



UNIVERSITI PUTRA MALAYSIA

**DESIGN AND SIMULATION OF DUAL-PURPOSE SOLAR
CONTINUOUS ADSORPTION SYSTEM USING MALAYSIAN
ACTIVATED CARBON**

MOHAMMAD AHMED ALGHOUL.

FS 2005 18



**DESIGN AND SIMULATION OF DUAL-PURPOSE SOLAR
CONTINUOUS ADSORPTION SYSTEM USING MALAYSIAN
ACTIVATED CARBON**

By

MOHAMMAD AHMED ALGHOUL

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirement for the Degree of Doctor of Philosophy**

September 2005



DEDICATION

Especially dedicated to the man of rare integrity and radiant nobility

Prof. Dr. Mohammad Yusof Sulaiman



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

**DESIGN AND SIMULATION OF DUAL-PURPOSE SOLAR
CONTINUOUS ADSORPTION SYSTEM USING MALAYSIAN
ACTIVATED CARBON**

By

MOHAMMAD AHMED ALGHOUL

September 2005

Chairman: Professor Mohammad Yusof Sulaiman, PhD

Faculty: Science

Solar adsorption refrigeration is mainly realized using activated carbon as adsorbent and methanol as adsorbate. The study tested adsorption characteristics of three types of Malaysian activated carbons (*AC-4060*, *AC-5060*, *AC-6070*) with methanol by fitting Dubinin equation to the characteristic curve of the activated carbons and thus determine the available porosity. The $P-T-X$ chart (pressure, temperature, and concentration) for each of the activated carbons was developed and the heat of adsorption was determined. A performance comparison of the activated carbons with methanol as the refrigerant for ice making was analyzed and the possibility of using the Malaysian activated carbon as adsorbent for adsorption refrigeration system was found satisfactory.



For solar intermittent adsorption system, refrigeration process takes place at night. The use of the two adsorber beds working out of phase helps maintain a continuous refrigeration cycle. Efforts have been made to commercialize the single-purpose solar adsorption refrigeration system, but has not been well received. The dual-purpose solar continuous adsorption system for domestic refrigeration and hot water is the result of a series of researches done in the field of single-purpose of solar adsorption system for refrigeration with respect to the practical needs of industries and customers.

A novel design and performance of a dual-purpose solar continuous adsorption system for domestic refrigeration and hot water is described. The system comprises of evacuated tube collectors, a water storage tank of two partitions each partition contains adsorber bed and condenser heat exchanger, a receiver, an evaporator, and ice box.

Further more, the heat rejected by the adsorber beds and condensers during cooling process of refrigeration subsystem was recovered and used to heat water for the purpose of domestic consumption. In a continuous 24-hour cycle, 16.86 MJ/day of heat can be recovered for heating of water storage tanks. In the single-purpose intermittent solar adsorption system, this heat is wasted. The total energy input to the dual-purpose system during 24-hour operation was 61.2 MJ/day and the total energy output was 50 MJ/day. The latter was made up of 44.69 MJ/day for water heating and 5.3 MJ/day for ice making. The amount of ice that can be produced was 12 kg/day.



Based on typical values for the efficiency (η) of evacuated tube collector of water heating system of 65%, the following Coefficients of Performance *COP*'s were obtained: 44% for adsorption refrigeration cycle, 73% for dual-purpose solar water heater, 8.5% for dual-purpose solar adsorption refrigeration and 81.5% for dual-purpose of both solar water heater and refrigerator.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia Sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**REKABENTUK DAN SIMULASI SISTEM PENJERAPAN BERTERUSAN
SOLAR DUA TUJUAN MENGGUNAKAN ARANG TERAKTIF
MALAYSIA**

Oleh

MOHAMMAD AHMED ALGHOUL

September 2005

Pengerusi: Professor Mohammad Yusof Sulaiman, PhD

Fakulti: Sains

Peti sejuk penjerapan suria lazimnya direalisasikan dengan menggunakan karbon teraktif sebagai bahan penjerap dan methanol sebagai bahan jerapan. Kajian ini dijalankan untuk menguji sifat-sifat penjerapan berbagai jenis karbon teraktif di Malaysia ke atas methanol, dan dengan menyepadankan persamaan Dubinin kepada lengkung cirian karbon teraktif tersebut, nilai keliangan dapat ditentukan. Carta P-T-X (tekanan, suhu dan kepekatan) bagi setiap karbon teraktif dibina dari mana haba penjerapan dapat ditentukan. Perbandingan prestasi karbon teraktif dengan methanol sebagai bahan penyejuk dibincangkan dan kemungkinan menggunakan karbon teraktif dari Malaysia sebagai bahan penjerap untuk sistem peti sejuk penjerapan didapati baik.



