

العنوان:	PERFORMANCE IMPROVEMENT OF A VAPOR COMPRESSION AIR CONDITIONING SYSTEM BY CONDENSATE AND FRESH WATER SOURCE
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ABSTRACT (ENGLISH)

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Considerable amount of electrical energy produced in the Kingdom of Saudi Arabia is consumed by air conditioning systems. In addition, water scarcity still exists in most of the arid and semi-arid countries. This thesis presents the outcome of a study conducted to bring down energy consumption and improve the performance of a vapor compression air conditioning system using condensate that is generated by the system. The base system used in the study is a 1.5 ton split type air conditioner. Three different options of system modifications are adopted to improve its performance. The three options are: option 'A'- air precooling before entering the evaporator using condensate, option 'B'- precooling the air entering the condenser by condensate and option 'C'- subcooling the refrigerant exiting the condenser using the condensate. Comparative study of the base system and the modified system is carried out. The results show that precooling the air entering the evaporator and condenser using condensate lowers the compressor discharge pressure. The discharge pressure also decreased significantly when subcooling is applied. The decrease in the discharge pressure resulted in the decrease in compressor power consumption to about 5% for option 'A', 4.8 % for option 'B' and 3.7% for option 'C' from experiments conducted for severest weather conditions. The severest weather conditions are 36 °C dry bulb temperature and 80% relative humidity obtained from the climate data of four major cities of Saudi Arabia. By decreasing the discharge pressure, the compressor's life expectancy can be improved. The coefficient of performance, COP is increased by about 30 %, 21% and 30% for options 'A', 'B' and 'C', respectively. The increase in the second law efficiencies obtained for options 'A', 'B', and 'C' are 24.85, 23.51 and 21.53%, respectively. The overall assessment of the three options is that option 'A' gives better system performance improvement followed by option 'B', then option

'C'. The rate of condensate extraction from the air conditioning system is studied and chemical analysis is carried out on the condensate sample to determine its quality. The amounts of condensate collected in Dhahran from the base system during the humid and hottest months of June, July, August and September are 1036, 1181, 2173 and 1781 kg, respectively, and these amounts are obtained experimentally on hourly basis. Analytical results of condensate extraction obtained by using hourly actual climate data are in good agreement with the experimental results. Condensate chemical analysis is conducted and the results are compared with the recommended guideline values of drinking water by World Health Organization. The Chemical analysis reveals that the condensate can be used as drinking water after undergoing simple bacterial removal process. It can also be used to improve the performance air conditioning systems and other applications such as cooling tower make up water and irrigation.

ABSTRACT (ARABIC)

الاسم الكامل: ناسيرو اسحاق ابراهيم

عنوان الرسالة: تحسين أداء أنظمة التكييف العاملة بضغط البخار بالتكثيف ومصدر مياه عذب

التخصص: هندسة ميكانيكية

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يتم إستهلاك كميات كبيرة من الطاقة الكهربائية المنتجة في المملكة العربية السعودية من قبل أنظمة التكييف. ومن جهة أخرى، لا تزال ندرة المياه موجودة في معظم البلدان القاحلة وشبه القاحلة. تقدم هذه الأطروحة نتائج دراسة أجريت لتقليل استهلاك الطاقة وتحسين أداء أنظمة التكييف التي تعمل بطريقة ضغط الغاز باستخدام البخار المكثف الناتج من قبل نظام التكييف. والنظام الأساسي المستخدم في هذه الدراسة هو مكيف هواء مشقوق بسعة 1.5 طن. تم اعتماد ثلاثة خيارات مختلفة لتحسين أداء النظام وتقليل استهلاك الطاقة. الخيارات الثلاثة هي: الخيار "أ"، تبريد الهواء قبل دخوله المبخر باستخدام مكثف. الخيار "ب"، تبريد باستخدام مكثف. التثقيب ز الخيار "ج" تبريد الغاز المبرد الخارج من المكثف الهواء قبل دخوله المبخر باستخدام التثقيب. تم عمل دراسة مقارنة للنظام الأساسي وانظام المعدل. اظهرت النتائج ان عملية التبريد المسبق للهواء قبل المبخر والمكثف باستخدام مكثف. وقللت عملية التبريد المسبق للهواء الداخل للمبخر والمكثف باستخدام الماء المكثف من ضغط التصريف للضاغط. أيضاً بشكل ملحوظ عندما تم تبريد الغاز المبرد لأقل من درجة الغليان. وأدى إنخفاض ضغط التصريف للمضخة إلى إنخفاض استهلاك الطاقة في المضخة إلى حوالي 5٪ للخيار "أ"، و 4.8٪ للخيار "ب"، و 3.7٪ للخيار "ث" الظروف المناخية الحادة هي 36 درجة مئوية و 80% رطوبة نسبية مأخوذة من بيانات الطقس للاربع مدن الرئيسية في المملكة العربية السعودية. ومن خلال خفض ضغط التصريف، يمكن تحسين متوسط العمر المتوقع للمضخة. وتم زيادة معامل الأداء (COP) بنحو 31 ٪ ، 21 ٪ و 30 ٪ للخيارات "أ" و"ب" و"ث" على التوالي. وكانت الزيادة في الكفاءة للقانون الثاني للخيارات "أ" و"ب" و"ث" هي 24.85، 23.51، و 21.53 ٪ على التوالي. وتبين من التقييم العام للخيارات الثلاثة أن الخيار "أ" يعطي أفضل تحسين لأداء النظام، يليها الخيار "ب" ثم الخيار "ث". وتم دراسة معدل استخراج الماء المكثف من نظام تكييف الهواء الذي يعتبر مصدراً إضافياً للماء بالإضافة إلى تحليله كيميائياً لتحديد درجة نقائه. وكانت كمية الماء المكثف من خلال النظام في منطقة الظهران خلال الأشهر يونيو ويوليو وأغسطس وسبتمبر هي 1036، 1076 ، 1181 ، 2173، و1781 كجم على التوالي، وتم جمع هذه الكميات في التجربة كل ساعة. وكانت النتائج التحليلية لعملية التثقيب والتي تم حسابها لكل ساعة باستخدام البيانات المناخية الفعلية في إتفاق جيد مع النتائج التجريبية. تم إجراء التحاليل الكيميائية والتي تمت مقارنة نتائجها مع الموصى بها للماء المقطر من منظمة الصحة. أظهرت التحاليل الكيميائية الماء المكثف أنه يمكن استخدامه على أنه ماء مقطر بعد عملية إزالة البكتيريا ، وايضا يمكن استخدامه لتحسين اداء أنظمة وتطبيقات تكييف الهواء كما فتعويض مياه أبراج التبريد، والرّي.

