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Study the Opportunity of Using Waste Heat of an IC Engine to Run an ARS

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

By
Tabarek Daood Salman
(BSc mechanical Engineering, 2018)

Supervised by
Asst. Prof. Ahmed Shihab Al-Samari,(Ph.D.)

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بِسْمِ اللَّهِ الرَّحْمنِ الرَّحِيمِ

(... قُلْ هَلْ يَسْتَوِي الَّذِينَ

يَعْلَمُونَ وَالَّذِينَ لَا يَعْلَمُونَ إِنَّمَا

يَتَذَكَّرُ أُولُو الْأَلْبَابِ)

صدق الله العظيم

سورة الزمر – الاية(9)

Dedication

I dedicate this work….

To the one who honored me by bearing his name, my father, may God have mercy on him, who made a lot of effort to let me get a high scientific degree.

To the light of my eyes, the light of my path, and the joy of my life, my mother... whose prayers and words are the source of my success...

To my brother, my sisters, and my friends…

To everyone who taught me a letter, to everyone who supported me, even with a smile…

The researcher

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Abstract

This study aims at investigating the opportunity of using renewable or sustainable energy resources for operating a refrigeration system. Waste heat represents one of heat energy resources that disposed to the surrounding without benefit. Therefore, it will be great opportunity to investigate the use of this waste heat for ARS.

Four scenarios are suggested for evaluating the effectiveness of exhaust to run the refrigerator. First scenario at no engine load, second scenario at 25% engine load, third scenario is at 50% engine load and the fourth scenario is at 75% engine load. The reason for choosing study at different loads is the different amount of heat energy exhaust at each condition of operation for the engine.

The kerosene fuel is used as a heat source for the generator of the refrigerator as well to study the effectiveness of it. Moreover, the convention heater that works on electricity is used also to analyze the refrigerator performance. The experiments are conducted repeatedly as possible to ensure the authenticity of the results.

The results of using waste heat have revealed variety of performance in accordance with engine loads. The refrigerator performance when engine at no load is the worst, and at engine load 75% is the best among the four scenarios. When the engine at no load, the temperature inside freezer does not decrease or change. Moreover, at 25% engine load the temperature inside freezer decrease from 14.2°C to -10.2°C during 180 minutes and in the fridge cabinet temperature varied from 14.8°C to 16.6°C during about 180 minutes with room temperatures between 15.9°C and 19.3°C. Further, at 50 % engine load the temperature inside freezer decrease from 27.7°C to -5.3°C during 180 minutes and in the

fridge cabinet temperature varied from 28°C to 29.9°C during about 180 minutes with room temperatures between 29.3°C and 38.5°C. Finally, at 75 % engine load the temperature inside freezer from 29.9°C to -13.5°C during 180 minutes and in the fridge cabinet temperature decreased from 30.7°C to 25.9°C during about 180 minutes with room temperatures between 31.8°C and 40.9°C. Therefore, the results show the effectiveness is increasing dramatically with respect to the heat entering the generator. Finally the waste heat rate range is from about 60 W to 180 W based on the engine loads.

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LIST OF SYMBOLS

Symbol	Description	Unit
$\dot{Q}_A$	The absorber head load	kW
$\dot{Q}_H$	The heat rejection from the condenser to the high-temperature environment	kW
$\dot{Q}_L$	The heat taken from the low-temperature environment to the evaporator.	kW
$\dot{Q}_{refrigerator}$	The refrigerator capacity	kW
$\dot{Q}$	The head load	kW
$\dot{q}$	the heat load	kJ
Δt	the difference in temperature	°C
A	area of the pipe	m^2
b	breadth	m
C.O.P	The coefficient of performance	……
C_P	specific heat capacity	(kJ/kg.°C)
h	height	m
m	mass	m
$\dot{m}$	The mass flow rate	kg/s
$\dot{m}_r$	The refrigerant mass flow rate	kg/s
$\dot{m}_{ss}$	The strong solution mass flow rate	kg/s
$\dot{m}_{ws}$	The weak solution mass flow rate	kg/s
V	volume	m^3
X_{ss}	The strong solution concentration	…..
X_{ws}	The weak solution concentration	…..
α	function of equilibrium temperature and pressure	……
η	Efficiency ratios	……
l	length	M
v	the velocity of exhaust gas	m/s
ρ	density of air	kg/m^3

