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Modifying a Compression Refrigeration System and Investigate the Enhancement of COP

A Thesis Submitted to the Council of College of Engineering/ University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

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بسم الله الرحمن الرحيم

لِيَجْزِيَهُمُ اللَّهُ أَحْسَنَ مَا عَمِلُوا وَيَزِيدَهُم مِّن فَضْلِهِ
وَاللَّهُ يَرْزُقُ مَن يَشَاء بِغَيْرِ حِسَابٍ

صدق الله العظيم

سورة النور – الآية 38

Dedication

In the Name of ALLAH, the most Merciful, the most Compassionate.

I dedicate this work first to those who taught me to follow the path of knowledge to my mother, may God have mercy on her, whose prayers and words are still the source of my success. I put a lot of effort into getting a high degree.You, my mother, are the rose that my letters always sing, and you are the most beautiful gift thing that God has commandedme in this life, so I thank you for what you have given me.

To the light of my eyes, my companion and the joy of my life for my dear husband, who supported me in the most difficult circumstances…

To my sister and my family…with love and dratitude .

To everyone who taught me a letter to everyone who supported me even with a smile...with respect

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Abstract

The Compression Refrigeration Cycles is the most conventional method used in air conditioning and refrigeration systems. It can be considered as the most effective technique due to its high thermal efficiency and capability of producing several tons of refrigeration and heating powers However, this cooling power and efficiency of the conventional vapor-compression air condition units can face a significant reduction when is operating at extremely severe (hot and dry) weather. This decrease is mainly affected by the rise of the temperature (and pressure) of the condenser of the refrigeration system as the temperature of the ambient air increases.Unfortunately, Iraq has the most extreme summer season especially in June and July when the temperature reaches or exceeds to 50 ºC.

Hence, the interpretation of utilizing geothermal cooling in harshly hot climatic conditions for improving the performance of conventional vapor-compression refrigeration systems was experimentally investigated in this study.The use of ground cooling in regions with a hot environment for split system air conditioners was emphasized. To support the success and effectiveness of the geothermal cooling technique, evaporative cooling was also performed for decreasing the temperature of the refrigerant in used A/C unit within the condenser's region.

During the hottest three months of the year (June, July and August), experimental tests of the standardized and modified vapor compression refrigeration system (A/C - split air conditioner) were conducted in the laboratory of Mechanical Engineering, at University of Diyala in Iraq. For the modified split A/C unit, three different methods were used to assess its thermal and overall performance. All of the utilized method (first, second and third methods) showed that a reduction in the energy consumption with a significant increase in the cooling capacity and coefficient of performance were achieved. Examination of the thermodynamic properties of the proposed system reveals increases in the performance coefficient of about 39%. Experimental results showed that the condenser temperature decreased from 115 to 105 °C during the use of ground cooling In addition, an improvement of 45% on the performance coefficient and an increase in the cooling capacity by 35%. As for the use of the geothermal heat exchanger, the condenser temperature decreased from 116 to 110 °C and the performance coefficient improved by 41% .When using evaporative cooling, the condenser temperature decreased from 110 to 88°C.In addition, 65% improvement was made to the performance coefficient of the vapor pressure refrigerator cycle, as well as a decrease in the evaporator temperature from 6 to 3.5 °C and an increase in the cooling capacity by an average of 52% .

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Latin Symbols

Symbol	Description	Unit
$\dot{W}_c$	Compressor work	W
W_{in}	Power input	W
$\dot{Q}_c$	Heat transfer at condenser	W
q_{rej}	Heat rejected	kj/kg
p_c	condenser pressure	Bar
p_{sat}	Saturated pressure	Bar
T_e	Evaporator temperature	^{o}C

$\dot{Q}_e$	Heat transfer rate at evaporator	W
q_{ref}	Refrigeration capacity	kj/kg
$\dot{m}$	Mass flow rate	kg/s
P_e	Evaporator pressure	Bar
COP	Coefficient of performance	…………
COP_R	Refrigeration coefficient of performance	………….
COP_{carnot}	Carnot coefficient of performance	………….
T_L	Low temperature	^oC
T_H	High temperature	^oC
$\dot{V}$	Volumetric flow rate at compressor inlet	m^3/s
v	Specific volume at compressor inlet	m^3/kg
T_A	Ambient temperature	^oC
T_B	Laboratory temperature	^oC
T_1	Comp inlet temperature	^oC
T_2	Comp exit temperature	^oC
T_3	Condenser exit temperature	^oC
T_4	Evaporator inlet temperature	^oC
T_{in}	Inlet temperature	^oC
T_{out}	Outlet temperature	^oC
T_a	Air temperature	^oC
T_C	Condenser average temperature	^oC
h_1	Specific enthalpy at inlet compressor	kj/kg