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TABLE OF CONTENTS

ACKNOWLEDGMENTS	V
LIST OF TABLES	X
LIST OF FIGURES	XII
NOMENCLATURE	XIX
ABSTRACT (ENGLISH).....	XXII
ABSTRACT (ARABIC).....	XXIV
CHAPTER 1	1
INTRODUCTION	1
1.1. Background	1
1.2. Principle of Operation of a Vapor Compression Air Conditioning System	3
1.3. Objectives of the Thesis.....	6
CHAPTER 2	8
LITERATURE REVIEW	8
2.1. Introduction.....	8
2.2. Atmospheric Water Vapor Condensation as a Water Source	8
2.3. Evaporative Cooling to Enhance Condenser Performance	11
2.4. Refrigerant Subcooling	13
2.4.1. Suction-liquid Line Subcooling	13
2.4.2. Mechanical Subcooling.....	14
2.4.3. External Heat Sink Subcooling.....	15
2.5. Hybrid Cooling	16

2.6.	Thermal Energy Storage Systems	17
2.7.	Second Law Analysis.....	19
CHAPTER 3		22
THEORETICAL STUDY OF A VAPOR COMPRESSION AIR CONDITIONING SYSTEM.....		22
3.1.	Introduction.....	22
3.2.	Thermodynamic Performance of VCAC System and Condensate Extraction	22
3.2.1.	Condensate Extraction Considering the Complete VCAC System	25
3.3	Performance Study of the Modified VCAC System.....	32
3.3.1	Option ‘A’: Evaporator Inlet Air Precooling	32
3.3.2	Option ‘B’: Condenser Inlet Air Precooling	34
3.3.3	Option ‘C’: Refrigerant Subcooling Downstream of the Condenser.....	34
3.3.4	Condensate Temperature Change During Air Precooling: Analytical Study ...	37
CHAPTER 4		40
CLIMATE DATA.....		40
4.1.	Overview of the Kingdom of Saudi Arabia	40
4.2.	Dhahran Climate Data.....	41
4.3.	Air Conditioners Usage in Saudi Arabia	48
CHAPTER 5		49
EXPERIMENTAL SET-UP		49
5.1.	The Experimentation Room.....	49
5.2.	The Base System.....	52
5.3.	Installation of Air Precooler for Option ‘A’	52
5.4.	Installation of Air Precooler for Option ‘B’	53
5.5.	Installation of Refrigerant Subcooler for Option ‘C’	56

5.6.	The Complete Experimental Set-up and Instrumentation.....	56
CHAPTER 6		61
RESULTS AND DISCUSSIONS.....		61
6.1.	Condensate Extraction from the Air Conditioning System	61
6.1.1.	Condensate Chemical Analysis.....	66
6.2.	System Performance Analysis	74
6.2.1.	Results for Evaporator Air Precooling: Option ‘A’	76
6.2.1.a	Experimental and Analytical Results for Severest Weather Conditions: Option ‘A’	77
6.2.1.b	Experimental Results for Intermediate Evaporator Inlet Air Conditions: Effects of Air Mass Flow Rate – Option ‘A’	90
6.2.2.	Experimental Results for Condenser Air Precooling - Option ‘B’	98
6.2.2.a	Experimental Results for Severest Weather Conditions – Option ‘B’	98
6.2.2.b	Experimental Results for Intermediate Evaporator Inlet Air Conditions – Option ‘B’	101
6.2.3.	Experimental Results for Refrigerant Subcooling – Option ‘C’	115
6.3.	Comparison of Experimental Results for Options ‘A’, ‘B’ and ‘C’	119
CHAPTER 7		129
UNCERTAINTY AND ERROR ANALYSES		129
7.1.	Uncertainty Analysis of the Experimental Results	130
7.2.	Error Analysis of Analytical Results	132
CHAPTER 8		139
CONCLUSIONS		139
8.1.	Condensate Extraction from the VCAC System.....	140
8.2.	Evaporator Inlet Air Precooling - Option ‘A’	141
8.3.	Condenser Inlet Air Precooling - Option ‘B’	142
8.4.	Refrigerant subcooling - Option ‘C’	143
8.5.	Overall Conclusions for the Three Options	143

8.6. Recommendations.....	144
APPENDICES	146
APPENDIX A: PHOTOGRAPHS OF EXPERIMENTAL SET-UP	146
APPENDIX B: NUMERICAL CODES	156
APPENDIX C: SAMPLE CALCULATIONS OF EXPERIMENTAL UNCERTAINTIES	166
REFERENCES	169
VITAE	176