LIST of ABBREVIATIONS

Abbreviations	Explanation
AARS	Aqua-ammonia absorption refrigeration system
ARS	Absorption refrigeration system
CFC_S	Chlorofluorocarbons
COP	Coefficient of Performance
COP_C	Carnot Coefficient of Performance
GAX	Generator–Absorber heat exchange
$HCFC_S$	Hydro chlorofluorocarbons
HC_S	Hydrocarbons
HFC_S	Hydro fluorocarbons
IC	Internal combustion
KC	Kalina cycle
LCC	Life cycle cost
LCCA	Life cycle cost analysis
LiBr	Lithium Bromide
LNG	Liquefied Natural Gas
ORC	Organic Rankine cycle
PCM_S	Phase change materials
POE	Polyolester
ppm	parts per million
PV	Photovoltaic
PWC	Present worth cost
RC	Rankine cycle
RE	Renewable energy
RHE	Refrigerant heat exchanger
RO	Reverse Osmosis
SCRC	Supercritical Rankine cycle
SDBS	Sodium dodecyl benzene sulfonate
SHE	Solution heat exchanger
SIO_2	Silicon dioxide
ST	Solar thermal

SWH	Solar water heating
TCS	Turbo compound system
TEG	Thermos-electric generator
TiO2	Titanium Dioxide
TR	Ton of Refrigeration
VAR	Vapor absorption refrigeration
VARS	Vapor absorption refrigeration system
VARSs	Vapor absorption refrigeration systems
VCR	Vapor compression refrigeration
VCRS	Vapor compression refrigeration system
VCRSs	Vapor compression refrigeration systems
WHR	Waste heat recovery
wt	Weight

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 Introduction

A well-known technology is absorption refrigeration system (ARS), which use renewable energy (RE) sources like solar and geothermal energy, as well as, waste heat sources like diesel engine exhaust and industrial plant exhaust to create cooling, save energy, and hence reduce emissions. Furthermore, because the absorption systems use natural refrigerant, they are ecologically beneficial and can compete with mechanically powered vapor compression refrigeration system (VCRS). Furthermore, because absorption systems are thermally operated, the absorption machine produces no vibration or noise, allowing Combined Heat Power Plants or boilers to operate for longer periods of time, particularly during the summer when heating requirements are lower. The absorption cycle, like the vapor compression cycle, is based on the cooling and heating processes associated with phase transitions of refrigerant fluid evaporation and condensation at various temperatures and pressures. Because the working fluid is made up of refrigerant and absorbent, the boiling temperature may be changed by adjusting the pressure or composition of the combination (Ref et al., 1996).

(Yuan et al., 2019) presented both the theoretical and experimental investigations of ARS and freezing pre-desalination-based marine engine exhaust heating system recovery systems. The result showed that the whole refrigeration output of the system ranges from 6.1 kW to 9.9 kW and also the system Coefficient of Performance (COP) can reach 16% under the experimental operating conditions . Additionally, the salinity of pre desalinated seawater was reduced to below 10 parts per million (ppm). Moreover, the price of Reverse Osmosis (RO) seawater desalination will be reduced by 26% through the pre-desalination process of seawater.

(Miraflor et al., 2019) investigated the heat exchange between the exhaust manifold and the refrigerant for the ARS. This research also looks at how well the exhaust gas heat exchanger collects heat from the internal combustion (IC) engines and uses it to evaporate the refrigerant molecules housed in the heat exchanger. (Girish et al., 2018) aimed to reduce the importance of the circulating ratio while increasing the COP. A prototype model was created, evaluated, and produced in the lab using scrap material. The heat was provided by a parabolic solar trough. ANSYS was used to simulate and analyze various components on a computer. The refrigeration effect RE and COP were used to analyze the unit's performance and efficiency COP. The experiment's findings were positive in terms of refrigerant composition and collector capacity.

