

العنوان:	Thermodynamic Analysis and Modeling Study of an Intermittent Solar Adsorption Refrigeration system
المؤلف الرئيسي:	Qasem, Naef
مؤلفين آخرين:	El Shaaewi, Maged A.(Super)
التاريخ الميلادي:	2013
موقع:	الظهران، السعودية
الصفحات:	1 - 134
رقم MD:	621520
نوع المحتوى:	رسائل جامعية
اللغة:	English
الدرجة العلمية:	رسالة ماجستير
الجامعة:	جامعة الملك فهد للبترول والمعادن
الكلية:	عمادة الدراسات العليا
الدولة:	السعودية
قواعد المعلومات:	Dissertations
مواضيع:	الهندسة الميكانيكية، التحليل الحراري
رابط:	https://search.mandumah.com/Record/621520

ABSTRACT

Full Name : Naef Abduljalil Abdulrahman Qasem
Thesis Title : Thermodynamic analysis and modeling study of an intermittent adsorption refrigeration system
Major Field : Mechanical Engineering
Date of Degree : May, 2013

Solar adsorption refrigeration systems have been increasingly attracting some research interests since last decade because they are clean, cheap and simple for use in air conditioning, ice making, food preservation and vaccine storage specially for remote areas. The idea of these devices is the reversible physical adsorption of vapor on the surface of a porous solid. The system consists of three important components: solar collector with adsorbent bed, condenser and evaporator.

The main objectives of this work are to improve the performance of the solar intermittent refrigeration system that uses activated carbon and methanol as adsorbent and adsorbate pair. The improvement of the system's performance is achieved through investigating the effect of the main operative and constructive parameters of the system. EES and MATLAB computer programs are exploited to analyze the thermodynamic cycle of the system and to model the system under Dhahran climate conditions, respectively.

The results show that the increase in the condenser temperature needs high values of the desorption temperature while lowering values of the evaporator temperature needs low values in the adsorption temperature to improve the performance. The absorbers of collector should have thin wall and should be coated by high absorptivity and low emissivity material. About 14.1 kg/m² of activated carbon NORIT RX3-Extra per m² of

collector surface is a suitable optimum choice for adsorption ice maker devices. Furthermore, double glazing, tilt angle of the solar collector and starting the cycle at suitable time as well as suitable collector back insulation increase the performance. Moreover, the study proposes an activated carbon/methanol solar adsorption ice-maker that could produce from 5 kg up to 13 kg of ice per day per m² of collector area with improved solar coefficients of performance of 0.12 and 0.24 according to weather conditions in the hot and the cold days, respectively.

ملخص الرسالة

الاسم الكامل : نائف عبد الجليل عبد الرحمن قاسم

عنوان الرسالة : تحليل حراري و دراسة نموذجة لآلة التبريد المتقطع بالامتزاز الشمسي

التخصص : هندسة ميكانيكية

تاريخ الدرجة العلمية : مايو ٢٠١٣م

في العقد الماضي زاد الاهتمام بدراسة التبريد بواسطة الامتزاز لما يعطيه من امتيازات كونه رخيص التشغيل ونظيف بيئيا بالإضافة الى امكانية استخدامه لأغراض التبريد والتكييف وحفظ الاطعمة واللقاحات الدوائية. فكرة هذه المنظومة قائمة على قدرة امتزاز المادة الصلبة المسامية - الممتزات - لبخار مائع التبريد - المازة- عند درجة حرارة منخفضة وايضا طرد المازة على شكل بخار عند التسخين. تتكون اجهزة الامتزاز من الممتزات المحتوية في مجمع شمسي غالبا ما يكون مسطح بالإضافة الى المكثف والمبخر- المبرد. في هذه الرسالة يتم التحليل الثيروديناميكي - الحراري- لالة التبريد الممتز عن طريق دراسة اهم العوامل المؤثرة فيها مثل: درجة حرارة الممتز الكبرى ودرجة حرارة الامتزاز الصغرى بالإضافة الى حرارة وضغط كل من المكثف والمبخر. التحليل الحراري يعطينا انطبعا عن الأداء التمهيدي للمنظومة مثل كمية الثلج المتوقع انتاجها ومعامل الاداء وتتم هذه الدراسة باستخدام برنامج EES في حين أن الدراسة الفعلية للمنظومة تتم من خلال النمذجة بواسطة برنامج MATLAB على حسب ظروف مناخ الظهران لإظهار الاداء الفعلي وكمية الثلج المتوقعة خلال الايام الباردة والحارة من السنة. لهذا تهدف هذه الدراسة الى تحسين اداء منظومة الامتزاز الشمسي المتقطع (الذي لا يعمل بصورة مستمرة وينتج تبريدا طوال الليل والنهار) باستخدام الكربون المنشط والميثانول بواسطة دراسة وتحسين العوامل المؤثرة فيه: كنوع الكربون المنشط وسمك معدن الانابيب الماصة للأشعة الشمسية بالإضافة الى امتصاصية وانبعائيه الطلاء الذي يغطي الماصات الشمسية الى جانب كل من كمية الكربون المنشط و الغلاف الزجاجي

المناسب وسماكة المادة العازلة التي تغطي قاعدة المجمع الشمسي وايضا زاوية ميلان المجمع الشمسي مع بداية التشغيل المناسبة. تهدف هذه الدراسة ايضا الى انتاج ٥ كجم او اكثر من الثلج لكل متر مربع من المجمع الشمسي باليوم الواحد. نتائج التحليل الحراري تشير الى انه في حالة ارتفاع درجة حرارة المكثف يجب تسخين الكربون المنشط بدرجات حرارة عالية وايضا في حالة الذهاب الى درجة حرارة منخفضة داخل المبخر يجب ان تكون درجة حرارة الامتزاز منخفضة ايضا. اما نتائج دراسة النمذجة توضح ان حوالي 1٤.1 كجم من الكربون المنشط NORIT RX3-Extra لكل متر مربع من المجمع الشمسي يعطي نتائج افضل من الانواع الاخرى ويفضل ان يكون سمك الانابيب الماصة اصغر ما يمكن من اجل تحسين اداء المنظومة. كما اوضحت الدراسة الى ان الغلاف الزجاجي الذي يتكون من طبقتين مفصولتين من الزجاج افضل من اللوح الزجاجي الواحد او الانظمة الزجاجية السامحة للأشعة الشمسية والعازلة للحرارة المفقودة (TIM) بالإضافة الى ان سماكة المادة العازلة تزيد من الكفاءة لكن يجب ان لا تزيد المجمع الشمسي عبء اضافي كزيادة سماكته. المنظومة المحسنة بالخصائص السابقة مع تميل المجمع الشمسي بزوايا مناسبة وبدء الدورة الحرارية عند الوقت المناسب يمكن ان ينتج كميات من الثلج تتراوح بين ٥ كجم الى ١٣ كجم لكل متر مربع من المجمع الشمسي وبمعامل اداء شمسي يتراوح بين ٠,١٢ و ٠,٢٤ للأيام الحارة والباردة على التوالي.