Bagi sistem penjerapan berkala suria, proses penyejukan berlaku pada waktu malam. Penggunaan dua alat-dasar (bed) penjerap yang bertindak tidak sefasa membantu mengekalkan kitaran penyejuk yang berterusan. Usaha telah dilakukan untuk mengkomersialkan sistem peti sejuk penjerapan suria satu gunaan tetapi tidak mendapat sambutan yang menggalakkan. Sistem penjerapan selanjar suria dua gunaan untuk tujuan penyejukan dan pemanasan di rumah adalah hasil kajian yang berterusan ke atas keperluan praktikal sistem peti sejuk penjerapan suria satu gunaan kepada industri dan pelanggan.

Satu reka bentuk bijak sistem penjerapan selanjar suria dua gunaan untuk tujuan penyejukan dan pemanasan di rumah dan prestasinya diperihalkan. Sistem ini terdiri dari tiub pengumpul vakum, tangki penyimpan air yang terdiri dari dua bahagian - tiap-tiap bahagian mengandungi alat-dasar penjerapan dan alat penukar haba kondenser, alat penerima, alat penyejat dan kebuk ais.

Setenjutnya, haba yang dibebaskan oleh alat-dasar penjerap dan kondenser semasa proses pendinginan subsistem penyejukan dapat dipulihkan dan diguna untuk memanaskan air untuk penggunaan domestik. Dalam kitaran selanjar 24 jam, sebanyak 16.86 MJ haba sehari boleh dipulihkan bagi memanaskan tangki penyimpan air. Dalam sistem penjerapan suria berkala satu gunaan haba ini terbazir sahaja. Jumlah tenaga yang diinputkan ke dalam sistem dua gunaan ketika beroperasi 24 jam adalah 61.2 MJ sehari dan jumlah tenaga yang dioutputkan adalah 50 MJ sehari. Daripada jumlah tenaga yang dioutputkan ini 44.69 MJ sehari digunakan untuk memanaskan air dan 5.3 MJ sehari untuk menghasilkan ais. Berat ais yang dihasilkan ialah 12 kg sehari. Berasaskan kepada nilai biasa

65% bagi kecekapan (η) tiub pengumpul vakum memanaskan air, Pekali Prestasi (*COP*) berikut diperolehi: 44% untuk kitaran penjerapan peti sejuk, 73% untuk pemanas air suria dua gunaan, 8.5% untuk peti sejuk penjerapan suria dua gunaan dan 81.5% untuk sistem dua gunaan pemanas air dan peti sejuk.

ACKNOWLEDGEMENTS

Firstly, praise be to Allah, for giving me the strength and patience to complete this work.

I am indebted to a good number of people who generously offered advice, encouragement, inspiration, and friendship throughout my time at UPM. I offer my sincere gratitude to my advisor and mentor Professor Dr. Mohammad Yusof Sulaiman with whom it has been an honour and a pleasure to work with. I thank him for a great number of things: for sharing his principles, for his humanity, and to whom I am grateful for the care and thoughtfulness extended to me throughout my tenure at UPM, for the opportunities he has provided me, for his accessibility, and his patience on which this thesis is based.

Thanks are also due to the members of my doctoral thesis committee. They are: Associate Professor Dr. Azmi Zakaria, and Dr. Mahdi Abd. Wahab who provided input on my research as well as invaluable advice.

I also wish place to record my thanks to the members and staff of the Department of Physics, who always offered assistance, especially En. Shaharuddin Hj. Abd Rahman, En. Marzuk H. Ismael and En. Razak Harun. The financial support extended by IRPA is gratefully acknowledged.



I would like to take this opportunity to thank my friends Mohammad Sharaf Eddin, Ibrahim Alshaikh, Khalid Osman who through their support and friendship made my research work a very enjoyable experience.

Finally, I extend by gratitude to my parents, brothers and sisters for being patient, understanding and supportive during the course of this study.