(Mendes et al., 2007) investigated a solar-assisted single-effect absorption refrigerator with an NH3/water working pair. A pre-cooler and a solution heat exchanger were included in this system. When the system was powered by hot water at 110°C, rejects heat at 32°C, and generates refrigeration at 11°C, the chiller COP is 0.54 according to the research. (Du et al., 2012) looked at a two-stage absorption system that used NH3/water as the source and has a nominal refrigeration power of 2 kW. The average system COP was 0.21 with a maximum value of 0.25 according to the authors. The NH3/water absorption pair was tested by (Lin et al., 2011) in a double-effect absorption machine powered by low-grade solar energy, with a COP of 0.35 of 5 kW nominal refrigeration power.

(El-Mahi & Nasr-El-Din Abdalla, 2005) studied the influence of condenser temperature on the performance of an ARS using an aqua-ammonia absorption refrigeration apparatus. The device was built with an intermittent cycle in mind. The experimental results were found to coincide with the theoretical predictions for three different condenser temperatures.

A solar aqua-ammonia absorption refrigeration system (AARS)with a single effect was investigated by (Abdulateef et al., 2008). The effects of operating circumstances and heat exchanger efficiency on component thermal loads, performance coefficients (Carnot Coefficient of Performance (COPc) and COP), and efficiency ratios (η) were studied. The results showed that when the generator and evaporator temperatures had rised, the COPc and COP values fall, while the condenser and absorber temperatures rise. With these temperatures, the (η) value changes. In addition, the heat exchanger's efficiency influences the highest temperature that may be employed to maximize the system's COP. In Madrid, a prototype of a 2 kW aqua-ammonia ARS was built and tested by (De Francisco et al., 2002) for solar-powered refrigeration in small rural enterprises. The equipment performed poorly in the tests, with a COP of less than 0.05. In the Middle East, a solar-powered absorption refrigeration cycle employing an aqua-ammonia solution was designed and built to chill a vaccination cabinet by (Hammad & Habali, 2000). With the generating temperature at 100-120°C and the cabinet interior temperature at 0-8°C, the thermal COP varied between 0.5 and 0.65 in a year-round simulation.

(Kalinowski et al., 2009) applied the ARS to the Liquefied Natural Gas (LNG) plant's recovery process, which is fuelled by waste heat from the electric power generating gas turbine. According to calculations, collecting waste heat from a 9 MW energy-generating process might offer 5.2 MW of additional cooling to the LNG facility while also saving 1.9 MW of electricity. A hybrid absorption/recompression refrigeration system was proposed by (Razmi et al., 2018) . A booster compressor was installed between the generator and the condenser to recover condensation heat. The system's efficiency was increased by altering the pressure ratio. A two-stage absorption–compression combined refrigeration system was subjected to an energy and exergy study by (Dixit et al., 2017). The results suggested that by lowering the condensation temperature and raising the evaporation temperature, the exergy destruction rate may be reduced and the COP improved.

To recover low-grade waste heat, (Sheng Yang et al., 2017) suggested a unique cascade absorption transformer. In a natural gas plant, the system was tested. Payback time is 0.77 of a year according to the findings.

(Yan et al., 2013) presented a unique waste heat-driven ARS to improve the thermal energy utilization efficiency in waste gas or water. The cycle was a single-effect/double-lift arrangement that can use heat at low temperatures and had a considerably wider temperature range for waste heat. The temperature of waste heat dissipation was about 20 K lower than that of the single-effect cycle. (Longo et al., 2005) suggested a novel system that combines two subsystems: a double-effect and a single-stage. Both subsystems' generators use both high-grade and low-grade waste heat. As a result, the total temperature range may be rather considerable. (Sun et al., 2013) presented a mid/low-temperature heat source-driven aqua-ammonia system for power and cooling. A Rankine system and an ARS were combined in this system. The waste heat from mid and low temperature was used for power generation and refrigeration, respectively. The waste heat temperature spread of the ARS is 37 K, while the solution generation process was at a constant temperature, indicating a substantial temperature differential and exergy destruction in the generator.

(Qin et al., 2007) developed a novel hydride pair for exhaust gas-driven automobile air conditioning. The results revealed that when the heat source temperature had rised, cooling power and system COP rise, while the minimum refrigeration temperature falls. For greater performance, the heat transfer qualities of the system are required to be modified.

