COMPARATIVE ENERGY AND EXERRGY ANALYSIS OF ORC-VCR AND MODIFIED ORC-VCR CYCLE USING DIFFERENT WORKING FLUIDS

A Thesis Submitted

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In

Thermal Engineering

SUBMITTED BY

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(2K19/THE/01)

UNDER THE GUIDANCE OF

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CANDIDATE'S DECLARATION

I, AKITA SUKHDAVE, hereby certify that the work which is being presented in this thesis entitled "**COMPARATIVE ENERGY AND EXERRGY ANALYSIS OF ORC-VCR AND MODIFIED ORC-VCR CYCLE USING DIFFERENT WORKING FLUIDS**" being submitted by me is an authentic record of my own work carried out under the supervision of **Prof. Rajesh Kumar, Department of Mechanical Engineering, Delhi Technological University, Delhi.**

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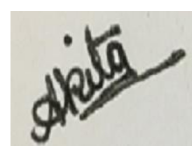

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CERTIFICATE

I,AKITA SUKHDAVE, hereby certify that the work which is being presented in this thesis entitled "**COMPARATIVE ENERGY AND EXERRGY ANALYSIS OF ORC-VCR AND MODIFIED ORC-VCR CYCLE USING DIFFERENT WORKING FLUIDS**" in the partial fulfillment of requirement for the award of degree of **Masters of Technology in Thermal Engineering** submitted in the **Department of Mechanical Engineering** at **Delhi College Of Engineering**, **Delhi University**, is an authentic record of my own work carried out during a period from July 2020 to July 2021, under the supervision of **Prof. Rajesh Kumar, Department of Mechanical Engineering, Delhi College of Engineering, Delhi.**

The matter presented in this thesis has not been submitted in any other University/Institute for the award of M.Tech Degree.

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It is a matter of great pleasure for me to present my dissertation report on "**COMPARATIVE ENERGY AND EXERRGY ANALYSIS OF ORC-VCR AND MODIFIED ORC-VCR CYCLE USING DIFFERENT WORKING FLUIDS**". First and foremost, I am profoundly grateful to my guide **Prof. Rajesh Kumar, Mechanical Engineering Department** for his expert guidance and continuous encouragement during all stages of thesis. I feel lucky to get an opportunity to work with him. Not only understanding the subject, but also interpreting the results drawn thereon from the graphs was very thought provoking. I am thankful to the kindness and generosity shown by him towards me, as it helped me morally complete the project before actually starting it.

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Finally and most importantly, I would like to thank **my family members** for their help, encouragement and prayers through all these months. I dedicate my work to them.

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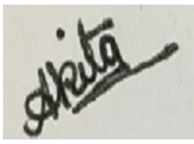

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ABSTRACT

This study examines the energy and exergy of a solar-powered Organic Rankine Cycle (ORC) that uses the refrigerants R245fa, R602, and R600 as working fluid to generate electricity. The suggested cycle combines a solar-sub system with a heliostat and a central receiver with an ORC. The rate of exergy destruction (irreversibility) in each component of the ORC cycle is calculated to assess the cycle's actual performance as well as the causes and locations of thermodynamic imperfection.

Using the first and second law technique, parametrical analysis is used to determine the influence of different operational factors on the performance of the ORC Cycle. The impact of several operating factors including turbine input pressure, turbine back pressure, and condenser temperature on energy and exergy efficiency, as well as irreversibility in ORC components such the heat recovery vapour generator, turbine, condenser, and pump, was investigated. Energy efficiency rises from 9.74 percent to 11.3 percent and exergetic efficiency increases from 10.43 percent to 12.10 percent with an increase in turbine intake pressure (1.58-2.38 MPa). The energy and exergy efficiency drops from 11.62 percent to 9.80 percent and 12.44 percent to 10.44 percent with an increase in turbine back pressure (0.18-0.26 MPa). Using R600, R602, and R245fa, the suggested solar-powered ORC cycle will be beneficial for power generation.