h_2	Specific enthalpy at exit compressor	kj/kg
h_3	Specific enthalpy at exit condenser	kj/kg
h_4	Specific enthalpy at inlet evaporator	kj/kg
D	Diameter of the pipe	Mm
T_E	Evaporator average temperature	^oC
T_5	Evaporator exit temperature	^oC
P_i	Compressor inlet pressure	Bar
P_e	Compressor exit pressure	Bar

LIST of ABBREVIATIONS

Abbreviations	Meaning
CRC	Compression Refrigeration Cycles
GHE	Ground heat exchanger
EWHE	Earth-water heat exchanger
SCW	Standing column well
DGCS	Direct ground cooling system
BHE	Borehole heat exchanger
GSHPS	Ground source heat pump system
GHE	Geothermal heat exchanger
AHE	Air heat exchanger

SC	Solar chimney
ACH	Air change per hour
SRC	Supercritical Rankine cycle
SAHD	Solar air heating duct
EEVs	Electronic expansion valve
HX_1	Primary heat exchanger
HX_2	Secondary heat exchanger
ETHE	Earth tube heat exchanger

Chapter One

INTRODUCTION

Chapter One

Introduction

1.1 Background

The compression refrigeration cycles (CRC) have been in use more than 200 years, as it has been widely used in all life applications such as: industrial sectors, natural gas facilities, petroleum refineries, and petrochemical plants, as well as the bulk of food and beverage industries (Larwa & Kupiec, 2020). In the opinion of some people, the technology of CRC considered as an inefficient and a harmful to environment, but it does not appear to be going away anytime soon. The standard of CRC operated under the principle of reverse Carnot engine. It is defined as a heat engine that work in transferring the heat from a low temperature to a high temperature. According to the second law of thermodynamic is a physical law based on universal experience concerning heat and energy interconversions. One simple statement of the law is that heat always moves from hotter objects to colder objects unless energy is supplied to reverse the direction of heat flow. Therefore, additional effort is required to complete the transfer. In air conditioning system, there are three kinds of condensers named: air-cooled, evaporative-cooled, and water-cooled. Among these types of condenser, air cooled condensers are the mostly used in the small tonnage residential split air conditioners for making the system as simple as possible without any addition equipment like water connection line. Air condenser seems reasonable as far as the air temperature in summer is moderate by about 40 ^oC(Zajch & Gough, 2021) In contrast, the performance of air condenser drops down in the area that air temperature increased to approach 50 ^oC. This can be explained as; increasing the ambient air temperature leads to increasing the temperature and pressure of condenser therefore, the compressor should be forced to work under greater pressure ratio, which results in more power consumption. To meet and prevent this problem, hot air must be cooled before passing over the condenser (Zajch & Gough, 2021). The performance of split air conditioner depends on heat transfer between the coils and the airflow. In this regard, air-cooled condensers need a high airflow rate to improve its performance, and thus sometimes results in a noise problem. So, in order to reduce the electrical power consumption of compressor and then improve the coefficient performance of the vapor compression system without changing the compressor design, several techniques are used by researchers in field of increasing the cool and heat rejection capacity, decreasing the refrigerant pressure loss or decreasing the pressure difference between the condenser and evaporator. As it is concluded, reducing the pressure difference between the condenser and evaporator is the fruitful one in comparison with those mentioned above. While the evaporating temperature is kept constant, lowering the condensing temperature results in the reduction of pressure difference (Lim & Lee, 2021). Among these techniques, using the water in cooling the condenser unit played a major role for improving its performance. Where, the water is used either by direct evaporative cooling (Maerefat & Haghighi, 2010),(Chaktranond & Doungsong, 2010),(Ozgoli & Seiedi Niaki, 2020) or indirect evaporative cooling (Jassim, 2011),(Misra et al., 2013),(De Paepe & Janssens, 2003). (Prajapati & Choube, 2014) used direct evaporative cooling technique to enhance the performance of conventional air conditioning system. Media pad manufactured from cellulose with 22-inch height, 1.5-inch thickness and curve shape with angle 90º (length of long side is 30 inch and short side 10 inch). The pad was installed behind the condenser about 2.5 cm distance from it. The water was circulated between the top of the pad and the sump of the tank using a small pump. The obtained results were investigated better enhancement as compared with the traditional system without evaporative cooling. Abd Ali et al., n.d.) carried out an experimental investigation to study the influence of using direct evaporative cooling to cool the outdoor unit on the performance of split air conditioning.As compared with traditional unit, the COP of the system was enhanced by 39%. Additionally, electric power consumption of system was decreased by (25-32) % .Geothermal energy is considered as one of sources that used in the cooling techniques by using the water due to its low temperature. Where, it used directly in the cooling of the buildings, which is called geothermal cooling systems. Or, it is used as additional unit namely: geothermal heat exchanger that connected with the outdoor unit of air conditioning systems to cool the condenser.