(Raghuvanshi & Maheshwari, 2011) created empirical relationships to assess the properties and performance of a single-stage aqua-ammonia VARS. The heat and mass transport equations, as well as the required equations characterizing the working fluid's thermodynamic characteristics at all thermodynamic states, were assessed. Each component was subjected to energy analysis, and numerical data from the cycle's various streams were collated. Finally, simulations and analyses of several thermodynamic parameters were performed. They came to the conclusion that as the generator, condenser, and absorber temperatures had rised, the system's efficiency drops, but as the heat exchanger's effectiveness had rised, the system's efficiency rises as well. Using the pinch point analysis, (Jawahar et al., 2010) studied an AARS in order to recover as much internal heat as possible from the streams and improve system performance. The system was tested at 120°C to 150°C for the generator, 25°C to 45°C for the sink, and -10°C to 10°C for the evaporator. The traditional cycle was adjusted without the requirement for rectification and its performance was compared, based on the greatest internal heat that could be created using this technique. With respect to the operating conditions investigated, the suggested cycle was determined to be 17 to 56 % higher than a conventional cycle.

(Zheng et al., 2007) simulated a single-stage ammonia absorption system and a Generator–Absorber heat exchange (GAX) cycle, finding that the latter's COP and exergy efficiency were 31% and 78 % greater than the former's, respectively, at 120°C, 25°C, and 5°C for the heat source, cooling medium, and cold temperatures. The absorption cycle was split into the heat pump and heat engine sub-cycles based on the notion of exergy coupling. A thermodynamic study was conducted for both frameworks using the energy grade factor enthalpy diagram, which revealed that the heat pump sub-cycle in the GAX cycle had the same exergy requirement as a single-stage cycle. The heat engine subcycle's external heat loss, external exergy loss, and internal exergy loss were minimized, resulting in lower energy consumption and improved benefit for the whole cycle.

1.2 Renewable energy sources overview

RE technologies are regarded to be clean energy sources, and their best application reduced environmental concerns. Moreover, RE technologies offer a great way to reduce greenhouse gas emissions and global warming by replacing traditional energy sources (Panwar et al., 2011). Therefore, solar water heaters, solar cookers, dryers, wind energy, biogas technology, biomass gasifiers, better cook-stoves, and biodiesel were among the primary RE devices developed for home and industrial purposes. In underdeveloped countries, solar drying of agricultural goods offer a lot of potential for saving energy. Furthermore, wind energy also had a good chance of reducing greenhouse gas emissions, where wind potential was accessible (Panwar et al., 2011). In recent decades, there has been a growing interest in utilizing RE resources. Since known fossil resources (oil, natural gasses, and others) are nearly depleted, RE resources are the only hope for humanity's survival in the near future.

Even if governments implement dynamic strategies to reduce energy use, demand continues to rise (Ciubota-Rosie et al., 2008).

1.2.1 Solar energy

Many industrial applications employ solar energy as an input power source for heat engines. Stirling engines run on any form of external heat. They are quite dependable, have a straightforward design and construction, are simple to use, and are inexpensive. Nonetheless, such mechanical devices have modest efficiency (Kongtragool & Wongwises, 2003). Solar energy may be used for both thermal and electrical energy generation (Suman et al., 2015). solar energy technology can be divided into two groups (Herrando & Markides, 2016): photovoltaic (PV) technology is made up of a solar collector and a PV cell. PV cells provide electrical energy, while the collector absorbs heat from the PV cells, which are heated owing to the absorption of undesired wavelengths of photons from the sun. Metal tubes are attached to the rear of the PV panel for this purpose. Researchers employ several Nano fluids as working fluids to improve the system's performance (Wahab et al., 2019). PV technology, which uses semiconductors to convert sunlight directly into electrical energy, has been a popular choice in recent years (Mohanty et al., 2016). And solar thermal (ST) technology converts solar energy into thermal energy for use in household and commercial applications such as drying, heating, cooling, and cooking (Raisul Islam et al., 2013a). Solar thermal is the most cost-effective option. Solar collectors and concentrators are often used to collect solar radiation, store it, and utilize it to heat air or water in the home, commercial, or industrial establishments (Kalogirou, 2004).