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INTRODUCTION

1.1. Background

Although fossil fuels used for most of the global energy use, they are thought to be limited resources since the pace of resource consumption exceeds the rate of finding of new reserves. The world is being pushed to transition its power dependency from fossil fuel to renewable energy suppliers and effective exploitation of current energy sources due to the fast reduction of fossil fuel resources and their conservation affect.

Energy as a key source of power production has grown more important, and it is predicted to grow soon. This is because solar energy systems have more benefits than traditional energy sources when it comes to generating power. Solar energy is an endless, clean, and safe form of energy that has gotten a lot of consideration as one of the most likely prospects to replace traditional energy sources (fuels).

ORC is a potential energy conversion technology that has involved a lot of interest in recent years because to its benefits of utilising low-cost industrial waste heat, solar energy, and geothermal energy are all examples of heat sources. Because organic fluid is used as the operating fluid as an alternative of water and high-pressure steam, it is identified as the Organic Rankine Cycle. ORC uses an natural fluid with a high molecular mass and a lower boiling temperature than water. There have been several research on the Organic Rankine Cycle for waste heat recovery electricity production.

For designing and analysing thermal systems that use exergy analysis, the second law of thermodynamics is combined with the conservation of mass and energy principles. The first law of thermodynamics is concerned with energy quantity and states that energy cannot be created or damaged. This low level just acts as a required tool for keeping track of energy throughout a process and poses no engineering issues. The second law of thermodynamics, on the other hand, is concerned with the energy quality. It is more precisely concerned with energy deterioration throughout a process, entropy creation, and missed job opportunities, and it has a lot of space for development.

In the optimization of complicated thermodynamic systems, the second law of thermodynamics has shown to be a highly useful tool. Considering the second rule of thermodynamics, we investigate the performance of engineering equipment. This section starts by defining exergy (also known as availability), which is the most useful work that an item or system may accomplish in any given condition, before moving on to reversible work, which is the highest useful output achievable throughout the course of a process. The last element is irreversibility (also known as exergy destruction or lost labour), which is the wasted potential for effort.

A solar-assisted ORC is suggested for energy production in this study. From the standpoint of energy and exergy, a thermodynamic study of the Organic Rankine Cycle will be performed. The performance of ORC will be tested utilising various organic fluids. The irreversibility (energy destruction) of ORC components such as the Heat Recovery Vapour Generator (HRVG), Turbine (T), Condenser (C), and Pump (P) will be assessed to determine which components have the most exergy loss.

1.2. Introduction

RAC play a critical part in contemporary human being existence by providing refrigeration and heat. This field has a wide variety of products, ranging from food conservation to enhancing people's thermal comfort and thereby living standards. The use of these devices in homes, buildings, cars, and factories offers thermal comfort in the a place to live and work, and so plays a critical role in any country's improved industrial productivity. Due to an increase in energy demand, mainly for RAC and HP products (around 26-30%), this results in environmental deprivation, global heating, and ozone layer reduction, among other things. To address these issues, there is an important demand for effective power utilisation, as well as notably after the Kyoto and Montreal conventions on waste heat recovery. Research into ecologically friendly refrigerants is a priority after the Kyoto and Montreal Protocols. However, in the search for alternative and environmentally acceptable refrigerants, the power effectiveness of these apparatus's while utilising traditional refrigerants is critical. For many years, CFCs and HCFCs have been the refrigerant fluids of choice for many purposes, and now non-ozone reducing HFCs have taken their place. In 1987, the Montreal Protocol prohibited the manufacturing and use of ozone-depleting chemicals and hastened the phase-out of CFC and HCFC to avoid ozone reduction, which could only be accomplished by employing HFCs in many functions. In 1997, the Kyoto Protocol established targets for reducing global warming chemicals, forcing the heat pump sector to explore for alternatives to CFCs and HCFCs.