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	vi
ACKNOWLEDGEMENTS	ix
APPROVAL	xi
DECLARATION	xiii
LIST OF TABLES	xvi
LIST OF FIGURES	xvii
LIST OF ABBREVIATIONS	xix
CHAPTER	
I INTRODUCTION	
Background	1
Overview of solar thermal adsorption refrigeration	3
Research hypotheses	5
Thesis objectives	6
Organisation of the thesis	8
II LITRATURE REVIEW	
Introduction	10
Adsorbent-Adsorbate-Adsorber Bed	12
Choice of adsorbate	12
Choice of adsorbent	14
Adsorber bed	17
Solar Adsorption Refrigeration Technologies	19
Single-purpose solar adsorption refrigeration	22
Intermittent basic cycle	22
Activated carbon–methanol refrigeration systems	23
Commercial units of intermittent basic cycle	26
Continuous adsorption refrigeration	26
Dual-purpose solar adsorption systems	30
Intermittent adsorption systems	31
Continuous adsorption system	39
III TESTING OF CHARCOAL-METHANOL ADSORPTION PROPERTIES	
Introduction	43
Activated Carbon	45
Principle of Solid Adsorption	49
Adsorption equilibrium	51
Adsorption isotherms equations	52
Experimental Test Rig	56
Adsorptive properties of activated carbon-methanol	58
Setup and experimental procedures	59
Experimental test rig data analysis and results	61



	Application of Clausius-Claperyon Equation	73
	Discussion and Results	86
IV	DUAL PURPOSE SOLAR CONTINUOUS ADSORPTION SYSTEM	
	Introduction	92
	Designing of the working cycle of the Dual-Purpose System	93
	Thermodynamic Design of the Dual-purpose System	110
	Heating process of the dual system	112
	Cooling process of the dual system	116
	Output of the dual purpose system	118
	Sizing of the Dual Purpose System Components	119
	Solar collector	119
	Water storage tank partitions	122
	Adsorber bed	123
	Condenser heat exchanger	126
	Evaporator heat exchanger	127
	Steady method	129
	Unsteady method	131
	Design and sizing of the receiver	134
	Performance Estimates	135
	Simulation Program	136
V	RESULTS AND DISCUSSION	138
	Effect of using different types of Malaysian activated carbons on the performance of the dual system	142
	Effect of temperature of hot water as heat source bed on the performance of the dual system	144
	Effect of desorption temperature of the second adsorber on the performance of the dual system	146
	Effect of adsorption-condensation temperature on the performance of the dual system	149
	Effect of mass of ice on the performance of the dual system	151
	The ideal cycle of the dual purpose continuous adsorption system	152
	Costing of the dual purpose system	155
	Effect of efficient activated carbon on the dual system	157
	Effect of heat-sheet collector on the cost of the dual system	164
VI	CONCLUSION	169
	Recommendation for Further Work	173
	REFERENCES	175
	APPENDIX	183
	BIODATA OF THE AUTHER	208



LIST OF TABLES

Table	Page	
3.1	Adsorptive properties of AC – 4050/methanol	62
3.2	Adsorptive properties of AC – 5060 /methanol	63
3.3	Adsorptive properties of AC – 6070/methanol	64
3.4	Numerical values of parameters of Equation (3.6)	73
5.1	Design parameters of the dual-purpose solar continuous adsorption system for domestic refrigeration and hot water	139
5.2	Properties of materials used in the dual solar system	140
5.3	The effect of using different Malaysian activated carbons on the performance of dual system	143
5.4	Effect of temperature of hot water as heat source on the performance of dual system	145
5.5	The effect of temperature of the second adsorber bed on the performance of the dual purpose system	148
5.6	Effect of adsorption-condensation temperature on the performance of the dual system	150
5.7	Cooling process of the adsorber beds and condensers heat exchangers	151
5.8	Effect of mass of ice on the dual system	152
5.9	The ideal cycle of the dual purpose system	154
5.10	The parameters associated with the design of the heat exchangers of the dual purpose system	156
5.11	Costing of the dual purpose system by using Malaysian activated carbon	157
5.12	Effect of efficient activated carbon on the performance of the dual system	159
5.13	Costing of the dual purpose system by using efficient activated carbon and heat sheet collector	166
5.14	Comparisons on a subjective level of the various aspects of the performance of the dual purpose adsorption systems	167