1.2.2 Wind energy

Wind energy for electricity generation is a mature, competitive, and pollution-free technology that is widely employed in many parts of the world today (M Balat, 2009). Through the utilization of wind turbines, wind technology turns the energy available in the wind into electricity or mechanical power (Mustafa Balat, 2005).

1.3 The Aims of the study

1- Decisively shed light on the evolution of using engine waste heat as a heat source to drive the absorption refrigeration system..

2- study the impact of using alternative fuels to operate the absorption refrigeration system such as kerosene fuel.

3- compare the absorption refrigeration system operating on alternative heat sources to the standard heat source (electrical heater).

1.4 Thesis Structure

This thesis consists of the following chapters:-

Chapter one is allocated to explain the introduction of this study that raises the motivation and objectives of this thesis. Moreover, the study aims and Structure involved are also described.

Chapter two presents An overview of ARS technology.The fundamental description of ARS is compared to mechanical VCRS in this chapter. RE sources, such as solar and wind, are also available. Furthermore, it is a waste of energy.

Chapter three presents a description of AARS. Moreover, properties of ammonia, calculations, and flow chart of experimental work.

Chapter four Includes project description which includes research requirements and system description, Measurements and devices are described in detail. This chapter also includes the experimental preparation.

Chapter five shows the experimental results which are conducted to analyze the performance of an ARS (refrigerator).

Chapter six concludes recommendations for future research in this field to improve and develop the analysis of system performance.

CHAPTR TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The need for energy is growing every day throughout the world as a result of the rising population, changing lifestyles, industrialization, and other factors (Pandey et al., 2018). Energy demand may be met by two different sources: fossil fuels, which have a finite supply in nature, and RE, which is plentiful and can be replenished at a rapid rate (Pandey et al., 2018). The majority of industrial processes require a lot of thermal energy, which is obtained by burning fossil fuels to generate steam or heat. Heat is discharged into the environment as a waste after the procedures. Using a heat-operated refrigeration system, such as an ARS, for this waste heat may be transformed to beneficial refrigeration. It is possible to lower the amount of electricity purchased from utility providers for standard VCR. The usage of heat-operated refrigeration systems aids in the reduction of global environmental issues such as the so-called greenhouse effect caused by CO_2 emissions from fossil fuel burning in utility power plants (Srikhirin et al., 2000). Solar-energy technologies are already widely recognized and increasing in the global electrical markets, and they are continuing to improve in terms of both technical and commercial maturity. This does not negate the necessity for ongoing research and development, whether to explore new technologies to ensure that RE satisfies the demands of future generations of customers. Moreover, to ensure that present technologies are trustworthy, durable, and dependable (Costa et al., 2018).

2.2 Absorption refrigeration system

A basic ARS consisting of an absorber, a pump, a generator, and a pressure reduction valve to replace the compressor in a VCRS (Pradesh, 2019). The system's other component is the same (condenser, evaporator and expansion valve). The refrigerant in this system is NH3, and the absorbent is water. The low-pressure ammonia vapor refrigerant from the evaporator enters the absorber, where it is absorbed by the cold water. The aqua ammonia solution is generated when water absorbs a considerable amount of ammonia vapor (Pradesh, 2019).To produce cooling, ARS use low-grade heat energy sources such as solar energy, geothermal energy, and waste heat. As a result, absorption systems offer a lot of promise for conserving primary energy and reducing thermal pollution in the environment (Florides et al., 2002).

(Jiang et al., 2019) explored experimentally the effect of varied quantities of Titanium Dioxide (TiO_2) nanoparticles on the COP of the AARS. TiO_2 Nano fluids in mass fractions of 0.1 %, 0.3 %, and 0.5 %were created and added to the newly designed miniaturized AARS as shown in Figure 2.1, as well as a mixture of 0.5 weight (wt)%TiO_2 and 0.02wt% sodium dodecyl benzene sulfonate (SDBS), based on the current prior experimental findings and other researchers' literature. Results show that The TiO_2 nanoparticles had a significant effect on AARS, and the COP could be increased by up to 27%; the mixture of 0.5wt% TiO_2 and 0.02 wt% SDBS had the most significant effect on the improvement of the COP when compared to other Nano fluids; the improvement of COP was strongly related to the number of nanoparticles stably dispersed in the base fluid, not just the nanoparticles added.