Although hydrocarbons have been used in numerous applications, they have been constrained by safety concerns. refrigeration cycle selection, working fluid (refrigerant), and decrease of refrigerant quantity and leakage in system design, results in energy savings and climate change.

It also pertains to the installation, servicing methods, and energy efficiency improvements to limit direct carbon dioxide emissions into the environment. Due to a lack of energy and a desire to preserve it in every manner feasible, energy conservation has become a catchphrase of the decade, and An investigation is underway into new methods of conserving energy that would otherwise be wasted. The scientific community is increasingly concerned with the use of waste heat for energy recovery and/or practical applications to improve system efficiency, and as a result, it is now being used in industrial systems. Constant energy problems have compelled scientists and engineers throughout the globe to consider energy saving solutions in a variety of businesses. Electricity and thermal energy consumption reductions are desired yet inevitable in light of the world's quick and competitive industrial expansion. Refrigeration and air conditioning systems are critical components of industrial expansion and have an impact on a country's food and energy issues. RAC systems contribute significantly to energy usage. As a result, a foundation for energy saving and reusing the heat that would otherwise be wasted from RAC and HP systems is desirable. As energy preservation becomes a more significant aspect/parameter, it is necessary to optimise thermodynamic processes to use the least amount of energy possible. A refrigeration cycle's performance is impacted by a number of elements. To optimise their design, a thorough investigation based on the second law of thermodynamics (exergy study) is required. Although the first rule of thermodynamic analysis is the most often employed method, This model can't explain irreversibility in a system or process since it only deals with energy conservation. Exergy analysis, which is based on the second law of thermodynamics, may be used to investigate these cycles. The second rule of thermodynamics, which identifies the amount of irreversible processes in a system, may be used to increase thermal system performance.

Numerous experts have been working on various types of refrigeration systems for a long time. Some of the refrigeration systems produced so far have not garnered significant relevance in terms of improving performance and making them cost efficient. This might be due to a variety of variables, including poor COP, expensive investment, and operating expenses, and/or inadequate heating and cooling capacity. The vapour compression machines have become the most common form of refrigeration system all over the globe. This is owing to their improved performance and inexpensive prices while taking up little space; also, by providing intermediate cooling, sub cooling, and super heating in single and multistage vapour compression systems, their performance has been increased. However, such systems are responsible for the use of conventional energy, whereas other types of refrigeration systems, such as concentration systems, offer the benefit of utilising waste heat or other low-grade energy; however, these systems have a low COP value. Because it may run on waste or low-grade energy, vapour absorption refrigeration technology reduces the consumption of conventional energy. There is a lot of waste energy in industrial process facilities that won't be used because the temperature is too low. Some industrial operations use process steam to power enormous vapour absorption units to keep the whole facility comfortable. From a thermodynamic and economic standpoint, it is always preferable to offer both heating and cooling with a single system. This implies that industrial heat pumps use a high temperature lift from the heat source to the heat sink to perform dual functions as a heater and a chiller. However, when it comes to vapour compression heat pumps, there is a limit to high temperature lift since the pressure ratio rises as the temperature rises. Most working fluid vapour curves are quite steep, resulting in a high-pressure ratio vs. temperature increase. Combining ammonia and water to generate temperature rises of more than 100 K is one option.

Low-pressure ammonia water and pressures of less than 20 bar may be used as working fluid, temperatures ranging from -10 to +160° C are possible. During the phase transition operations, the ammonia-water combination is a broad boiling mixture that experiences enormous temperature variations. The cost of energy conservation technology must be competitive for it to be practicable for industry and cost-effective in comparison to other options. Standard components are often employed to assure cheap installation costs, and as a result, It is possible that the cost of energy from improved waste heat will be competitive with that from other types of energy sources. When it comes to energy saving, it's frequently better to employ thermally activated systems that can use both thermal energy and high-grade exergy, such as electricity used exclusively for lighting and mechanical functions. The contemporary interest in compression/absorption cycles stems from two needs: first, finding heat pumps that can handle high-temperature lifts, and second, using low-grade heat for sorption cooling.

