

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

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يتم استهلاك 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. التكثيف ز الخيار "ج" تبريد الغاز المبرد الخارج من المكثف الهواء قبل دخوله المبخر باستخدام التكييف. تم عمل دراسة مقارنة للنظام الأساسي والنظام المعدل. أظهرت 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، و 1781 كجم على التوالي، وتم جمع هذه الكميات في التجربة كل ساعة. وكانت النتائج التحليلية لعملية التكثيف 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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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

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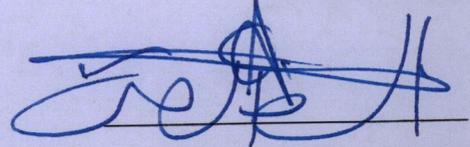
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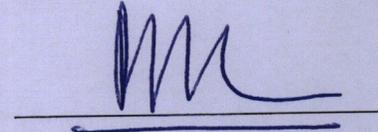
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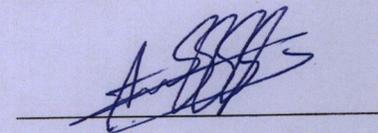
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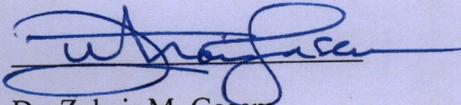
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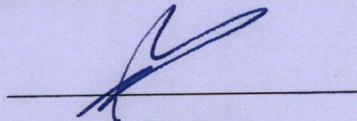


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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

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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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

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 استهلاك 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. التكثيف ز الخيار "ج" تبريد الغاز المبرد الخارج من المكثف. الهواء قبل دخوله المبخر باستخدام التكييف. تم عمل دراسة مقارنة للنظام الأساسي والنظام المعدل. أظهرت 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، و 1781 كجم على التوالي، وتم جمع هذه الكميات في التجربة كل ساعة. وكانت النتائج التحليلية لعملية التكثيف 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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**PERFORMANCE IMPROVEMENT OF A VAPOR
COMPRESSION AIR CONDITIONING SYSTEM BY
CONDENSATE AND FRESH WATER SOURCE**

BY

NASIRU ISHAQ IBRAHIM

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DHAHRAN, SAUDI ARABIA

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MASTER OF SCIENCE

In

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