LIST OF FIGURES

Figure	Page	
2.1	The main components of solar adsorption refrigerator	23
2.2	Solar-powered adsorption–ejection refrigeration system	29
2.3	Schematic of the solar water heater and refrigerator, Wang et al. (2000)	33
2.4	Schematic of a solar water heater and adsorption refrigerator, Wang et al. (2002)	35
2.5	Sketch of flat plate solar hybrid system with water heater and refrigerator, Li et al. (2002) _c	38
2.6	Continuous dual solar system of hybrid solid adsorption- -ejector for domestic refrigeration and heating, Zhang and Wang (2002) _a	40
2.7	Continuous solid adsorption refrigeration and heating hybrid system driven by solar energy, Zhang and Wang (2002) _b	42
3.1	The schematic diagram of the test rig	57
3.2	$D - R$ representation of AC – 4050	66
3.3	$D - R$ representation of AC – 5060	67
3.4	$D - R$ representation of AC – 6070	68
3.5	$D - A$ representation of AC – 4050	70
3.6	$D - A$ representation of AC – 5060	71
3.7	$D - A$ representation of AC – 6070	72
3.8	$P - T - X$ diagram for an ideal cycle of adsorption refrigeration system	75
3.9	$P - T - X$ chart for AC – 4050/methanol pair	80
3.10	$P - T - X$ chart for AC – 5060/methanol pair	81
3.11	$P - T - X$ chart for AC – 6070/methanol pair	82
3.12	System refrigeration cycle performance with different Malaysian activated carbon	89
3.13	System refrigeration cycle performance with AC – 5060 - methanol under the ideal cycle with different values of W_0	90
3.14	Desorbed methanol vs. desorption temperature with different Malaysian activated carbon	91
4.1.a	Components of first design of the dual-purpose solar continuous adsorption system	95
4.1.b	First design of continuous solar water heating cycle in the dual purpose system	96
4.1.c	First design of continuous adsorption refrigeration cycle in the dual-purpose solar system	97
4.2.a	Components of the second design of the dual-purpose system	99
4.2.b	Second design of continuous solar water heating cycle in the dual purpose system	100
4.2.c	Second design of continuous adsorption refrigeration cycle in the dual-purpose solar system	101
4.3	Schematic of the conventional solar flat plate collector of water heating system	102
4.4	Schematic of the hybrid solar collector of adsorption	



	refrigeration subsystem	103
4.5	Sketch of evacuated tube collector	108
4.6	Cross section of water in evacuated glass solar water heater	109
4.7	Diagram of the flow process between components in an ideal cycle of adsorption refrigeration	111
5.1	Effect of efficient and normal activated carbon on mass of hot water, activated carbon and adsorber tubes	160
5.2	Effect of efficient and normal activated carbon on the gained heat energy of total domestic hot water, domestic hot water by direct solar, domestic hot water by heat recovery and the required heat of the adsorber	160
5.3	Effect of efficient and normal activated carbon on the area of solar collector	161
5.4	Effect of efficient and normal activated carbon on the number of required adsorber tubes	161
5.5	Effect of efficient and normal activated carbon on the cost of solar collectors, adsorber tubes and activated carbon	162
5.6	Effect of efficient and normal activated carbon on the coefficient of performance of refrigeration cycle, refrigeration subsystem in the dual purpose system, domestic hot water subsystem in the dual purpose system, and the dual purpose system	163



LIST OF ABBREVIATIONS

A_0	Constant of equation [3.15]
A_1	Constant of equation [3.15]
AC	Activated Carbon
A_{con}	Heat transfer area of the condenser (m ²)
A_{evp}	Heat transfer area of the evaporator (m ²)
A_{coll}	Area of collector (m ²)
$C_{v\ ice}$	Specific volume of ice at 0 ⁰ C (m ³ /kg)
C_{steel}	Specific heat of galvanized steel (kJ/kgK)
C_{ac}	Average specific heat of activated carbon (kJ/kgK)
C_a	Specific heat of adsorber tube (kJ/kgK)
C_w	Specific heat of water (kJ/kgK)
C_{copper}	Specific heat of copper (kJ/kgK)
$C_{l, meth}$	Average specific heat of liquid methanol (kJ/kgK)
$COP_{cycle-ice}$	Coefficient of performance of the refrigeration cycle
$COP_{dual.system-ice}$	Coefficient of performance of ice production in the dual system
$COP_{dual.system-domestic.hot.wewater}$	Coefficient of performance of water heating production in the dual system
$COP_{dual-system}$	Coefficient of performance of the dual system
D	Constant of equation [3.6]
$H_{global-horizontal}$	Global solar radiation on horizontal surface (MJ/day)
h	Average enthalpy of heat of adsorption of the first adsorber bed (kJ/kg)
h'	Average enthalpy of heat of adsorption of the second adsorber bed (kJ/kg)
H_{ads}	Heat of adsorption (kJ)
$I.D_{ads-tube}$	Inside diameter of adsorber copper tube (m)
$I.D_{con, evp, perforated-tube}$	Inside diameter of condenser, evaporator, and perforated copper tubes (m)