العنوان:	Thermodynamic Analysis and Modeling Study of an Intermittent Solar Adsorption Refrigeration system
المؤلف الرئيسي:	Qasem, Naef
مؤلفين آخرين:	El Shaaewi, Maged A.(Super)
التاريخ الميلادي:	2013
موقع:	الظهران، السعودية
الصفحات:	1 - 134
رقم MD:	621520
نوع المحتوى:	رسائل جامعية
اللغة:	English
الدرجة العلمية:	رسالة ماجستير
الجامعة:	جامعة الملك فهد للبترول والمعادن
الكلية:	عمادة الدراسات العليا
الدولة:	السعودية
قواعد المعلومات:	Dissertations
مواضيع:	الهندسة الميكانيكية، التحليل الحراري
رابط:	https://search.mandumah.com/Record/621520

TABLE OF CONTENTS

ACKNOWLEDGMENTS	V
TABLE OF CONTENTS	VI
LIST OF TABLES	IX
LIST OF FIGURES.....	X
NOMENCLATURE	XIII
ABSTRACT	XVI
CHAPTER 1 INTRODUCTION.....	1
1.1 Introductory Background	1
1.2 System and Processes Description	2
CHAPTER 2 LITERATURE REVIEW.....	5
2.1 Background	5
2.2 Adsorption Working Pairs	6
2.2.1 Activated Carbon/Methanol systems	7
2.2.2 Activated Carbon/Ammonia Systems	13
2.2.3 Zeolite/Water Systems.....	14
2.2.4 Silica Gel/Water Systems	15
2.2.5 Calcium Chloride/Ammonia Systems	16
2.2.6 Other Working Pairs.....	17
2.2.7 Previous Studies on Working Pairs Comparison	17
2.2.8 Improving Adsorbent Heat Transfer	19
2.3 Adsorption Thermodynamic Cycles.....	21
2.3.1 Basic Single Bed Cycle (Intermittent Cycle).....	21
2.3.2 Multi-Bed Cycle	21
2.3.3 Heat and Mass Recovery Adsorption Cycle.....	23
2.3.4 Thermal Wave Cycle.....	23
2.3.5 Cascaded Cycle.....	25
2.4 Solar Intermittent Adsorption Refrigeration Systems	25

2.4.1	Collector	26
2.4.2	Condenser	31
2.4.3	Evaporator and Water Tank	32
2.4.4	Reservoir, Valves and Sensors	34
2.5	Objectives	35
CHAPTER 3 THERMODYNAMIC ANALYSIS AND MODELLING		36
3.1	Thermodynamic Analysis	37
3.1.1	Sorption Concentration Rate	37
3.1.2	Isosteric Heating Process	40
3.1.3	Isobaric Desorption Process	41
3.1.4	Isosteric Cooling Process	42
3.1.5	Isobaric Adsorption Process	43
3.1.6	Evaporation and Condensation Heats	43
3.1.7	Performance of the System	45
3.2	Heat and Mass Transfer Modeling	46
3.2.1	Physical Description of the System	46
3.2.2	Modeling Assumptions	48
3.2.3	Collector Overall Heat Transfer Coefficient	49
3.2.4	Absorber Plate	51
3.2.5	Adsorbent Bed	52
3.2.6	Condenser and Evaporator	53
3.2.7	Boundary and Initial Conditions	55
3.3	Research and Solution Methodology	57
3.3.1	Overall Literature Review	57
3.3.2	Thermodynamic Analysis	57
3.3.3	System Modeling	58
3.3.4	Improving the Performance	59
CHAPTER 4 RESULTS AND DISCUSSION		60
4.1	Thermodynamic Analysis Results	60
4.2	Modeling Results	68
4.2.1	Wind Heat Transfer Coefficient of Top and Back Faces of Solar Collector	68
4.2.2	Overall Top Heat Transfer Coefficient (U_{top})	73
4.2.3	Actual Thermal Behavior of the System	78
4.2.3.1	Validation of the Code	78
4.2.3.2	Performance under Hot and Cold Climate Conditions	79
4.2.3.3	Activated Carbon Type	88
4.2.3.4	Absorber Plate and Absorber Coating	93
4.2.3.5	Adsorbent Bed Thickness (Amount of Activated Carbon)	99

4.2.3.6	Glazing Cover Number and Types	101
4.2.3.7	Back Insulation Thickness	105
4.2.3.8	Other Improvements	108
4.2.3.9	Actual System Behavior after Improving the Main Collector Parameters.....	113
CHAPTER 5 CONCLUSIONS		123
REFERENCES		126
VITA		134

LIST OF TABLES

Table 2.1 Performance of different adsorption cooling systems	19
Table 4.1 Validation of the present results with those of Wang et al.....	61
Table 4.2 Heat losses from selective collector ($\epsilon_{pw} = 0.1$, $T_{pw} = 50$ °C, $T_{amb} = 25$ °C).	74
Table 4.3 Heat losses from nonselective collector ($\epsilon_{pw} = 0.9$, $T_{pw} = 50$ °C, $T_{amb} = 25$ °C).	75
Table 4.4 Comparison between present simulation results with Medini [15] experimental results.....	79
Table 4.5 System performance for June 2011.	85
Table 4.6 System performance for December 2011.	88
Table 4.7 System summer and winter performance predicted for 2011.	88
Table 4.8 Characteristics of activated carbon types.	89
Table 4.9 Main constructive and operative parameters of the activated carbon types on 19 th June and 19 th December 2011.	90
Table 4.10 The performance of the activated carbon types on 19 th June and 19 th December 2011.....	92
Table 4.11 The effect of absorber tube thickness on the system operating parameters.	94
Table 4.12 Effect of absorber tube thickness on the system performance.	95
Table 4.13 The effect of absorber absorptivity on system operating parameters at $\epsilon_{pw} = 0.1$	96
Table 4.14 The effect of absorber absorptivity on performance parameters at $\epsilon_{pw} = 0.1$	97
Table 4.15 The effect of absorber emissivity on system operating parameters at $\alpha_{pw} = 0.9$	98
Table 4.16 The effect of absorber emissivity on system performance at $\alpha_{pw} = 0.9$	98
Table 4.17 The effect of the absorber emissivity on system operating parameters.....	100
Table 4.18 The effect of absorber emissivity on system performance parameters.	100
Table 4.19 Effect of glazing cover systems on operating and performance parameters.	105
Table 4.20 The effect of collector back insulation thickness on system operating parameters.....	106
Table 4.21 The effect of collector back insulation thickness on system performance parameters.....	107
Table 4.22 Average monthly collector tilt angle for Dhahran.....	109
Table 4.23 Effect of collector tilt angle and time offset on operating and performance parameters.....	113
Table 4.24 System performance for June 2011.	117
Table 4.25 System performance for December 2011.	121
Table 4.26 System predicted performance data for both June and December of 2011..	122
Table 4.27 Comparison between thermodynamic analysis and modeling performance results.....	122