1.2 Description of Traditional compression refrigeration cycles

The compression refrigeration cycle is the one that is most frequently utilized in real-world applications like air conditioning, refrigeration, food refrigeration, and other facilities (Di Donna et al., 2021). In this cycle, a vapor is compressed, and then condensed into a liquid, following which the pressure dropped so that fluid can evaporate at a low pressure. The refrigeration cycle requires an addition of external work for its operation. Figure 1.1 shows the equipment of the refrigeration cycle. The processes, which constitute the cycle, are (1-2) Adiabatic compression (2-3) Isothermal rejection of heat (3-4) Adiabatic expansion (4-1) Isothermal addition of heat.

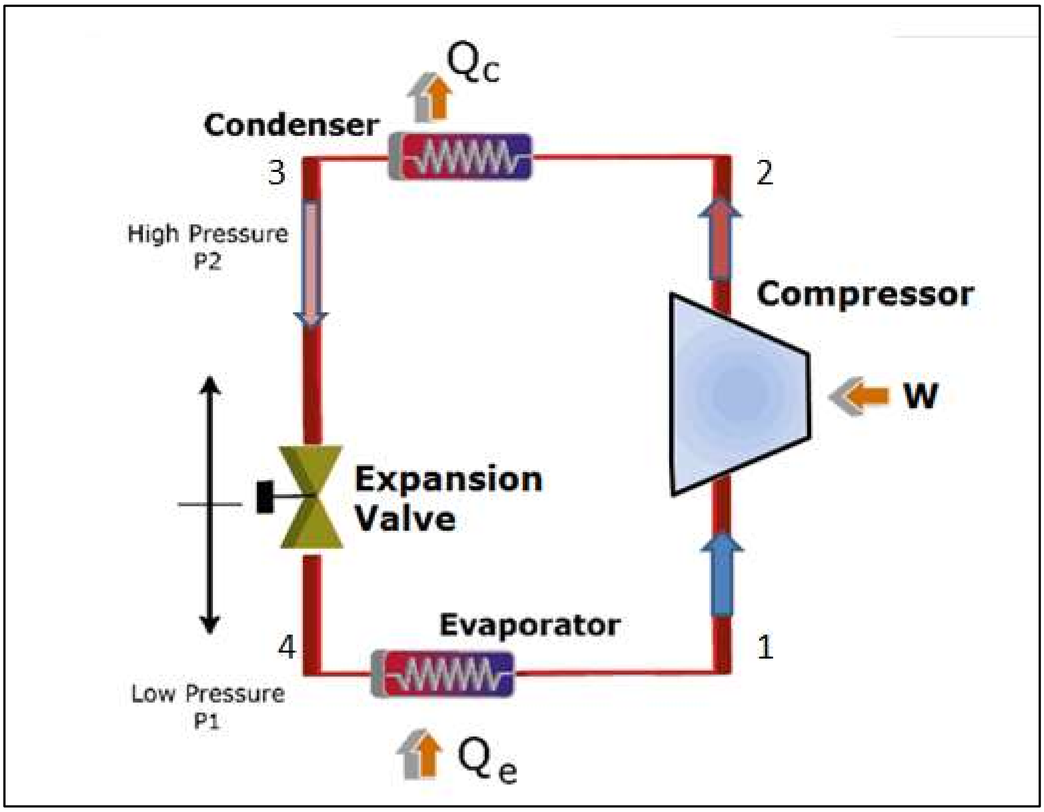

Figure 1.1 Schematic diagram of traditional vapor compression refrigeration cycle (Di Donna et al., 2021)

The refrigeration cycle processes can be represented on pressure enthalpy diagram as it is shown in Figure 1.2

a. The top horizontal line 2-3 represents the condensing phase.

b. The vertical line represents 3-4 the pressure drop through an expansion device.

c. The bottom horizontal line 4-1 represents the evaporating phase.

d. The horizontal line 1-1́ represents the heat gain in the suction line.

e. The diagonal line 1́-2 represents the compression of refrigerant gas from suction to the discharge pressure.