LIST OF TABLES

Table 4.1 Summary of Dhahran maximum and minimum temperature and relative humidity: 2009 – 2012.	45
Table 4.2 Hourly variations of ambient temperature and relative humidity of typical days in June through September, Dhahran.	47
Table 5.1 Characteristics of the base air conditioning system.	52
Table 6.1 The 32 sets of experimental data and the corresponding amount of condensate extracted from the VCAC system.	63
Table 6.2 Comparison of condensate extraction rate for typical days in June through September, Dhahran.	68
Table 6.3 Experimental and analytical daily condensate extraction for the months of June through September.	69
Table 6.4 Chemical concentrations in condensate sample compared with WHO acceptable limits.	75
Table 6.5 Enthalpies of severest weather conditions in major cities of Saudi Arabia.	78
Table 6.6 Experimental conditions of options ‘A’, ‘B’ and ‘C’ for severest weather conditions.	78
Table 6.7 Summary of results for evaporator air precooling for severest weather conditions – Option ‘A’.	90
Table 6.8 Summary of experimental results for evaporator air precooling for intermediate evaporator inlet air conditions– Option ‘A’.	97

Table 6.9 Average percentage reduction/increase of performance parameters for air mass flow rate of 0.13 kg/s - Option 'A'.....	97
Table 6.10 Average values of improvements of modified system over the base system – Option 'B'.....	106
Table 6.11 Experimental conditions for intermediate evaporator inlet air conditions - Option 'B'.....	107
Table 6.12 Comparison of experimental results of base system with the modified system for severest weather conditions.....	127
Table 6.13 Improvement of the modified system over the base system.....	127
Table 7.1 Uncertainty values of experimental results: Base system.....	132
Table 7.2 Uncertainty values of experimental results: Option 'A'.....	133
Table 7.3 Uncertainty values of experimental results: Option 'B'.....	133
Table 7.4 Uncertainty values of experimental results: Option 'C'.....	134

LIST OF FIGURES

Figure 1.1 Basic components of conventional vapor compression system.	4
Figure 1.2 Schematic of pressure versus enthalpy diagram of conventional simple vapor compression cycle.	5
Figure 1.3 Schematic of temperature versus entropy diagram of conventional vapor compression cycle.	5
Figure 3.1 Schematic of the modified air conditioning system.	23
Figure 3.2 Schematic of a cooling with dehumidification process.	27
Figure 3.3 Psychrometric representation of cooling and dehumidification process.	27
Figure 3.4 Schematic of the modified system integrated with air precooler - Option 'A'.	33
Figure 3.5 Schematic of the modified system integrated with condenser air precooler - Option 'B'.	35
Figure 3.6 Schematic of the modified system integrated with subcooler - Option 'C'.	36
Figure 3.7 Pressure-enthalpy diagram of the modified system - Option 'C'.	36
Figure 4.1 Comparison of monthly maximum temperature of the years 2009 to 2012 in Dhahran.	43
Figure 4.2 Comparison of monthly mean temperature of the years 2009 to 2012 in Dhahran.	43
Figure 4.3 Comparison of monthly maximum relative humidity of the years 2009 to 2012 in Dhahran.	44

Figure 4.4 Comparison of monthly mean relative humidity of the years 2009 to 2012 in Dhahran.....	44
Figure 4.5 Variations of Ambient dry bulb temperature of typical days in June through September, Dhahran.....	46
Figure 4.6 Variations of Ambient relative humidity of typical days in June through September, Dhahran.....	46
Figure 5.1 Schematic of the experimentation room with climate chamber inside.....	51
Figure 5.2 Schematic of experimental rig for option 'A'.....	54
Figure 5.3 Schematic of experimental rig with option 'B'.....	55
Figure 5.4 Schematic of experimental rig with option 'C'.....	57
Figure 5.5 Schematic of the complete experimental set-up.....	59
Figure 5.6 Schematic of the air conditioning system showing the temperature and pressure measurement locations.	60
Figure 6.1 Hourly variations of condensate extraction rate and relative humidity for a typical day of August, Dhahran.	65
Figure 6.2 Variation of condensate extraction rate with relative humidity at different dry bulb temperatures.....	67
Figure 6.3 Comparison of analytical with experimental rate of condensate extraction for the month of June.....	70
Figure 6.4 Comparison of analytical with experimental rate of condensate extraction for the month of July.	71
Figure 6.5 Comparison of analytical with experimental rate of condensate extraction for the month of August.....	72

Figure 6.6 Comparison of analytical with experimental rate of condensate extraction for the month of September.	73
Figure 6.7 Air temperatures across precooler of option 'A' for severest weather conditions.	80
Figure 6.8 Variation of ΔT and precooler effectiveness of option 'A' for severest weather conditions.	81
Figure 6.9 Comparison of compressor pressures of base system with option 'A' for severest weather conditions.	82
Figure 6.10 Comparison of compressor power of base system with option 'A' for severest weather conditions.	83
Figure 6.11 Comparison of COP of base system with option 'A' for severest weather conditions.	84
Figure 6.12 Comparison of evaporator exit air temperature of base system with option 'A' for severest weather conditions.	86
Figure 6.13 Comparison of second law efficiency of base system with option 'A' for severest weather conditions.	87
Figure 6.14 Variation of condensate temperature the tank with time for severest weather conditions- Option 'A'.	88
Figure 6.15 Variation of condensate temperature inside tank for complete day during on and off- periods: analytical study.	89
Figure 6.16 Variation of cooling effect with air mass flow rate at different ΔT - Option 'A'.	92

Figure 6.17 Variation of compressor power with air mass flow rate at different ΔT - Option 'A' .	94
Figure 6.18 Variation of COP with air mass flow rate at different ΔT - Option 'A' .	95
Figure 6.19 Variation of second law efficiency with air mass flow rate at different ΔT - Option 'A' .	96
Figure 6.20 Variation of condensate inlet temperature and ΔT for severest weather conditions - Option 'B' .	99
Figure 6.21 Comparison of suction and discharge pressures of the base system with option 'B' for severest weather conditions.	100
Figure 6.22 Comparison of compressor power of base system with option 'B' for severest weather conditions.	102
Figure 6.23 Comparison of evaporator exit air temperature of base system with option 'B' for severest weather conditions.	103
Figure 6.24 Comparison of cooling effect of base system with option 'B' for severest weather conditions.	104
Figure 6.25 Comparison of COP of base system with option 'B' for severest weather conditions.	105
Figure 6.26 Comparison of second law efficiency of base system with option 'B' for severest weather conditions.	106
Figure 6.27 Temperature variations across precooler - Option 'B' .	108
Figure 6.28 Comparison of compressor discharge pressure of base system with modified system - Option 'B' .	110