$I.S.A_{ads-tube}$	Inside surface area of one meter length of adsorber copper tube (m^2 /m)
$I.S.A_{con, evp, perforated-tube}$	Inside surface area of one meter length of condenser, evaporator, and perforated copper tube (m^2 /m)
K_{ice}	Conductivity of ice layer (W/m.K)
$l_{ads-tube}$	Length of adsorber tube (m)
L_{meth}	Latent heat of methanol (kJ/kg)
L_{ice}	Latent heat of ice (kJ/kg)
$l_{con-tubes}$	The total length of condenser tube (m)
$l_{evptubes}$	Total length of evaporator tube (m)
M	Molecular weight of the methanol (kg/mol)
m	Number of adsorber tubes
M_{ice}	Mass of domestic ice during 24 hours (kg)
M_{meth}	Mass of desorbed methanol (kg)
M_a	Mass of adsorber tubes (kg)
M_{ac}	Mass of activated carbon (kg)
M'_{ac}	Mass of activated carbon in the second adsorber (kg)
$M_{hw} = M_{hot-water}$	Mass of hot water (kg)
M_{con}	Mass of condenser (kg)
M_{evp}	Mass of evaporator (kg)
M_{rec}	Mass of receiver (kg)
n	Constant of equation [3.6]
$O.D_{ads-tube}$	Outside diameter of adsorber copper tube (m)
$OSA_{ads-tube}$	Outside surface area of one meter length of adsorber copper tube (m^2 /m)
$O.D_{con, evp, perforated-tube}$	Outside diameter of one meter length of condenser, evaporator, and perforated copper tube (m)
$OSA_{con, evp, perforated-tube}$	Outside surface area of one meter length of condenser, evaporator, and perforated copper tube (m^2 /m)
P_{con}	Pressure of methanol at condenser temperature (bar)
P_{evp}	Pressure of methanol at evaporator temperature (bar)
$Q_{heat-ads}$	Heating energy of the first adsorber bed (kJ)
$\dot{Q}_{heat-ads}$	Heat energy of the second adsorber bed (kJ)

$Q_{cool-ads}$	Cooling energy of the first adsorber bed (kJ)
$Q'_{cool-ads}$	Cooling energy of the second adsorber bed (kJ)
$Q_{hot.water}$	Energy of solar water heating (kJ)
$Q_{solar.heat}$	Useful heat produced by solar energy (kJ)
$Q_{hot.water-heat.recovery}$	Total energy of hot water produced from heat recovery (kJ)
$Q_{domestic.hot.water-total}$	The total energy output of domestic hot water during 24 hours (kJ)
Q_{con}	The rejected heat energy during condensation process (kJ)
Q_{evp}	The gained heat energy during evaporation process.
Q_{cc}	Sensible cool energy of metallic (evaporator, receiver, water tray) from $T_0 \rightarrow T_{ice}$ (kJ)
$Q_{Netcooling}$	Net cooling energy for producing ice(kJ)
R	Gas constant (kJ/kgmoleK)
T_0	City water temperature ($^{\circ}C$)
T_{evp}	Evaporator temperature for ice making ($^{\circ}C$)
T_{a1}	Initial temperature of adsorption process in the first adsorber bed ($^{\circ}C$)
T'_{a1}	Initial temperature of adsorption process in the second adsorber bed ($^{\circ}C$)
T_{a2}	Minimum temperature of adsorption process ($^{\circ}C$)
T_{con}	Minimum temperature of condensation process ($^{\circ}C$)
$T_{hw} = T_{hot-water}$	Hot water temperature as heat source for heating process of the second adsorber bed ($^{\circ}C$)
$T_{g2} = T_{g2-2nd-adsorber.bed}$	Maximum temperature of the first adsorber bed during desorption process ($^{\circ}C$)
$T'_{g2} = T_{g2-1st-adsorber.bed}$	Maximum temperature of the second adsorber bed during desorption process ($^{\circ}C$)
T_{ice}	Ice temperature ($^{\circ}C$)
$Time_{heat.process}$	Time of heating process (hr)
$Time_{cooling.process}$	Time of cooling process (hr)
$Time_{isoster(a2-g1)}$	Time of sensible heating process of the adsorber bed from $T_{a2} \rightarrow T_{g1}$ (hr)
$Time_{desorption}$	Time of desorption process (hr)
$Time_{isoster(g2-a1)}$	Time of sensible cooling process of the adsorber bed (hr)
$Time_{adsorption}$	Time of adsorption process of the adsorber bed (hr)