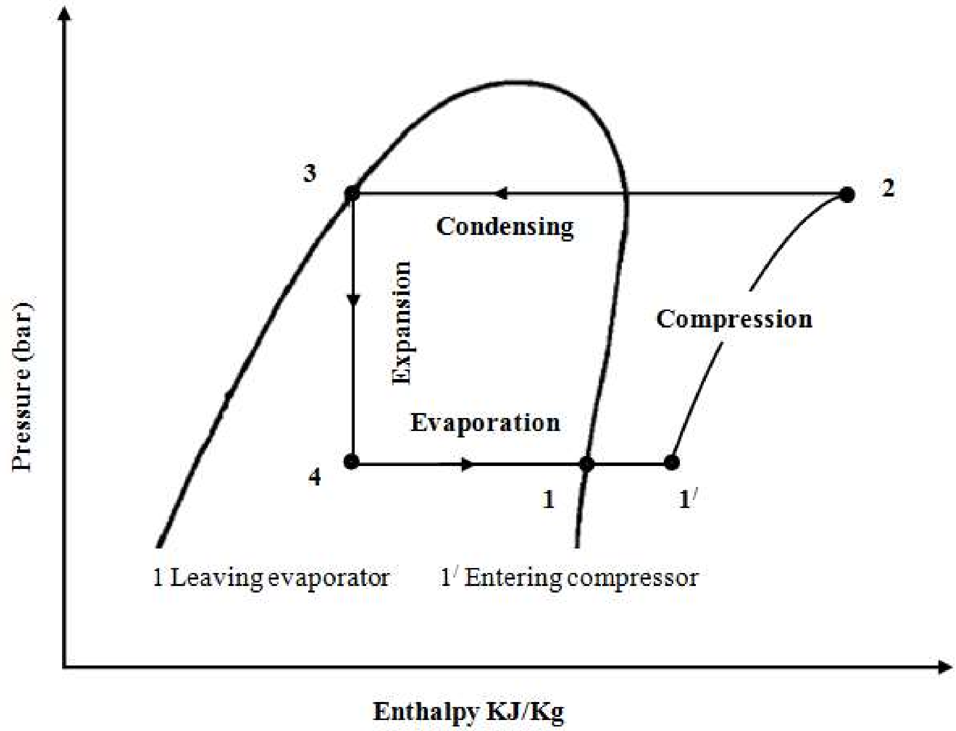

Figure 1.2 Pressure-enthalpy diagram of a refrigeration cycle (Dalkilic & Wongwises, 2010)

1.3 Components of vapor-compression cycle

Generally, each vapor-compression cycle is consisted of four main components,which are :

a. Compressor

The first stage in the cycle is called a compressor component. Where, the refrigerant enters this stage at low pressure steam to compressed it to high pressure and temperature. Therefore, leaving the first stage in case of gaseous state using an electric motor(Zhang et al., 2021).

b. Condenser

The second stage of cycle is called the condensation process. This stage receives the hot vapor refrigerant in order to pass it through a pipes. After the hot refrigerant flows inside the pipes, an air is blown using a fan to condense the refrigerant and turn it into a high-pressure liquid(Moran, Michael et a.,1992) .

c. Expansion / (Throttle Valve)

The high-pressure liquid refrigerant enters the expansion valve on the third stage of the compression refrigeration system. The function of expansion component is expanding the liquid refrigerant and then lowering its pressure on the outlet side. In addition, the temperature of the liquid refrigerant is reduced during the expansion process. The refrigerant exits the throttle valve as a liquid vapor mixture, typically in amounts ranging from 75% to 25%. Throttling valves are required in the vapor compression cycle for maintaining a pressure difference between the two sides and controlling the amount of liquid refrigerant to enter the evaporator(Shapiro et al.,1992).