Figure 6.29 Comparison of compressor discharge temperature of base system with modified system - Option 'B'.....	111
Figure 6.30 Comparison of compressor power consumption of base system with modified system - Option 'B'.....	112
Figure 6.31 Comparison of COP of base system with modified system - Option 'B' ..	113
Figure 6.32 Comparison of second law efficiency of base system with modified system - Option 'B'.....	114
Figure 6.33 Variations of refrigerant temperatures across subcooler and subcooler effectiveness for severest weather conditions – Option 'C'.....	116
Figure 6.34 Comparison of compressor discharge pressure of the base system with option 'C' for severest weather conditions.....	117
Figure 6.35 Comparison of compressor discharge temperature of base system with option 'C' for severest weather conditions.....	118
Figure 6.36 Comparison of compressor power consumption of base system with option 'C' for severest weather conditions.....	120
Figure 6.37 Variation of subcooler inlet condensate temperature and amount of subcooling for severest weather conditions - Option 'C'.....	121
Figure 6.38 Comparison of evaporator exit air temperature of base system with option 'C' for severest weather conditions.	122
Figure 6.39 Comparison of evaporating temperature of base system with option 'C' for severest weather conditions.....	123
Figure 6.40 Comparison of cooling effect of base system with option 'C' for severest weather conditions.....	124

Figure 6.41 Comparison of COP of base system with option ‘C’ for severest weather conditions.	125
Figure 6.42 Comparison of second law efficiency of base system with option ‘C’ for severest weather conditions.	126
Figure 7.1 Polynomial curve fitting of the analytical versus experimental condensate extracted in June.	135
Figure 7.2 Polynomial curve fitting of the analytical versus experimental condensate extracted in July.	136
Figure 7.3 Polynomial curve fitting of the analytical versus experimental condensate extracted in August.	137
Figure 7.4 Polynomial curve fitting of the analytical versus experimental condensate extracted in September.	138
Figure A-1 Experimental set-up: the climate chamber.	146
Figure A-2 Photograph of the precooler for option ‘A’ before installation.	147
Figure A-3 Picture of experimental rig for option ‘A’.	148
Figure A-4 Picture of precooler for condenser air precooling: option ‘B’.	149
Figure A-5 Installation of precooler for option ‘B’ behind the condenser.	149
Figure A-6 Precooler for option ‘B’ after installation.	150
Figure A-7 Picture of subcooler for option ‘C’ before installation.	150
Figure A-8 Glassed-face picture of subcooler showing water inlet before installation. .	151
Figure A-9 Three-D picture of subcooler showing the refrigerant inlet and outlet connections.	151
Figure A-10 Picture of the subcooler after installation.	152

Figure A-11 Front-face of the completed experimental set-up showing the outdoor unit and subcooler. 153

Figure A-12 Photograph of the experimental set-up outside the room showing the outdoor unit and condensate-storage tank. 154

Figure A-13 Data acquisition system that is used during the experiments..... 155

Figure B-1 Flow chart for the ambient temperature data sets..... 156

Figure B-2 Flow chart for the relative humidity data sets. 157

NOMENCLATURE

A	area (m^2)
ADP	apparatus dew point
ARI	Air Conditioning and Refrigeration Institute
COP	coefficient of performance
C_p	specific heat capacity (kJ/kg-K)
\dot{C}	heat capacity rate (kW/K)
D	diameter (m)
dp	dew point
EER	energy efficiency rating
f''	fouling factor (W/K)
h	specific enthalpy (kJ/kg-K)
\tilde{h}	convective heat transfer coefficient ($\text{W/m}^2\text{-K}$)
k	thermal conductivity (W/m-K)
L	length (m)
NTU	number of transfer unit
M	mass of condensate in the storage tank (kg)
m	mass flow rate, kg/s
P	pressure (kPa)
\dot{Q}	rate of heat transfer (kW)

T	temperature ($^{\circ}\text{C}$ or K)
t	time (s or h)
UA	conductance (W/K)
WHO	World Health Organization
\dot{W}	rate of work (kW)

Greek Symbols

Δ	difference
ε	effectiveness
ϕ	relative humidity
η	efficiency
ω	specific humidity
δ	uncertainty value

Subscripts

a	air
avg	average
com	compressor
c	condenser, condensate
e	exit
ev	evaporator
f	fin
H	high
i	inside, initial, inlet
i,e	instrument error

L	low
max	maximum
min	minimum
o	outside
pc	precooler
r	refrigerant
r,e	random error
s	isentropic, surface
sat	saturated
sc	subcooler
sf	fin surface
t	tube
tot	total
w	water

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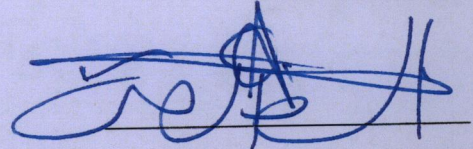
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DHAHRAN- 31261, SAUDI ARABIA

DEANSHIP OF GRADUATE STUDIES

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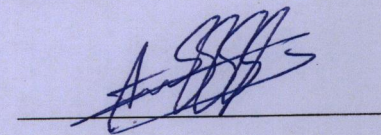
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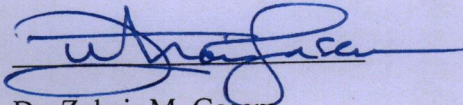
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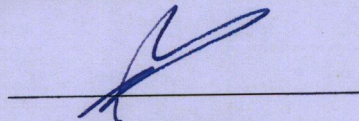