$Time_{sensible\ cooling-water}$	Time of sensible cooling of water from $T_0 \rightarrow T_{ice}$ (hr)
$Time_{for\ min\ g-ice}$	Time of forming ice process (hr)
$Thick_{con, evp, perforated-tube}$	Wall thickness of condenser, evaporator, and perforated copper tube (m)
$Thick_{steel}$	Thickness of galvanized steel (m)
$Thick_{ads-tube}$	Wall thickness of adsorber copper tube (m)
U_{con}	Overall heat transfer coefficient of condenser ($W/K.m^2$)
$V_{ads-bed}$	Volume of adsorber bed (m^3)
V_{rec}	Volume of the receiver of methanol (m^3)
$V_{storage\ tank\ k-partition}$	The volume of the partition of water storage tank (m^3)
W_0	Maximum volume of the adsorption space (m^3/kg_{ac})
$w_{ads-tube}$	Weight of one meter adsorber copper tube (kg/m)
$w_{con, evp, perforated-tube}$	Weight of one meter copper tube used for condenser, evaporator, and methanol mass transfer (kg/m)
$w_{rec-tube}$	Weight of one meter steel tube used for receiver (kg/m)
x	Thickness of ice layer (m)
X_{conc}	Maximum concentration of methanol during adsorption process (kg_{meth}/kg_{ac}).
X_{dil}	Minimum concentration of methanol at the end of heating process (kg_{meth}/kg_{ac}).
X'_{dil}	Minimum concentration of methanol in the second adsorber at the end of heating process (kg_{meth}/kg_{ac}).
η_{coll}	Efficiency of solar evacuated tube collector on average summer performance level
ρ_{ac}	Bulk density of activated carbon (kg/m^3)
ρ_{steel}	Density of galvanized steel (kg/m^3)
ρ_{ice}	Density of ice at $0^\circ C$ (kg/m^3)
ρ_{evp}	Density of methanol at evaporator temperature (kg/m^3)
ρ_{con}	Density of methanol at condenser temperature (kg/m^3)

CHAPTER I

INTRODUCTION

Background

Solar power technology has gradually become more efficient and widespread. It has recently gained prominence in many areas as the full effects of burning fossil fuels for electricity are being realized. Global climate change, acid rain, and smog are among some of the key environmental problems that solar energy could solve besides the increasingly important problem of peak load in summer. It is also important to remember that as supplies of fossil fuels continue to be depleted, their price will increase. Solar technologies on the other hand will become less expensive as they evolve into more efficient forms.

In most developing countries there is a demand for extensive use of refrigeration. The prospect for an increased production of perishable foodstuff is very high in many areas, but lack of adequate storage and transport facilities severely limits the utilization of these potentials. In the health field, the role of refrigeration in the immunization of populations against infectious diseases, thanks to refrigerators for vaccine storage, can be highlighted and linked to increasing life expectancy. A striking example is the contribution of refrigeration to the eradication of poliomyelitis: in 2000, the number of cases of poliomyelitis occurring worldwide was less than 3500, which is a 99% decrease in comparison with the 350000 cases registered in 1988 as reported by IIR and UNEP (2000). Conventional



refrigeration plants are dependent on a regular energy supply as well as on the availability of trained servicemen, demands that in many countries can be met only in the vicinity of urban areas. Since most of developing countries are located in the tropical or subtropical zones, solar-powered refrigeration systems present attractive alternative.

Solar cooling is needed most when the solar radiation is at its peak, thus making its use for this purpose all the more attractive. Among the various thermal applications of solar energy, cooling is one of the more complexes, both in concept and in construction. This is one of the reasons why its utilization at present is not as wide spread as space or water heating. Here it is not sufficient to collect the solar heat, store and distribute. The energy must be converted to cold effect through suitable device, capable of absorbing heat at a low temperature from conditioned space and rejected it into the environment.

The use of solar energy to drive cooling cycles has been considered for two different but related purposes. The first is to provide refrigeration for food preservation, vaccine storage, ice making...etc. The second is to provide comfort cooling.

The electric driven vapor compression refrigeration system is facing a real challenge as CFCs and HCFCs are not suitable for sustainable development. The commonly used substitutes for refrigerant, R134a is also facing the problem of green house effect. Natural refrigerants fluids such as water, ammonia, methanol, etc. will be welcome for the future refrigeration and air conditioning industries.