c. Evaporator

The refrigerant leaves the expansion stage in case of mixed enter the coiled tubes in evaporator component. A warm air from the conditioned environment is blown across the evaporator coils by fans. The cold refrigerant within the evaporator absorbs the heat from the hot air and lowering the temperature in the conditioned space. As the high pressure liquid refrigerant passes through the metering device it enters a low pressure environment, causing it to flash off in to a vapour meanwhile, the refrigerant begins to boil and transform into a low-pressure vapor as it absorbs heat from the air. The low-pressure vapor is then sucked back into the compressor, restarting the cycle. The refrigerant is cooler than its surroundings at this point in the vapor compression refrigeration cycle. As a result, it evaporates and absorbs latent vaporization heat. Low pressure and temperature are employed to extract heat from the refrigerated space((Shapiro et al.,1992) .

1.4 Types of vapor compression refrigeration system

There are three various types of vapor compression refrigeration cycles. Compression, condensation and throttling, so the evaporation processes are the essence of any vapor compression cycle as early described. The majority of scientists have devoted their efforts in improving the cycle's coefficient of performance. Despite the fact that there are numerous cycles, the following are the most relevant from the perspective of the subject. Generally, the refrigeration cycles could be operating with(Ameen et al., 2006) :-

- Dry saturated vapor after compression
- Wet vapor after compression
- Superheated vapor after compression
- Superheated vapor before compression, and
- Undercooling or sub cooling of refrigerant.

1.5 Motivation Behind the Current Study

In the Iraq's climate, the air-conditioning systems including: cooling and refrigerating are considered as one of the most pressing issues in terms of energy usage. In addition, global warming has worsened the climate conditions to get hotter and make it difficult to live without refrigeration. The traditional vapor-compression cycles are the main refrigeration systems that used in the and industrial applications due to their capabilities of effectively producing high cooling power. During the summer season and between the 1st of June and 31th of August, Iraq suffers from significant drop in the supply of electrical power. On the other hand, the demands of the power for cooling and food refrigeration usages will be intensely increased. Furthermore, the rate of cooling powers and efficiencies of these air-conditioning and refrigerating systems shill be remarkably decreased due the extreme weather's conditions in Iraq. The temperature/pressure of the condensers of these systems will be dramatically high during summer season due to the increasing of the ambient temperature to reach 50 ^{o}C in some of days. In the summer, the earth plays as a heat sink while plays as a heat source in winter. The property of the temperature stability at the specific depth from the earth's surface along the year gives the possibility of using it in cooling and heating the buildings in summer and winter respectively. This is what is known as geothermal energy which defined as a one type of renewable energies. This type of energy can be utilized in a variety of purposes, including power generation, space heating, cooling, and water heating and cooling.

1.6 Aim and Objectives

The primary aim of the current investigation is to enhance the thermal characteristics of conventional vapor compression refrigeration systems utilizing the geothermal cooling in summer season. These characteristics include the cooling capacities, minimum temperature and overall efficiency. This enhancement will lead to reduce the consumption of electrical power and effectively increasing cooling power. In order to investigate the aim of this study, the following four objectives are proposed:

Improving the thermal and overall performance of a vapor compression refrigeration cycle by reducing the temperature and pressure of the condenser.

1. Utilizing the earth as a heat sink in the summer for space cooling in residential and commercial structures for the constancy of soil temperature.
2. Minimizing the electrical power consumption of cooling via the utilization of geothermal cooling energy.

3. Investigating the usage of evaporative cooling technique for cooling the condenser of traditional refrigerators.

1.7 Thesis Outline

This thesis is the result of a research work within the context of a bigger project, which is sponsored by the of University of Diayla, college of Engineering. An overview about the principle operation of compression refrigeration system and their types are reported in this chapter. Furthermore, the significance and objectives of this project are bravely disclosed. Additional information is discussed in the balance of this study to achieve it objectives. This thesis is divided into five technical chapters, each of which is devoted to the description of a specific part of the research activities as follows:

Chapter two deals with the literature review about the geothermal cooling and heating systems. In addition, the technologies of improving the compression refrigeration systems operation are described in details.

Chapter three presents the methodology of the mathematical model that used in analysis the performance of the system.

Chapter four presents The experimental setup components are described in details. This chapter also includes data acquisition and and deals with the materials and project description, which include research requirements and system description.

Chapter five presents the simulation and experimental results. Comparisons between the results of the present study with studies available in literature are presented.

Chapter six involves conclusions and suggestions for future studies in this field to improve and develop the performance of the proposed system.