LIST OF FIGURES

Figure 1.1 Schematic of the solar adsorption cooling system.	3
Figure 1.2 Schematic view of the adsorption process on Clapeyron diagram.	4
Figure 2.1 Solar cooling systems.....	6
Figure 2.2 Multi-stage, Multi-bed adsorption refrigerator	22
Figure 2.3 Rotary adsorbent generation device	22
Figure 2.4 Thermal wave cycle	24
Figure 2.5 Cascaded cycle.....	25
Figure 2.6 Solar adsorption cooling system.	27
Figure 2.7 Geometry shapes of adsorbent bed.	27
Figure 2.8 The solar adsorption collector with TIM cover.....	30
Figure 2.9 Air and water condensers.....	32
Figure 2.10 Trapezoidal and tubular configuration of the evaporator.....	33
Figure 3.1 P-T-x diagram of ideal and actual adsorption refrigeration cycle.....	36
Figure 3.2 Schematic of solar collector and adsorbent bed.....	46
Figure 3.3 TIM cover in adsorption solar collector.....	47
Figure 3.4 Schematic of trapezoidal evaporator.....	48
Figure 4.1 Effect of the desorption and condenser temperatures on the performance.	62
Figure 4.2 Effect of the adsorption and evaporation temperatures on the performance. .	64
Figure 4.3 Effect of the condenser pressure on the methanol desorbed.	65
Figure 4.4 Effect of the evaporator pressure on the methanol adsorbed.	66
Figure 4.5 Effect of initial water temperature on amount of produced ice.....	66
Figure 4.6 Velocity, temperature and stream function contours for almost southerly winds.....	69
Figure 4.7 Effect of southerly wind velocity on the top and back wind heat transfer coefficient of the collector.....	70
Figure 4.8 Velocity, temperature and stream function contours for almost northerly wind	72
Figure 4.9 Effect of northerly wind velocity on the top and back wind heat transfer coefficient of the collector.....	73
Figure 4.10 Effect of space between absorber and single glazing cover on top heat transfer coefficient for some selected values of T_{pw} and ϵ_{pw}	76
Figure 4.11 Effect of space between absorber and double glazing cover on top heat transfer coefficient for some selected values of T_{pw} and ϵ_{pw}	77
Figure 4.12 System configuration details.....	80
Figure 4.13 Solar radiation on collector (I_T) and ambient temperature (T_{amb}) recorded during the period June 14-20, 2011.....	82
Figure 4.14 Collector absorber (T_{pw}), adsorbent bed (T), condenser (T_c) and evaporator (T_e) temperatures calculated for the period 14-20 June 2011.....	82

Figure 4.15 Schematic diagram for variations of methanol uptake and system pressure for one day.....	83
Figure 4.16 Methanol uptake(m_m), adsorbent bed pressure (P) and amount of produced ice (M_{ice}) calculated for the period 14-20 June 2011.....	84
Figure 4.17 Solar radiation on collector (I_T) and ambient temperature (T_{amb}) recorded during the period December 17-23, 2011.....	85
Figure 4.18 Collector absorber (T_{pw}), adsorbent bed(T), condenser (T_c) and evaporator (T_e) temperatures calculated for the period 17-23 December 2011.	86
Figure 4.19 Methanol uptake (m_m), adsorbent bed pressure (P) and amount of produced ice (M_{ice}) calculated for the period 17-23 December 2011.	87
Figure 4.20 Methanol uptake (m_m) for three types of activated carbon for 19 th December.	93
Figure 4.21 Effect of metal thickness on the performance.....	95
Figure 4.22 The effect of the activated carbon NORIT RX3-Exta amount (M_{ac}) on the performance.	101
Figure 4.23 Transmissivity absorptivity product ($\tau_g\alpha_{pw}$) of the three glazing cover systems.....	102
Figure 4.24 Overall collector heat loss coefficient (U_L) during heat generation time of the three glazing cover systems.....	103
Figure 4.25 Adsorbent (T) and evaporator (T_e) temperatures of the three glazing cover systems.....	104
Figure 4.26 Methanol uptake (m_m) and amount of produced ice (M_{ice}) for the three glazing cover systems.....	104
Figure 4.27 Effect of back insulation thickness (t_i) on M_{ice} and SCOP.	108
Figure 4.28 Effect of collector tilt angle on incident solar radiation on collector on 19 th June.....	109
Figure 4.29 Effect of collector tilt angle on adsorbent (T) and evaporator (T_e) temperatures on 19 th June.	110
Figure 4.30 Effect of collector tilt angle on methanol uptake (T_d), pressure (P) and amount of produced ice (M_{ice}) on 19 th June.....	110
Figure 4.31 Effect of time offset on adsorbent (T) and evaporator (T_e) temperatures at Tilt = 3.4° on 19 th June.....	112
Figure 4.32 Effect of time offset on methanol uptake (m_m), pressure (P) and produced ice (M_{ice}) at Tilt = 3.4° on 19 th June.....	112
Figure 4.33 System configuration details after the improvements.....	114
Figure 4.34 Solar radiation on collector (I_T) and ambient temperature (T_{amb}) recorded in June 2011.....	115
Figure 4.35 Collector absorber (T_{pw}), adsorbent bed (T), condenser (T_c) and evaporator (T_e) temperatures calculated for June 2011.	116

Figure 4.36 Methanol uptake (m_m), adsorbent bed pressure (P) and amount of produced ice (M_{ice}) calculated for June 2011.116

Figure 4.37 Methanol uptake(m_m), adsorbent bed pressure (P) and amount of produced ice (M_{ice}) calculated for 18th, 19th and 20th June 2011 (for $m_w=5$ kg).118

Figure 4.38 Incident solar radiation on collector (I_T) and ambient temperature (T_{amb}) recorded during December 17-26, 2011.119

Figure 4.39 Collector absorber (T_{pw}), adsorbent bed (T), condenser (T_c) and evaporator (T_e) temperatures calculated for the period 17-26 December 2011.120

Figure 4.40 Methanol uptake(m_m), adsorbent bed pressure (P) and amount of produced ice (M_{ice}) calculated for the period 17-26 December 2011.120

NOMENCLATURE

A	area (m^2)
COP	Coefficient of Performance
C_p	specific heat at constant pressure (J/kg K)
C_v	specific heat at constant volume (J/kg K)
D	Dubinin-Astakhov constant (K^{-1})
D1	diameter of inner pass tube (m)
D2	internal diameter of absorber tube (m)
D3	external diameter of absorber tube (m)
D_o	surface diffusion coefficient (m^2/s)
E_a	activation energy of surface diffusion (J/mol)
E_o	characteristic adsorption energy for a reference vapour (J/mole)
ESCOP	Effective Solar Coefficient of Performance
h	specific enthalpy (J/kg)
h	heat transfer coefficient (W/m^2K)
H	heat of desorption or adsorption per unit mass of methanol (J/kg)
I_T	incident solar radiation (W/m^2)
k	thermal conductivity (W/m K)
k	adsorbent constant
L	latent heat (J/kg)
L_c	collector length (m)
M, m	mass (kg)
m_m	methanol uptake (kg)
n	Dubinin-Astakhov constant
N_g	number of glass cover
n_{tube}	number of absorber tubes
P	system pressure (Pa)
Q	heat amount (J)
R	gas constant (J/mole K)
r	radius (m)
R1	radius of inner pass tube (m)
R2	internal radius of absorber tube (m)
R3	external radius of absorber tube (m)
r_p	average radius of adsorbent particles (m)
SCOP	Solar Coefficient of Performance
SCP	Specific Cooling Power (W/kg)