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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Dedicated

To My Parents and Family

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“In the name of Allah, The Most Gracious and The Most Merciful”

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TABLE OF CONTENTS

ACKNOWLEDGMENTS	V
LIST OF TABLES	X
LIST OF FIGURES	XII
NOMENCLATURE	XIX
ABSTRACT (ENGLISH).....	XXII
ABSTRACT (ARABIC).....	XXIV
CHAPTER 1	1
INTRODUCTION	1
1.1. Background	1
1.2. Principle of Operation of a Vapor Compression Air Conditioning System	3
1.3. Objectives of the Thesis.....	6
CHAPTER 2	8
LITERATURE REVIEW	8
2.1. Introduction.....	8
2.2. Atmospheric Water Vapor Condensation as a Water Source	8
2.3. Evaporative Cooling to Enhance Condenser Performance	11
2.4. Refrigerant Subcooling	13
2.4.1. Suction-liquid Line Subcooling	13
2.4.2. Mechanical Subcooling.....	14
2.4.3. External Heat Sink Subcooling.....	15
2.5. Hybrid Cooling	16

2.6.	Thermal Energy Storage Systems	17
2.7.	Second Law Analysis.....	19
CHAPTER 3		22
THEORETICAL STUDY OF A VAPOR COMPRESSION AIR CONDITIONING SYSTEM.....		22
3.1.	Introduction.....	22
3.2.	Thermodynamic Performance of VCAC System and Condensate Extraction	22
3.2.1.	Condensate Extraction Considering the Complete VCAC System	25
3.3	Performance Study of the Modified VCAC System.....	32
3.3.1	Option ‘A’: Evaporator Inlet Air Precooling.....	32
3.3.2	Option ‘B’: Condenser Inlet Air Precooling.....	34
3.3.3	Option ‘C’: Refrigerant Subcooling Downstream of the Condenser.....	34
3.3.4	Condensate Temperature Change During Air Precooling: Analytical Study ...	37
CHAPTER 4		40
CLIMATE DATA.....		40
4.1.	Overview of the Kingdom of Saudi Arabia	40
4.2.	Dhahran Climate Data.....	41
4.3.	Air Conditioners Usage in Saudi Arabia	48
CHAPTER 5		49
EXPERIMENTAL SET-UP		49
5.1.	The Experimentation Room.....	49
5.2.	The Base System.....	52
5.3.	Installation of Air Precooler for Option ‘A’	52
5.4.	Installation of Air Precooler for Option ‘B’	53
5.5.	Installation of Refrigerant Subcooler for Option ‘C’	56

5.6.	The Complete Experimental Set-up and Instrumentation.....	56
CHAPTER 6		61
RESULTS AND DISCUSSIONS.....		61
6.1.	Condensate Extraction from the Air Conditioning System	61
6.1.1.	Condensate Chemical Analysis.....	66
6.2.	System Performance Analysis	74
6.2.1.	Results for Evaporator Air Precooling: Option ‘A’	76
6.2.1.a	Experimental and Analytical Results for Severest Weather Conditions: Option ‘A’	77
6.2.1.b	Experimental Results for Intermediate Evaporator Inlet Air Conditions: Effects of Air Mass Flow Rate – Option ‘A’	90
6.2.2.	Experimental Results for Condenser Air Precooling - Option ‘B’	98
6.2.2.a	Experimental Results for Severest Weather Conditions – Option ‘B’	98
6.2.2.b	Experimental Results for Intermediate Evaporator Inlet Air Conditions – Option ‘B’	101
6.2.3.	Experimental Results for Refrigerant Subcooling – Option ‘C’	115
6.3.	Comparison of Experimental Results for Options ‘A’, ‘B’ and ‘C’	119
CHAPTER 7		129
UNCERTAINTY AND ERROR ANALYSES		129
7.1.	Uncertainty Analysis of the Experimental Results	130
7.2.	Error Analysis of Analytical Results	132
CHAPTER 8		139
CONCLUSIONS		139
8.1.	Condensate Extraction from the VCAC System.....	140
8.2.	Evaporator Inlet Air Precooling - Option ‘A’	141
8.3.	Condenser Inlet Air Precooling - Option ‘B’	142
8.4.	Refrigerant subcooling - Option ‘C’	143
8.5.	Overall Conclusions for the Three Options	143

8.6. Recommendations.....	144
APPENDICES	146
APPENDIX A: PHOTOGRAPHS OF EXPERIMENTAL SET-UP	146
APPENDIX B: NUMERICAL CODES	156
APPENDIX C: SAMPLE CALCULATIONS OF EXPERIMENTAL UNCERTAINTIES	166
REFERENCES	169
VITAE	176

LIST OF TABLES

Table 4.1 Summary of Dhahran maximum and minimum temperature and relative humidity: 2009 – 2012.	45
Table 4.2 Hourly variations of ambient temperature and relative humidity of typical days in June through September, Dhahran.	47
Table 5.1 Characteristics of the base air conditioning system.	52
Table 6.1 The 32 sets of experimental data and the corresponding amount of condensate extracted from the VCAC system.	63
Table 6.2 Comparison of condensate extraction rate for typical days in June through September, Dhahran.	68
Table 6.3 Experimental and analytical daily condensate extraction for the months of June through September.	69
Table 6.4 Chemical concentrations in condensate sample compared with WHO acceptable limits.	75
Table 6.5 Enthalpies of severest weather conditions in major cities of Saudi Arabia.	78
Table 6.6 Experimental conditions of options ‘A’, ‘B’ and ‘C’ for severest weather conditions.	78
Table 6.7 Summary of results for evaporator air precooling for severest weather conditions – Option ‘A’.	90
Table 6.8 Summary of experimental results for evaporator air precooling for intermediate evaporator inlet air conditions– Option ‘A’.	97