On the theoretical side, compression/absorption heat pumps have received a lot of attention. The use of waste heat or other low-grade energy is a benefit of absorption systems. These systems, on the other hand, have a low COP value. These systems are being more widely employed across the globe because of policy improvements. A hybrid vapor-compression-absorption (VCA) system was used to attain greater COP values. The VCA hybrid refrigeration system can extract heat from waste hot water for use in various industries, such as the dye industry and general hot water uses, in addition to building heating and cooling. This not only makes better use of waste heat by allowing it to be used at greater temperatures, but it is also safer for the environment. Refrigeration systems, as we all know, not only use a large portion of a building's energy but also affect the ozone layer and, as a result, human health. There are systems that can operate on renewable energy, such as solar or biogas, in part or entirely.

In compared to other existing refrigeration systems, the vapor-compression-absorption hybrid system not only provides high temperature heating but also low temperature cooling, making it better and more suited. Because the temperature of the refrigerant may be raised either by heating or by compression using a vapour compressor, replacing the compressor with a solar collector and biogas burner can save a significant amount of energy. Because solar energy is abundant and can be harvested effectively, although it is intermittent in nature, it may be supplemented by biogas or waste hot water from various sectors. Given the necessity of energy conservation, it is necessary to optimise thermodynamic processes to use the least amount of energy possible. Many restrictions influence the absorption system's performance, resulting in real performance that is far lower than the ideal reversible case. The first rule of thermodynamics is used to assess cooling performance and improve operating parameters; nevertheless, it is focused with energy conservation and cannot demonstrate where irreversibility in the system occurs, resulting in COP deterioration.

Exergy analysis and exergo economics will be used to assess the irreversibility and, as a result, inefficiencies of different industrial processes that are responsible for increased consumption of natural resources, increased pollution, and increased end-product costs. The exergy technique, also known as second law analysis, is a thermodynamic attribute that determines how much useful work a material may create or how much effort is required to accomplish a process. First and second principles of thermodynamics are used simultaneously in exergy analysis, which provide only the magnitude of exergy destruction in the various thermodynamic losses are caused by components and processes, and thus it provides a ranking among the components of the system that should be serviced or replaced first to improve thermodynamic performance. Exergy analysis can only determine the amount of exergy destruction in various plant components; it cannot lower the size of exergy destruction. Exergy analysis and entropy production minimization begin at this stage. The use of thermodynamics is inadequate when using the entropy generation minimization approach, which differentiates entropy generation from energy analysis. The analyst must utilise the relationship between temperature differences and mass flow rate to minimise the entropy production of the given n system. In addition to thermodynamics, we must use cardiac transfer and fluid mechanism concepts to apply the entropy production minimization strategy. Although second law analysis helps in identifying the mechanisms and system components that cause thermodynamic losses, energy analysis is ineffective in reducing these losses.

Quiet operation, excellent reliability, extended service life, simpler capacity management, quicker installation, and cheap maintenance are all benefits of the absorption refrigeration system over the VCR. It is generally acknowledged as a viable contender for solar energy cooling applications that are both efficient and cost-effective. Furthermore, absorption refrigeration is a better option since it can take use of solar thermal power. without converting it to mechanical energy, as a VCR cycle must. At a lower temperature, the absorption cycle also utilises thermal energy.

Heat transfer equipment such as the evaporator, condenser, and compressor are still being researched and developed to increase their performance. Because the instruments utilised in the business are still as a result of the fundamental principle of thermodynamics, identifying inefficiencies and their limitations for future development is becoming more challenging. Even though the second rule and the exergy notion are well-known in textbooks, engineers and researchers in this sector seem to be hesitant to apply them in their design, testing, and assessment. Large quantities of heat are released into the environment through thermodynamic processes in refrigeration systems. Heat transfer occurs at a limited temperature differential between the system and the surrounding environment, which may be a key cause of irreversibility in the cycle. Individual thermodynamic processes that make up the cycle must be considered when evaluating the cycle's losses. In the study of thermal systems, energy (first law) analysis is still the most often utilised approach.