T	temperature ($^{\circ}\text{C}$ or K)
t	time (s) / thickness (m)
TIM	Transparent Insulation Material
U	overall heat transfer coefficient ($\text{W}/\text{m}^2\cdot\text{K}$)
V	micropore volume filled with the adsorbed phase (m^3/m^3)
V_o	limiting micropore volume (m^3/m^3)
V_w	wind velocity (m/s)
W_c	collector width (m)
x	concentration ratio of adsorbate inside adsorbent (kg/kg)
x_o	maximum limit of mass adsorbed (kg/kg)

Greek Symbols

Δ	difference / change
τ	transmittance
α	absorptivity
ϵ	emissivity
σ	Stefan Boltzmann constant ($\text{W}/\text{m}^2 \text{K}^4$)
β	affinity coefficient or collector tilt angle
ρ	density (kg/m^3)

Subscripts

1,2,3,4	processes terminal locations
ac	activated carbon
a	adsorption
amb	ambient
b	back
c	condenser
d	desorption
e	evaporator
eq	equivalent
g	generation / glass
i	insulation

ice	ice
is	collector side insulation
L	collector overall
m	methanol
max	maximum
min	minimum
pw	absorber plate wall
s	side
sa	starting adsorption
sat	saturated
sd	starting desorption
sol	solidification
t	top
w	water

العنوان:	Thermodynamic Analysis and Modeling Study of an Intermittent Solar Adsorption Refrigeration system
المؤلف الرئيسي:	Qasem, Naef
مؤلفين آخرين:	El Shaaewi, Maged A.(Super)
التاريخ الميلادي:	2013
موقع:	الظهران، السعودية
الصفحات:	1 - 134
رقم MD:	621520
نوع المحتوى:	رسائل جامعية
اللغة:	English
الدرجة العلمية:	رسالة ماجستير
الجامعة:	جامعة الملك فهد للبترول والمعادن
الكلية:	عمادة الدراسات العليا
الدولة:	السعودية
قواعد المعلومات:	Dissertations
مواضيع:	الهندسة الميكانيكية، التحليل الحراري
رابط:	https://search.mandumah.com/Record/621520

**THERMODYNAMIC ANALYSIS AND MODELING STUDY
OF AN INTERMITTENT SOLAR ADSORPTION
REFRIGERATION SYSTEM**

BY

NAEF QASEM

A Thesis Presented to the
DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

1963 ١٣٨٣

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

MECHANICAL ENGINEERING

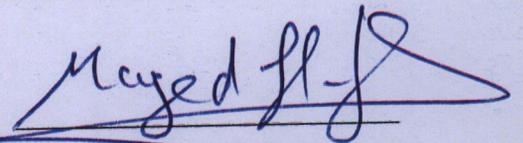
MAY, 2013

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

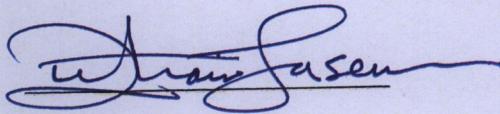
DHAHRAN- 31261, SAUDI ARABIA

DEANSHIP OF GRADUATE STUDIES

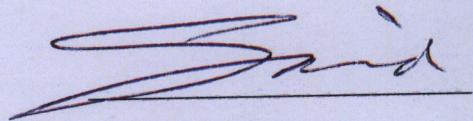
This thesis, written by **NAEF ABDULJALIL ABDULRAHMAN QASEM** under the direction his thesis advisor and approved by his thesis committee, has been presented and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN MECHANICAL ENGINEERING.**



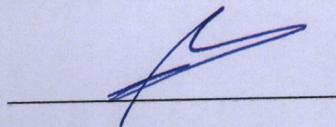
Dr. Maged A. I. El-Shaarawi
(Advisor)



Dr. Zuhair M. Gasem
Department Chairman



Dr. Syed A. M. Said
(Member)



Dr. Salam A. Zummo
Dean of Graduate Studies



Dr. Amro M. Al-Qutub
(Member)

19/5/13

Date

© Naef Abduljalil Abdulrahman Qasem

2013

Dedication

To my beloved parents, wife, brothers, sisters and my small daughter.

ACKNOWLEDGMENTS

Thanks and all praise be to Allah (azzawagal) who created me, blessed me with health and who grant me success.

I would like to state my deep appreciation and gratitude to my thesis advisor Prof. Maged A. I. El-Shaarawi who has always been providing kindest support, continual encouragement and supervision.

I also would like to acknowledge my committee members: Prof. Syed A. M. Said and Prof. Amro M. Al-Qutub for their valuable advices and guidance.

I also acknowledge KFUPM and Mechanical Engineering Department (ME) as well as the all faculties who taught and helped me.

Finally, I acknowledge Kingdom of Saudi Arabia for providing me MS scholarship and for all different facilitations.

TABLE OF CONTENTS

ACKNOWLEDGMENTS	V
TABLE OF CONTENTS	VI
LIST OF TABLES	IX
LIST OF FIGURES.....	X
NOMENCLATURE	XIII
ABSTRACT	XVI
CHAPTER 1 INTRODUCTION.....	1
1.1 Introductory Background	1
1.2 System and Processes Description	2
CHAPTER 2 LITERATURE REVIEW.....	5
2.1 Background	5
2.2 Adsorption Working Pairs	6
2.2.1 Activated Carbon/Methanol systems	7
2.2.2 Activated Carbon/Ammonia Systems	13
2.2.3 Zeolite/Water Systems.....	14
2.2.4 Silica Gel/Water Systems	15
2.2.5 Calcium Chloride/Ammonia Systems	16
2.2.6 Other Working Pairs.....	17
2.2.7 Previous Studies on Working Pairs Comparison	17
2.2.8 Improving Adsorbent Heat Transfer	19
2.3 Adsorption Thermodynamic Cycles.....	21
2.3.1 Basic Single Bed Cycle (Intermittent Cycle).....	21
2.3.2 Multi-Bed Cycle	21
2.3.3 Heat and Mass Recovery Adsorption Cycle.....	23
2.3.4 Thermal Wave Cycle.....	23
2.3.5 Cascaded Cycle.....	25
2.4 Solar Intermittent Adsorption Refrigeration Systems	25

2.4.1	Collector	26
2.4.2	Condenser	31
2.4.3	Evaporator and Water Tank	32
2.4.4	Reservoir, Valves and Sensors	34
2.5	Objectives	35
CHAPTER 3 THERMODYNAMIC ANALYSIS AND MODELLING		36
3.1	Thermodynamic Analysis	37
3.1.1	Sorption Concentration Rate	37
3.1.2	Isosteric Heating Process	40
3.1.3	Isobaric Desorption Process	41
3.1.4	Isosteric Cooling Process	42
3.1.5	Isobaric Adsorption Process	43
3.1.6	Evaporation and Condensation Heats	43
3.1.7	Performance of the System	45
3.2	Heat and Mass Transfer Modeling	46
3.2.1	Physical Description of the System	46
3.2.2	Modeling Assumptions	48
3.2.3	Collector Overall Heat Transfer Coefficient	49
3.2.4	Absorber Plate	51
3.2.5	Adsorbent Bed	52
3.2.6	Condenser and Evaporator	53
3.2.7	Boundary and Initial Conditions	55
3.3	Research and Solution Methodology	57
3.3.1	Overall Literature Review	57
3.3.2	Thermodynamic Analysis	57
3.3.3	System Modeling	58
3.3.4	Improving the Performance	59
CHAPTER 4 RESULTS AND DISCUSSION		60
4.1	Thermodynamic Analysis Results	60
4.2	Modeling Results	68
4.2.1	Wind Heat Transfer Coefficient of Top and Back Faces of Solar Collector	68
4.2.2	Overall Top Heat Transfer Coefficient (U_{top})	73
4.2.3	Actual Thermal Behavior of the System	78
4.2.3.1	Validation of the Code	78
4.2.3.2	Performance under Hot and Cold Climate Conditions	79
4.2.3.3	Activated Carbon Type	88
4.2.3.4	Absorber Plate and Absorber Coating	93
4.2.3.5	Adsorbent Bed Thickness (Amount of Activated Carbon)	99