Table 6.9 Average percentage reduction/increase of performance parameters for air mass flow rate of 0.13 kg/s - Option 'A'.....	97
Table 6.10 Average values of improvements of modified system over the base system – Option 'B'.....	106
Table 6.11 Experimental conditions for intermediate evaporator inlet air conditions - Option 'B'.....	107
Table 6.12 Comparison of experimental results of base system with the modified system for severest weather conditions.....	127
Table 6.13 Improvement of the modified system over the base system.....	127
Table 7.1 Uncertainty values of experimental results: Base system.....	132
Table 7.2 Uncertainty values of experimental results: Option 'A'.....	133
Table 7.3 Uncertainty values of experimental results: Option 'B'.....	133
Table 7.4 Uncertainty values of experimental results: Option 'C'.....	134

LIST OF FIGURES

Figure 1.1 Basic components of conventional vapor compression system.	4
Figure 1.2 Schematic of pressure versus enthalpy diagram of conventional simple vapor compression cycle.	5
Figure 1.3 Schematic of temperature versus entropy diagram of conventional vapor compression cycle.	5
Figure 3.1 Schematic of the modified air conditioning system.	23
Figure 3.2 Schematic of a cooling with dehumidification process.	27
Figure 3.3 Psychrometric representation of cooling and dehumidification process.	27
Figure 3.4 Schematic of the modified system integrated with air precooler - Option 'A'.	33
Figure 3.5 Schematic of the modified system integrated with condenser air precooler - Option 'B'.	35
Figure 3.6 Schematic of the modified system integrated with subcooler - Option 'C'.	36
Figure 3.7 Pressure-enthalpy diagram of the modified system - Option 'C'.	36
Figure 4.1 Comparison of monthly maximum temperature of the years 2009 to 2012 in Dhahran.	43
Figure 4.2 Comparison of monthly mean temperature of the years 2009 to 2012 in Dhahran.	43
Figure 4.3 Comparison of monthly maximum relative humidity of the years 2009 to 2012 in Dhahran.	44

Figure 4.4 Comparison of monthly mean relative humidity of the years 2009 to 2012 in Dhahran.....	44
Figure 4.5 Variations of Ambient dry bulb temperature of typical days in June through September, Dhahran.....	46
Figure 4.6 Variations of Ambient relative humidity of typical days in June through September, Dhahran.....	46
Figure 5.1 Schematic of the experimentation room with climate chamber inside.....	51
Figure 5.2 Schematic of experimental rig for option 'A'.....	54
Figure 5.3 Schematic of experimental rig with option 'B'.....	55
Figure 5.4 Schematic of experimental rig with option 'C'.....	57
Figure 5.5 Schematic of the complete experimental set-up.....	59
Figure 5.6 Schematic of the air conditioning system showing the temperature and pressure measurement locations.	60
Figure 6.1 Hourly variations of condensate extraction rate and relative humidity for a typical day of August, Dhahran.	65
Figure 6.2 Variation of condensate extraction rate with relative humidity at different dry bulb temperatures.....	67
Figure 6.3 Comparison of analytical with experimental rate of condensate extraction for the month of June.....	70
Figure 6.4 Comparison of analytical with experimental rate of condensate extraction for the month of July.	71
Figure 6.5 Comparison of analytical with experimental rate of condensate extraction for the month of August.....	72

Figure 6.6 Comparison of analytical with experimental rate of condensate extraction for the month of September.	73
Figure 6.7 Air temperatures across precooler of option 'A' for severest weather conditions.	80
Figure 6.8 Variation of ΔT and precooler effectiveness of option 'A' for severest weather conditions.	81
Figure 6.9 Comparison of compressor pressures of base system with option 'A' for severest weather conditions.	82
Figure 6.10 Comparison of compressor power of base system with option 'A' for severest weather conditions.	83
Figure 6.11 Comparison of COP of base system with option 'A' for severest weather conditions.	84
Figure 6.12 Comparison of evaporator exit air temperature of base system with option 'A' for severest weather conditions.	86
Figure 6.13 Comparison of second law efficiency of base system with option 'A' for severest weather conditions.	87
Figure 6.14 Variation of condensate temperature the tank with time for severest weather conditions- Option 'A'.	88
Figure 6.15 Variation of condensate temperature inside tank for complete day during on and off- periods: analytical study.	89
Figure 6.16 Variation of cooling effect with air mass flow rate at different ΔT - Option 'A'.	92

Figure 6.17 Variation of compressor power with air mass flow rate at different ΔT - Option 'A' .	94
Figure 6.18 Variation of COP with air mass flow rate at different ΔT - Option 'A' .	95
Figure 6.19 Variation of second law efficiency with air mass flow rate at different ΔT - Option 'A' .	96
Figure 6.20 Variation of condensate inlet temperature and ΔT for severest weather conditions - Option 'B' .	99
Figure 6.21 Comparison of suction and discharge pressures of the base system with option 'B' for severest weather conditions.	100
Figure 6.22 Comparison of compressor power of base system with option 'B' for severest weather conditions.	102
Figure 6.23 Comparison of evaporator exit air temperature of base system with option 'B' for severest weather conditions.	103
Figure 6.24 Comparison of cooling effect of base system with option 'B' for severest weather conditions.	104
Figure 6.25 Comparison of COP of base system with option 'B' for severest weather conditions.	105
Figure 6.26 Comparison of second law efficiency of base system with option 'B' for severest weather conditions.	106
Figure 6.27 Temperature variations across precooler - Option 'B' .	108
Figure 6.28 Comparison of compressor discharge pressure of base system with modified system - Option 'B' .	110

