iv) use of heat driven refrigerator or ice-maker.

Options (i) to (iii) above are too expensive to suggest that cold storage will be available to the areas in most need of them. This leaves the heat driven ice-maker as the most viable solution to the problem of extending cold to rural areas. The operation of heat driven refrigerators is either continuous or intermittent. While the continuous heat driven refrigerator still depends on electricity to power solution pumps, the intermittent system depends only on heat for operation and does not have any moving part. Because low-grade heat is required to power the system, it is possible for locally available heat sources, like solar energy and fossil fuel, to be used. This makes it very attractive in remote regions without grid connected electricity.

Cold production using solar energy appears very attractive. This is because cold is needed most when solar radiation is highest. Also, solar radiation is freely available and non-polluting. Solar cooling seems to be a very attractive application for solar energy since more cooling is necessary when more solar energy is available. Nevertheless, to date, most efforts for promoting solar cooling have failed. Solar cooling would be a useful technology in areas of the world where there is a demand for cooling high isolation levels and no firm electricity supply to power conventional systems. In tropical areas, domestic hot water and space heating are not neccssities, but also solar refrigeration could be used for storing agricultural products, food and medicines. The most promising applications are vaccine storage and food storage (particularly fish). Several different solar thermal refrigeration have been studied for some years and many refrigerators were built and tested.

There are two ways to use solar energy to operate refrigerators. The first one is to convert solar radiation into heat to run a thermally powered absorption or adsorption refrigeration system. The second way is to convert solar radiation into electricity by means of photovoltaic cells to drive a conventional refrigerator.

Photovoltaic converters and compression refrigerators are currently being developed for small-scale domestic use and for the preservation of vaccines in isolated areas. Adsorption refrigeration systems with thermal solar collectors enjoy a wider range of possible applications, which include air-conditioning, medium-scale cold storage, ice manufacturing, and the same small-scale uses as the photovoltaic systems.

The whole subject of solar powered refrigeration thus embraces a variety of solar and refrigeration technologies, all of which are active areas of research and development at the present time. However, none of the systems developed to date are economically viable because they are too expensive. Efforts are being made to improve efficiencies and bring down costs, but there is still little to choose between the various types, and it is difficult to see which, if any, will ultimately secure appreciable markets.

The direct used of solar energy as thermal power has gathered considerable interest. Comparing with PV system, the thermal cooling system is low cost, more maintenance free and the possibility of local production in developing countries. The simplest form of thermal adsorption refrigeration cycle is intermittent which requires low maintenance. The only complex control action needed is that the power source cycles from the off to on start. Since the sun automatically cycle, this complexity is even removed. It may additional be an advantage in vaccine cooling application that the collection of the solar energy is necessarily passive, so that the system can be imagined to function independently of any operator input.

In the field of liquid absorption, ammonia-water and lithium bromide-water pairs were widely used in experimental units of solar refrigeration (Ward et al., 1979 and Staicovici, 1986). Different prototypes utilizing saline ammoniac solutions (Swartman, 1975) as well as solid absorption reactions (Worsoe-Schmidt, 1983) have also been studied. As compared to the above-mentioned devices, solid adsorption systems show some advantages: the adsorbent is not submitted to any change of column during the sorption processes, as in solid absorption; it does not need a rectifying column as in liquid absorption.

Efficient refrigerators based on the adsorption cycle can be performed using only thermal energy. Several experimental developments have proved that adsorptive refrigeration systems are well adapted to soft technology applications, since they can operate without moving parts and with low-grade thermal energy from different sources. Adsorption cooling cycles are a possible response to this problem since they operate with non-toxic refrigerant fluids like water and methanol, which are fully ecologically compatible.

Since, adsorption techniques also allow cycling large amounts of refrigerant fluid, adsorptive refrigerators can be most efficient, and a design of a new ice maker using the activated carbon-methanol pair and solar regeneration is theoretically analyzed and its behavior simulated.

Although silica gel has been used in at least one closed cycle refrigerant system, the best majority of experience is with the zeolites or activated carbons. The most commonly utilized adsorbents are silica gel, activated carbon, aluminas and zeolites. Zeolite water and activated carbon-methanol are the most used adsorbent-adsorbate pairs in refrigeration systems. These two pairs have entirely different physical and chemical properties. Methanol is easily desorbed from activated carbon when it is heated, while zeolite, the water is kept much longer.

Thus the activated carbon-methanol pair is best adapted to operating cycles with small evaporating temperature variation (up to 40^{o} C). Adsorption cycles with the zeolite water pair need a longer evaporating temperature change (70^{o} C or more) to operate according to (Meunier and Douss, 1990). (Critoph and Vogel, 1986) compared zeolites and active charcoal with refrigerants R11, R12, R22 and R114 and in all cases found charcoal a preferable adsorbent for solar cooling. (Meunier et al., 1990) have compared synthetic zeolite-water, synthetic zeolite-methanol, and charcoal-methanol combinations. They find that activated charcoal-methanol gives a better Coefficient of Performance (COP) generally, but that when the nighttime ambient temperature to evaporating temperature difference is particularly higher then a zeolite-water combination is better. However, this will also require a higher generating temperature to evaporating temperature from the solar collector during the day. (Meunier, 1990) comparing AC35-methanol with zeolite 13X-water, suggests that the zeolite combination will only be superior when the temperature lift (adsorption-evaporation temperature) exceeds 45^o C. The COP is based on heat input to the adsorbent rather than to the solar collector and so the reduced solar collector efficiency at higher temperatures may actually make charcoal-methanol combinations superior at even higher temperature lifts. Through the previous work of others we know that charcoal as adsorbent, methanol as adsorbate is a suitable pair for solar powered adsorption refrigeration.

There are other reasons for preferring charcoals:

1. Activated charcoals are cheaper than zeolites.
2. Activated charcoals can be made with properties to suit particular applications.
3. Activated charcoals (particularly coconut shell charcoal) can be manufactured in the country of origin.

For these reason it was decided to concentrate on activated charcoal as an adsorbent.

The research report in this dissertation is a study of the activated charcoal-methanol solar thermally powered adsorption refrigeration system, which is intermitted, taking advantage of the diurnal cycling of the solar source, with a view to its eventual commercialization in developing countries in Asia. The project included