4.2.3.6	Glazing Cover Number and Types	101
4.2.3.7	Back Insulation Thickness	105
4.2.3.8	Other Improvements	108
4.2.3.9	Actual System Behavior after Improving the Main Collector Parameters.....	113
CHAPTER 5 CONCLUSIONS		123
REFERENCES		126
VITA		134

LIST OF TABLES

Table 2.1 Performance of different adsorption cooling systems	19
Table 4.1 Validation of the present results with those of Wang et al.....	61
Table 4.2 Heat losses from selective collector ($\epsilon_{pw} = 0.1$, $T_{pw} = 50$ °C, $T_{amb} = 25$ °C).	74
Table 4.3 Heat losses from nonselective collector ($\epsilon_{pw} = 0.9$, $T_{pw} = 50$ °C, $T_{amb} = 25$ °C).	75
Table 4.4 Comparison between present simulation results with Medini [15] experimental results.....	79
Table 4.5 System performance for June 2011.	85
Table 4.6 System performance for December 2011.	88
Table 4.7 System summer and winter performance predicted for 2011.....	88
Table 4.8 Characteristics of activated carbon types.	89
Table 4.9 Main constructive and operative parameters of the activated carbon types on 19 th June and 19 th December 2011.	90
Table 4.10 The performance of the activated carbon types on 19 th June and 19 th December 2011.....	92
Table 4.11 The effect of absorber tube thickness on the system operating parameters.	94
Table 4.12 Effect of absorber tube thickness on the system performance.	95
Table 4.13 The effect of absorber absorptivity on system operating parameters at $\epsilon_{pw} = 0.1$	96
Table 4.14 The effect of absorber absorptivity on performance parameters at $\epsilon_{pw} = 0.1$	97
Table 4.15 The effect of absorber emissivity on system operating parameters at $\alpha_{pw} = 0.9$	98
Table 4.16 The effect of absorber emissivity on system performance at $\alpha_{pw} = 0.9$	98
Table 4.17 The effect of the absorber emissivity on system operating parameters.....	100
Table 4.18 The effect of absorber emissivity on system performance parameters.	100
Table 4.19 Effect of glazing cover systems on operating and performance parameters.	105
Table 4.20 The effect of collector back insulation thickness on system operating parameters.....	106
Table 4.21 The effect of collector back insulation thickness on system performance parameters.....	107
Table 4.22 Average monthly collector tilt angle for Dhahran.....	109
Table 4.23 Effect of collector tilt angle and time offset on operating and performance parameters.....	113
Table 4.24 System performance for June 2011.	117
Table 4.25 System performance for December 2011.	121
Table 4.26 System predicted performance data for both June and December of 2011..	122
Table 4.27 Comparison between thermodynamic analysis and modeling performance results.....	122

LIST OF FIGURES

Figure 1.1 Schematic of the solar adsorption cooling system.	3
Figure 1.2 Schematic view of the adsorption process on Clapeyron diagram.	4
Figure 2.1 Solar cooling systems.....	6
Figure 2.2 Multi-stage, Multi-bed adsorption refrigerator	22
Figure 2.3 Rotary adsorbent generation device	22
Figure 2.4 Thermal wave cycle	24
Figure 2.5 Cascaded cycle.....	25
Figure 2.6 Solar adsorption cooling system.	27
Figure 2.7 Geometry shapes of adsorbent bed.	27
Figure 2.8 The solar adsorption collector with TIM cover.....	30
Figure 2.9 Air and water condensers.....	32
Figure 2.10 Trapezoidal and tubular configuration of the evaporator.....	33
Figure 3.1 P-T-x diagram of ideal and actual adsorption refrigeration cycle.....	36
Figure 3.2 Schematic of solar collector and adsorbent bed.....	46
Figure 3.3 TIM cover in adsorption solar collector.....	47
Figure 3.4 Schematic of trapezoidal evaporator.....	48
Figure 4.1 Effect of the desorption and condenser temperatures on the performance.	62
Figure 4.2 Effect of the adsorption and evaporation temperatures on the performance. .	64
Figure 4.3 Effect of the condenser pressure on the methanol desorbed.	65
Figure 4.4 Effect of the evaporator pressure on the methanol adsorbed.	66
Figure 4.5 Effect of initial water temperature on amount of produced ice.....	66
Figure 4.6 Velocity, temperature and stream function contours for almost southerly winds.....	69
Figure 4.7 Effect of southerly wind velocity on the top and back wind heat transfer coefficient of the collector.....	70
Figure 4.8 Velocity, temperature and stream function contours for almost northerly wind	72
Figure 4.9 Effect of northerly wind velocity on the top and back wind heat transfer coefficient of the collector.....	73
Figure 4.10 Effect of space between absorber and single glazing cover on top heat transfer coefficient for some selected values of T_{pw} and ϵ_{pw}	76
Figure 4.11 Effect of space between absorber and double glazing cover on top heat transfer coefficient for some selected values of T_{pw} and ϵ_{pw}	77
Figure 4.12 System configuration details.....	80
Figure 4.13 Solar radiation on collector (I_T) and ambient temperature (T_{amb}) recorded during the period June 14-20, 2011.....	82
Figure 4.14 Collector absorber (T_{pw}), adsorbent bed (T), condenser (T_c) and evaporator (T_e) temperatures calculated for the period 14-20 June 2011.....	82