Figure 6.29 Comparison of compressor discharge temperature of base system with modified system - Option 'B'.....	111
Figure 6.30 Comparison of compressor power consumption of base system with modified system - Option 'B'.....	112
Figure 6.31 Comparison of COP of base system with modified system - Option 'B' ..	113
Figure 6.32 Comparison of second law efficiency of base system with modified system - Option 'B'.....	114
Figure 6.33 Variations of refrigerant temperatures across subcooler and subcooler effectiveness for severest weather conditions – Option 'C'.....	116
Figure 6.34 Comparison of compressor discharge pressure of the base system with option 'C' for severest weather conditions.....	117
Figure 6.35 Comparison of compressor discharge temperature of base system with option 'C' for severest weather conditions.....	118
Figure 6.36 Comparison of compressor power consumption of base system with option 'C' for severest weather conditions.....	120
Figure 6.37 Variation of subcooler inlet condensate temperature and amount of subcooling for severest weather conditions - Option 'C'.....	121
Figure 6.38 Comparison of evaporator exit air temperature of base system with option 'C' for severest weather conditions.	122
Figure 6.39 Comparison of evaporating temperature of base system with option 'C' for severest weather conditions.....	123
Figure 6.40 Comparison of cooling effect of base system with option 'C' for severest weather conditions.....	124

Figure 6.41 Comparison of COP of base system with option ‘C’ for severest weather conditions.	125
Figure 6.42 Comparison of second law efficiency of base system with option ‘C’ for severest weather conditions.	126
Figure 7.1 Polynomial curve fitting of the analytical versus experimental condensate extracted in June.	135
Figure 7.2 Polynomial curve fitting of the analytical versus experimental condensate extracted in July.	136
Figure 7.3 Polynomial curve fitting of the analytical versus experimental condensate extracted in August.	137
Figure 7.4 Polynomial curve fitting of the analytical versus experimental condensate extracted in September.	138
Figure A-1 Experimental set-up: the climate chamber.	146
Figure A-2 Photograph of the precooler for option ‘A’ before installation.	147
Figure A-3 Picture of experimental rig for option ‘A’.	148
Figure A-4 Picture of precooler for condenser air precooling: option ‘B’.	149
Figure A-5 Installation of precooler for option ‘B’ behind the condenser.	149
Figure A-6 Precooler for option ‘B’ after installation.	150
Figure A-7 Picture of subcooler for option ‘C’ before installation.	150
Figure A-8 Glassed-face picture of subcooler showing water inlet before installation. .	151
Figure A-9 Three-D picture of subcooler showing the refrigerant inlet and outlet connections.	151
Figure A-10 Picture of the subcooler after installation.	152

Figure A-11 Front-face of the completed experimental set-up showing the outdoor unit and subcooler.	153
Figure A-12 Photograph of the experimental set-up outside the room showing the outdoor unit and condensate-storage tank.	154
Figure A-13 Data acquisition system that is used during the experiments.	155
Figure B-1 Flow chart for the ambient temperature data sets.	156
Figure B-2 Flow chart for the relative humidity data sets.	157

NOMENCLATURE

A	area (m^2)
ADP	apparatus dew point
ARI	Air Conditioning and Refrigeration Institute
COP	coefficient of performance
C_p	specific heat capacity (kJ/kg-K)
\dot{C}	heat capacity rate (kW/K)
D	diameter (m)
dp	dew point
EER	energy efficiency rating
f''	fouling factor (W/K)
h	specific enthalpy (kJ/kg-K)
\tilde{h}	convective heat transfer coefficient ($\text{W/m}^2\text{-K}$)
k	thermal conductivity (W/m-K)
L	length (m)
NTU	number of transfer unit
M	mass of condensate in the storage tank (kg)
m	mass flow rate, kg/s
P	pressure (kPa)
\dot{Q}	rate of heat transfer (kW)

T	temperature (°C or K)
t	time (s or h)
UA	conductance (W/K)
WHO	World Health Organization
\dot{W}	rate of work (kW)

Greek Symbols

Δ	difference
ϵ	effectiveness
ϕ	relative humidity
η	efficiency
ω	specific humidity
δ	uncertainty value

Subscripts

a	air
avg	average
com	compressor
c	condenser, condensate
e	exit
ev	evaporator
f	fin
H	high
i	inside, initial, inlet
i,e	instrument error

L	low
max	maximum
min	minimum
o	outside
pc	precooler
r	refrigerant
r,e	random error
s	isentropic, surface
sat	saturated
sc	subcooler
sf	fin surface
t	tube
tot	total
w	water

ABSTRACT (ENGLISH)

Full Name : Nasiru Ishaq Ibrahim

Thesis Title : Performance Improvement of a Vapor Compression Air Conditioning System by Condensate and Fresh Water Source.

Major Field : Mechanical Engineering

Date of Degree : Safar, 1435, December, 2013

Considerable amount of electrical energy produced in the Kingdom of Saudi Arabia is consumed by air conditioning systems. In addition, water scarcity still exists in most of the arid and semi-arid countries. This thesis presents the outcome of a study conducted to bring down energy consumption and improve the performance of a vapor compression air conditioning system using condensate that is generated by the system. The base system used in the study is a 1.5 ton split type air conditioner. Three different options of system modifications are adopted to improve its performance. The three options are: option 'A'- air precooling before entering the evaporator using condensate, option 'B'- precooling the air entering the condenser by condensate and option 'C'- subcooling the refrigerant exiting the condenser using the condensate. Comparative study of the base system and the modified system is carried out. The results show that precooling the air entering the evaporator and condenser using condensate lowers the compressor discharge pressure. The discharge pressure also decreased significantly when subcooling is applied. The decrease in the discharge pressure resulted in the decrease in compressor power consumption to about 5% for option 'A', 4.8 % for option 'B' and 3.7% for option 'C' from experiments conducted for severest weather conditions. The severest weather conditions are 36 °C dry bulb temperature and 80% relative humidity obtained from the climate data of four major cities of Saudi Arabia. By decreasing the discharge pressure, the compressor's life expectancy can be improved. The coefficient of performance, COP is increased by about 30 %, 21% and 30% for options 'A', 'B' and 'C', respectively. The increase in the second law efficiencies obtained for options 'A', 'B', and 'C' are 24.85, 23.51 and 21.53%, respectively. The overall assessment of the three options is that option 'A' gives better system performance improvement followed by option 'B', then option