Figure 4.15 Schematic diagram for variations of methanol uptake and system pressure for one day.....	83
Figure 4.16 Methanol uptake(m_m), adsorbent bed pressure (P) and amount of produced ice (M_{ice}) calculated for the period 14-20 June 2011.....	84
Figure 4.17 Solar radiation on collector (I_T) and ambient temperature (T_{amb}) recorded during the period December 17-23, 2011.....	85
Figure 4.18 Collector absorber (T_{pw}), adsorbent bed(T), condenser (T_c) and evaporator (T_e) temperatures calculated for the period 17-23 December 2011.	86
Figure 4.19 Methanol uptake (m_m), adsorbent bed pressure (P) and amount of produced ice (M_{ice}) calculated for the period 17-23 December 2011.	87
Figure 4.20 Methanol uptake (m_m) for three types of activated carbon for 19 th December.	93
Figure 4.21 Effect of metal thickness on the performance.....	95
Figure 4.22 The effect of the activated carbon NORIT RX3-Exta amount (M_{ac}) on the performance.	101
Figure 4.23 Transmissivity absorptivity product ($\tau_g\alpha_{pw}$) of the three glazing cover systems.....	102
Figure 4.24 Overall collector heat loss coefficient (U_L) during heat generation time of the three glazing cover systems.....	103
Figure 4.25 Adsorbent (T) and evaporator (T_e) temperatures of the three glazing cover systems.....	104
Figure 4.26 Methanol uptake (m_m) and amount of produced ice (M_{ice}) for the three glazing cover systems.....	104
Figure 4.27 Effect of back insulation thickness (t_i) on M_{ice} and SCOP.	108
Figure 4.28 Effect of collector tilt angle on incident solar radiation on collector on 19 th June.....	109
Figure 4.29 Effect of collector tilt angle on adsorbent (T) and evaporator (T_e) temperatures on 19 th June.	110
Figure 4.30 Effect of collector tilt angle on methanol uptake (T_d), pressure (P) and amount of produced ice (M_{ice}) on 19 th June.....	110
Figure 4.31 Effect of time offset on adsorbent (T) and evaporator (T_e) temperatures at Tilt = 3.4° on 19 th June.....	112
Figure 4.32 Effect of time offset on methanol uptake (m_m), pressure (P) and produced ice (M_{ice}) at Tilt = 3.4° on 19 th June.....	112
Figure 4.33 System configuration details after the improvements.....	114
Figure 4.34 Solar radiation on collector (I_T) and ambient temperature (T_{amb}) recorded in June 2011.....	115
Figure 4.35 Collector absorber (T_{pw}), adsorbent bed (T), condenser (T_c) and evaporator (T_e) temperatures calculated for June 2011.	116

Figure 4.36 Methanol uptake (m_m), adsorbent bed pressure (P) and amount of produced ice (M_{ice}) calculated for June 2011.116

Figure 4.37 Methanol uptake(m_m), adsorbent bed pressure (P) and amount of produced ice (M_{ice}) calculated for 18th, 19th and 20th June 2011 (for $m_w=5$ kg).118

Figure 4.38 Incident solar radiation on collector (I_T) and ambient temperature (T_{amb}) recorded during December 17-26, 2011.119

Figure 4.39 Collector absorber (T_{pw}), adsorbent bed (T), condenser (T_c) and evaporator (T_e) temperatures calculated for the period 17-26 December 2011.120

Figure 4.40 Methanol uptake(m_m), adsorbent bed pressure (P) and amount of produced ice (M_{ice}) calculated for the period 17-26 December 2011.120

NOMENCLATURE

A	area (m^2)
COP	Coefficient of Performance
C_p	specific heat at constant pressure (J/kg K)
C_v	specific heat at constant volume (J/kg K)
D	Dubinin-Astakhov constant (K^{-1})
D1	diameter of inner pass tube (m)
D2	internal diameter of absorber tube (m)
D3	external diameter of absorber tube (m)
D_o	surface diffusion coefficient (m^2/s)
E_a	activation energy of surface diffusion (J/mol)
E_o	characteristic adsorption energy for a reference vapour (J/mole)
ESCOP	Effective Solar Coefficient of Performance
h	specific enthalpy (J/kg)
h	heat transfer coefficient (W/m^2K)
H	heat of desorption or adsorption per unit mass of methanol (J/kg)
I_T	incident solar radiation (W/m^2)
k	thermal conductivity (W/m K)
k	adsorbent constant
L	latent heat (J/kg)
L_c	collector length (m)
M, m	mass (kg)
m_m	methanol uptake (kg)
n	Dubinin-Astakhov constant
N_g	number of glass cover
n_{tube}	number of absorber tubes
P	system pressure (Pa)
Q	heat amount (J)
R	gas constant (J/mole K)
r	radius (m)
R1	radius of inner pass tube (m)
R2	internal radius of absorber tube (m)
R3	external radius of absorber tube (m)
r_p	average radius of adsorbent particles (m)
SCOP	Solar Coefficient of Performance
SCP	Specific Cooling Power (W/kg)

T	temperature ($^{\circ}\text{C}$ or K)
t	time (s) / thickness (m)
TIM	Transparent Insulation Material
U	overall heat transfer coefficient ($\text{W}/\text{m}^2\cdot\text{K}$)
V	micropore volume filled with the adsorbed phase (m^3/m^3)
V_o	limiting micropore volume (m^3/m^3)
V_w	wind velocity (m/s)
W_c	collector width (m)
x	concentration ratio of adsorbate inside adsorbent (kg/kg)
x_o	maximum limit of mass adsorbed (kg/kg)

Greek Symbols

Δ	difference / change
τ	transmittance
α	absorptivity
ϵ	emissivity
σ	Stefan Boltzmann constant ($\text{W}/\text{m}^2 \text{K}^4$)
β	affinity coefficient or collector tilt angle
ρ	density (kg/m^3)

Subscripts

1,2,3,4	processes terminal locations
ac	activated carbon
a	adsorption
amb	ambient
b	back
c	condenser
d	desorption
e	evaporator
eq	equivalent
g	generation / glass
i	insulation

ice	ice
is	collector side insulation
L	collector overall
m	methanol
max	maximum
min	minimum
pw	absorber plate wall
s	side
sa	starting adsorption
sat	saturated
sd	starting desorption
sol	solidification
t	top
w	water

ABSTRACT

Full Name : Naef Abduljalil Abdulrahman Qasem
Thesis Title : Thermodynamic analysis and modeling study of an intermittent adsorption refrigeration system
Major Field : Mechanical Engineering
Date of Degree : May, 2013

Solar adsorption refrigeration systems have been increasingly attracting some research interests since last decade because they are clean, cheap and simple for use in air conditioning, ice making, food preservation and vaccine storage specially for remote areas. The idea of these devices is the reversible physical adsorption of vapor on the surface of a porous solid. The system consists of three important components: solar collector with adsorbent bed, condenser and evaporator.

The main objectives of this work are to improve the performance of the solar intermittent refrigeration system that uses activated carbon and methanol as adsorbent and adsorbate pair. The improvement of the system's performance is achieved through investigating the effect of the main operative and constructive parameters of the system. EES and MATLAB computer programs are exploited to analyze the thermodynamic cycle of the system and to model the system under Dhahran climate conditions, respectively.

The results show that the increase in the condenser temperature needs high values of the desorption temperature while lowering values of the evaporator temperature needs low values in the adsorption temperature to improve the performance. The absorbers of collector should have thin wall and should be coated by high absorptivity and low emissivity material. About 14.1 kg/m^2 of activated carbon NORIT RX3-Extra per m^2 of

collector surface is a suitable optimum choice for adsorption ice maker devices. Furthermore, double glazing, tilt angle of the solar collector and starting the cycle at suitable time as well as suitable collector back insulation increase the performance. Moreover, the study proposes an activated carbon/methanol solar adsorption ice-maker that could produce from 5 kg up to 13 kg of ice per day per m² of collector area with improved solar coefficients of performance of 0.12 and 0.24 according to weather conditions in the hot and the cold days, respectively.

ملخص الرسالة

الاسم الكامل : نائف عبد الجليل عبد الرحمن قاسم

عنوان الرسالة : تحليل حراري و دراسة نموذجة لآلة التبريد المتقطع بالامتزاز الشمسي

التخصص : هندسة ميكانيكية

تاريخ الدرجة العلمية : مايو ٢٠١٣م

في العقد الماضي زاد الاهتمام بدراسة التبريد بواسطة الامتزاز لما يعطيه من امتيازات كونه رخيص التشغيل ونظيف بيئيا بالإضافة الى امكانية استخدامه لأغراض التبريد والتكييف وحفظ الاطعمة واللقاحات الدوائية. فكرة هذه المنظومة قائمة على قدرة امتزاز المادة الصلبة المسامية - الممتزات - لبخار مائع التبريد - المازة- عند درجة حرارة منخفضة وايضا طرد المازة على شكل بخار عند التسخين. تتكون اجهزة الامتزاز من الممتزات المحتوية في مجمع شمسي غالبا ما يكون مسطح بالإضافة الى المكثف والمبخر- المبرد. في هذه الرسالة يتم التحليل الثيروديناميكي - الحراري- لالة التبريد الممتز عن طريق دراسة اهم العوامل المؤثرة فيها مثل: درجة حرارة الممتز الكبرى ودرجة حرارة الامتزاز الصغرى بالإضافة الى حرارة وضغط كل من المكثف والمبخر. التحليل الحراري يعطينا انطبعا عن الأداء التمهيدي للمنظومة مثل كمية الثلج المتوقع انتاجها ومعامل الاداء وتتم هذه الدراسة باستخدام برنامج EES في حين أن الدراسة الفعلية للمنظومة تتم من خلال النمذجة بواسطة برنامج MATLAB على حسب ظروف مناخ الظهران لإظهار الاداء الفعلي وكمية الثلج المتوقعة خلال الايام الباردة والحارة من السنة. لهذا تهدف هذه الدراسة الى تحسين اداء منظومة الامتزاز الشمسي المتقطع (الذي لا يعمل بصورة مستمرة وينتج تبريدا طوال الليل والنهار) باستخدام الكربون المنشط والميثانول بواسطة دراسة وتحسين العوامل المؤثرة فيه: كنوع الكربون المنشط وسمك معدن الانابيب الماصة للأشعة الشمسية بالإضافة الى امتصاصية وانبعائيه الطلاء الذي يغطي الماصات الشمسية الى جانب كل من كمية الكربون المنشط و الغلاف الزجاجي

المناسب وسماكة المادة العازلة التي تغطي قاعدة المجمع الشمسي وايضا زاوية ميلان المجمع الشمسي مع بداية التشغيل المناسبة. تهدف هذه الدراسة ايضا الى انتاج ٥ كجم او اكثر من الثلج لكل متر مربع من المجمع الشمسي باليوم الواحد. نتائج التحليل الحراري تشير الى انه في حالة ارتفاع درجة حرارة المكثف يجب تسخين الكربون المنشط بدرجات حرارة عالية وايضا في حالة الذهاب الى درجة حرارة منخفضة داخل المبخر يجب ان تكون درجة حرارة الامتزاز منخفضة ايضا. اما نتائج دراسة النمذجة توضح ان حوالي 1٤.1 كجم من الكربون المنشط NORIT RX3-Extra لكل متر مربع من المجمع الشمسي يعطي نتائج افضل من الانواع الاخرى ويفضل ان يكون سمك الانابيب الماصة اصغر ما يمكن من اجل تحسين اداء المنظومة. كما اوضحت الدراسة الى ان الغلاف الزجاجي الذي يتكون من طبقتين مفصولتين من الزجاج افضل من اللوح الزجاجي الواحد او الانظمة الزجاجية السامحة للأشعة الشمسية والعازلة للحرارة المفقودة (TIM) بالإضافة الى ان سماكة المادة العازلة تزيد من الكفاءة لكن يجب ان لا تزيد المجمع الشمسي عبء اضافي كزيادة سماكته. المنظومة المحسنة بالخصائص السابقة مع تميل المجمع الشمسي بزاوية مناسبة وبدء الدورة الحرارية عند الوقت المناسب يمكن ان ينتج كميات من الثلج تتراوح بين ٥ كجم الى ١٣ كجم لكل متر مربع من المجمع الشمسي وبمعامل اداء شمسي يتراوح بين ٠,١٢ و ٠,٢٤ للأيام الحارة والباردة على التوالي.

CHAPTER 1

INTRODUCTION

1.1 Introductory Background

Refrigeration and air conditioning demands are widely increasing because of the increase in population as well as the dramatic growth of industries. Many refrigeration technologies were developed during the last century. The vapor compression systems broadly dominate the human use for satisfying comfort conditions or food preservation. These traditional refrigeration systems consume a significant amount of electric power. In addition, such systems rely on refrigerants as chlorofluorocarbons CFCs and hydrochlorofluorocarbons HCFCs which increase the depletion of the Earth's ozone layer. Consequently, alternative refrigeration technologies became very much needed; especially the current sources of energy such oil may run dry in the near future. The electricity is not also covering all human living areas. For now, there are numerous places without electricity especially in countryside of some developing countries. So people living in such areas cannot preserve their food and store vaccine in their local clinics. Accordingly, solar adsorption refrigeration technology has attracted some research interests since 1990 because it is clean, cheap and simple for use in air conditioning, ice making, food preservation and vaccine storage. The idea of these devices is the reversible physical adsorption of vapor on the surface of a porous solid. An intermittent adsorptive

solar ice-maker is an attractive application that is composed from adsorbent bed as adsorptive reactor integrated into a solar collector for the desorption of the sorbent material during the day. During the night adsorption occurs by the adsorbent when the refrigerant comes back from the evaporator, in which the cooling effect is obtained and some ice may be produced.

This research aims to understand the thermodynamic processes of the intermittent adsorption cooling system and study the effect of the operative parameters on the performance of the system. Moreover, improving the performance of the system will be investigated through studying the effect of the constructive parameters and then proposing a solar adsorption ice-maker to produce 5 kg of ice or more per day per m² of collector area under Dhahran climatic conditions.

1.2 System and Processes Description

Intermittent adsorption systems usually have a single bed adsorption cycle that has been improved for some applications such as preservation of food and vaccine storage. The adsorption system consists of three main parts: solar collector with adsorbent bed where a porous solid material is placed, condenser and evaporator, Fig. 1.1. The operating cycle of the system has four processes as shown in the Clapeyron diagram in Fig. 2.2. The heating process (1-2) and the desorbing process (2-3) represent half the cycle while the cooling (3-4) and adsorption (4-1) processes represent the other half. During the heating period, the adsorbent bed receives heat from solar energy which raises the temperature of the pair of adsorbent and adsorbate as shown in Fig. 2.2 by line 1-2 (isosteric heating

process, at constant concentration of the adsorbate x_{\max}). When the adsorbent bed pressure reaches the pressure of the condenser, the adsorbate vapor diffuses from the collector and is collected and condensed in the condenser (line 2-3, desorption process at condenser pressure). So the concentration of the adsorbate in the reactor reaches the minimum value (x_{\min}) at the end of this desorption process. This process is followed by cooling the generator (line 3-4, isosteric cooling process). Then, the liquid adsorbate flows from the condenser to the evaporator. After that, the adsorbent adsorbs the refrigerant that is coming from the evaporator (line 4-1, adsorption process at evaporator pressure). As a result, the liquid water in evaporator is converted into ice or become cold.