'C'. The rate of condensate extraction from the air conditioning system is studied and chemical analysis is carried out on the condensate sample to determine its quality. The amounts of condensate collected in Dhahran from the base system during the humid and hottest months of June, July, August and September are 1036, 1181, 2173 and 1781 kg, respectively, and these amounts are obtained experimentally on hourly basis. Analytical results of condensate extraction obtained by using hourly actual climate data are in good agreement with the experimental results. Condensate chemical analysis is conducted and the results are compared with the recommended guideline values of drinking water by World Health Organization. The Chemical analysis reveals that the condensate can be used as drinking water after undergoing simple bacterial removal process. It can also be used to improve the performance air conditioning systems and other applications such as cooling tower make up water and irrigation.

ABSTRACT (ARABIC)

الاسم الكامل: ناسيرو اسحاق ابراهيم

عنوان الرسالة: تحسين أداء أنظمة التكييف العاملة بضغط البخار بالتكثيف ومصدر مياه عذب

التخصص: هندسة ميكانيكية

تاريخ الدرجة العلمية: سفر 1435. ديسمبر 2013

يتم إستهلاك كميات كبيرة من الطاقة الكهربائية المنتجة في المملكة العربية السعودية من قبل أنظمة التكييف. ومن جهة أخرى، لا تزال ندرة المياه موجودة في معظم البلدان القاحلة وشبه القاحلة. تقدم هذه الأطروحة نتائج دراسة أجريت لتقليل استهلاك الطاقة وتحسين أداء أنظمة التكييف التي تعمل بطريقة ضغط الغاز باستخدام البخار المكثف الناتج من قبل نظام التكييف. والنظام الأساسي المستخدم في هذه الدراسة هو مكيف هواء مشقوق بسعة 1.5 طن. تم اعتماد ثلاثة خيارات مختلفة لتحسين أداء النظام وتقليل استهلاك الطاقة. الخيارات الثلاثة هي: الخيار "أ"، تبريد الهواء قبل دخوله المبخر باستخدام مكثف. الخيار "ب"، تبريد باستخدام مكثف. التثقيب ز الخيار "ج" تبريد الغاز المبرد الخارج من المكثف الهواء قبل دخوله المبخر باستخدام التثقيب. تم عمل دراسة مقارنة للنظام الأساسي وانظام المعدل. اظهرت النتائج ان عملية التبريد المسبق للهواء قبل المبخر والمكثف باستخدام مكثف. وقللت عملية التبريد المسبق للهواء الداخل للمبخر والمكثف باستخدام الماء المكثف من ضغط التصريف للضاغط. أيضاً بشكل ملحوظ عندما تم تبريد الغاز المبرد لأقل من درجة الغليان. وأدى إنخفاض ضغط التصريف للمضخة إلى إنخفاض استهلاك الطاقة في المضخة إلى حوالي 5٪ للخيار "أ"، و 4.8٪ للخيار "ب"، و 3.7٪ للخيار "ث" الظروف المناخية الحادة هي 36 درجة مئوية و 80% رطوبة نسبية مأخوذة من بيانات الطقس للاربع مدن الرئيسية في المملكة العربية السعودية. ومن خلال خفض ضغط التصريف، يمكن تحسين متوسط العمر المتوقع للمضخة. وتم زيادة معامل الأداء (COP) بنحو 31 ٪ ، 21 ٪ و 30 ٪ للخيارات "أ" و"ب" و"ث" على التوالي. وكانت الزيادة في الكفاءة للقانون الثاني للخيارات "أ" و"ب" و"ث" هي 24.85، 23.51، و 21.53 ٪ على التوالي. وتبين من التقييم العام للخيارات الثلاثة أن الخيار "أ" يعطي أفضل تحسين لأداء النظام، يليها الخيار "ب" ثم الخيار "ث". وتم دراسة معدل استخراج الماء المكثف من نظام تكييف الهواء الذي يعتبر مصدراً إضافياً للماء بالإضافة إلى تحليله كيميائياً لتحديد درجة نقائه. وكانت كمية الماء المكثف من خلال النظام في منطقة الظهران خلال الأشهر يونيو ويوليو وأغسطس وسبتمبر هي 1036، 1076 ، 1181 ، 2173، و1781 كجم على التوالي، وتم جمع هذه الكميات في التجربة كل ساعة. وكانت النتائج التحليلية لعملية التثقيب والتي تم حسابها لكل ساعة باستخدام البيانات المناخية الفعلية في إتفاق جيد مع النتائج التجريبية. تم اجراء التحاليل الكيميائية والتي تمت مقارنة نتائجها مع الموصى بها للماء المقطر من منظمة الصحة. أظهرت التحاليل الكيميائية الماء المكثف أنه يمكن استخدامه على أنه ماء مقطر بعد عملية ازالة البكتيريا ، وايضا يمكن استخدامه لتحسين اداء أنظمة وتطبيقات تكييف الهواء كما فتعويض مياه أبراج التبريد، والرّي.

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**PERFORMANCE IMPROVEMENT OF A VAPOR
COMPRESSION AIR CONDITIONING SYSTEM BY
CONDENSATE AND FRESH WATER SOURCE**

BY

NASIRU ISHAQ IBRAHIM

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