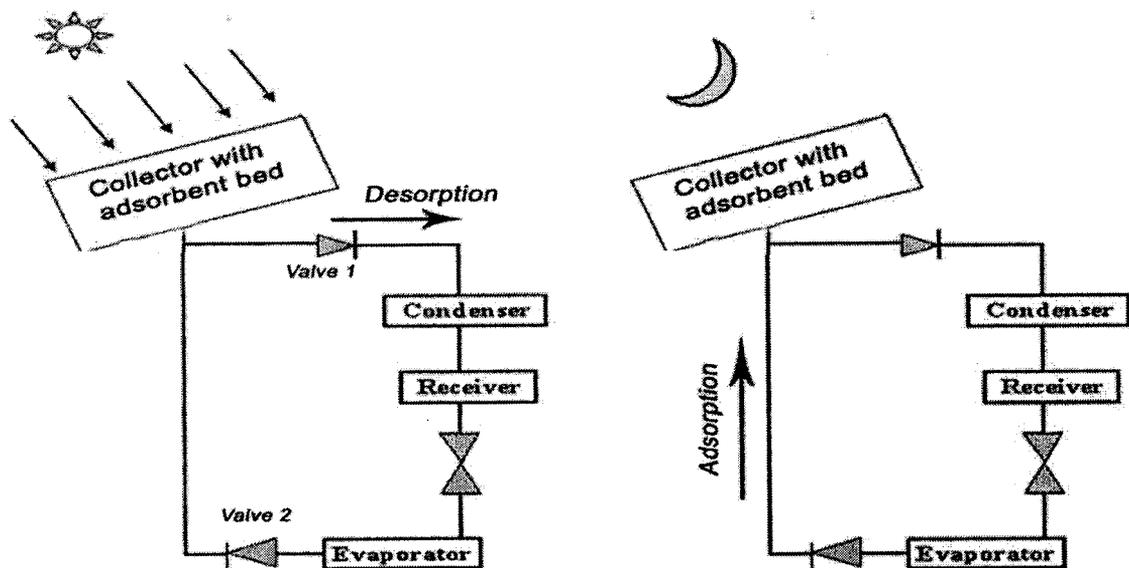


Figure 1.1 Schematic of the solar adsorption cooling system.

The heating and cooling processes are run at constant concentration of adsorbate while the concentration of refrigerant varies through adsorption and desorption processes.

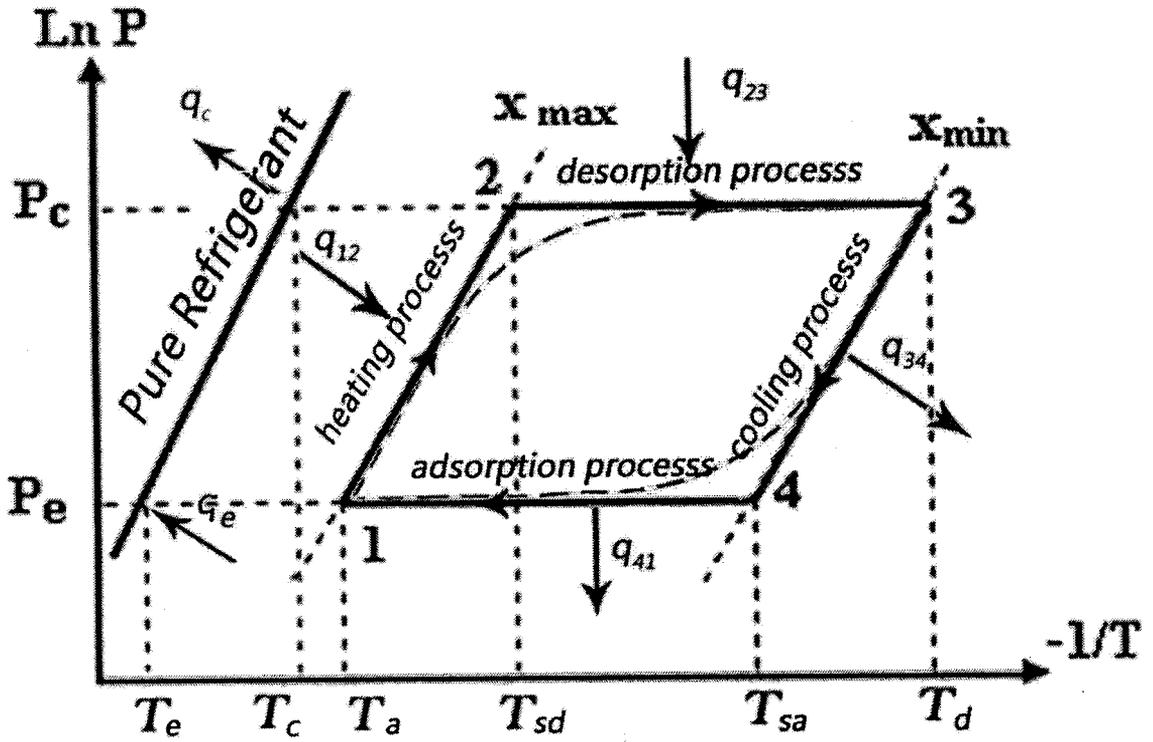


Figure 1.2 Schematic view of the adsorption process on Clapeyron diagram.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

Although a refrigeration system has been founded since the middle of the eighteenth century by William Cullen, the practical refrigeration system was built as an ice-maker by Jacob Perkins in 1834 [1]. Since that time, there have been many refrigeration and heat pump systems that are categorized according to either the principle of work or the operating source of energy: vapor-compression, absorption refrigeration, adsorption refrigeration, thermoelectric refrigeration, vortex tube, paramagnetic refrigeration, sterling cycle, gas refrigeration cycle and vapor-jet refrigeration systems. However, there are five different technologies that are currently used for solar cooling systems: sorption (absorption/adsorption) refrigeration, photovoltaic vapor compression refrigeration, open-cycle refrigeration, and ejector cycle. Some of them are widely used because of their high coefficient of performance like the vapor compression system for which we need electricity to run the compressor. On the other hand, some of the systems are not used for ice making because they cannot produce a temperature below zero degree. However, these systems are widely used for air conditioning and fresh food preservation. Examples of these systems are desiccant cycles, ejector cycle and some absorption and adsorption pairs.

العنوان:	Thermodynamic Analysis and Modeling Study of an Intermittent Solar Adsorption Refrigeration system
المؤلف الرئيسي:	Qasem, Naef
مؤلفين آخرين:	El Shaaeawi, Maged A.(Super)
التاريخ الميلادي:	2013
موقع:	الظهران، السعودية
الصفحات:	1 - 134
رقم MD:	621520
نوع المحتوى:	رسائل جامعية
اللغة:	English
الدرجة العلمية:	رسالة ماجستير
الجامعة:	جامعة الملك فهد للبترول والمعادن
الكلية:	عمادة الدراسات العليا
الدولة:	السعودية
قواعد المعلومات:	Dissertations
مواضيع:	الهندسة الميكانيكية، التحليل الحراري
رابط:	https://search.mandumah.com/Record/621520

**THERMODYNAMIC ANALYSIS AND MODELING STUDY
OF AN INTERMITTENT SOLAR ADSORPTION
REFRIGERATION SYSTEM**

BY

NAEF QASEM

A Thesis Presented to the
DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

1963 ١٣٨٣

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

MECHANICAL ENGINEERING

MAY, 2013