The first rule simply addresses energy conservation and provides no information on how, where, or why system performance is compromised. An exergy study is frequently performed to establish the system's maximum performance and to locate exergy destruction locations. Exergy analysis of a complicated system may be done by studying the system's components individually. Identifying the primary sources of exergy loss points in the right direction for future improvements. Finding the least effort necessary for a particular outcome is an essential goal of exergy testing for methods that use energy, such as refrigeration, gas, and water extraction. Exergy is inextricably linked to the idea of energy quality. As a result, exergy analysis has been frequently used in conjunction with energy assessment to determine the most efficient use of power. The greatest hypothetical effort that may be obtained from a method in each environment is its exergy. As a result, exergy is a quantity of a given energy flow's ability to be turned into high-quality energy. Since the early 1970s, exergy analysis has been used to determine the most efficient use of energy, which includes minimising fossil fuel usage, increasing to ensure that the quality criteria of energy supply and demand are met. Exergy analysis is a useful method for energy system design, optimization, and performance assessment. Exergy analysis has well-established ideas and methodology. [4-8].

While there is a large body of analysis of power plant exergy [9-18], The use of exergy in the built environment might be addressed early. Exergy is defined as the greatest theoretical work that may be achieved from a system's interaction with its surroundings before equilibrium is attained [19].

It may also be thought as as a system's departure from its reference environment [20]. As a result, exergy is a thermodynamic feature that is reliant depending on the current situation of affairs in question and its immediate surroundings, referred to as the "reference environment”.

They are used to transmit heat from a low-temperature channel to another medium at a higher temperature. The vapor-compression refrigeration cycle is the most prevalent.. There are four basic components in a refrigeration system: a condenser (to cool the liquid), an evaporator, a compressor, and a capillary tube (which acts as an expansion device). According to first-law theory, the COP is an indicator of the cooling cycle's efficiency A vapour compression cycle's coefficient of performance (COP) measures how much cooling is produced for every unit of effort. To get the best possible COP, a reversible refrigeration cycle should be used.

Although it is impossible to judge a refrigerated system's performance only based on its COP value, Real refrigeration systems may be compared to one other to that of reversible systems for the same refrigeration and ambient temperatures. The amount of work spent by the real cycle is always larger than the amount consumed by the equivalent reversible cycle, and the difference represents the amount of work wasted. To calculate the wasted work, first calculate the entropy generation. The magnitude of a process' irreversibility is measured by its entropy generation. A reversible thermodynamic process may be reversed without harming the environment. That is, at the completion of the reverse process, the system and its surroundings are reverted to their original conditions. This is only conceivable if the system's net heat and work exchange with the environment is zero. There are no reversible processes in the actual world.

Different refrigeration cycles, such as vapour compression, vapour absorption, and a modified hybrid VCARS using ammonia-water as the operating fluid, have been suggested for exploration in this study. In addition to the surplus waste heat from businesses, the VARS and modified hybrid vapour compression–absorption refrigeration system may use renewable energy sources such as solar energy and biogas. Based on energy and exergy analysis, the theoretical as well as experimental performance of several systems has been explored.

1.3. Waste Heat Energy Recovery

Many industries, processes, and procedures are affected by waste heat energy recovery. Because of the wide scope of the field, it will be necessary to define the region of interest as well as the approach to be used for every specific operation. To have the greatest effect on CO2 emissions reduction in India, the technology must be adopted in a sector with a significant remaining heat improvement potential. Though, it should be promoted to be used in other industries where waste heat is created.

1.3.1 Where Can Waste Heat Energy Be Recovered?

Since 1980, India's economy has seen a dramatic shift in the amount of energy it consumes. Even while transportation, home, and service sector energy consumption has increased by 68 percent, industry's consumption has decreased by 33 percent owing to structural differences and improvements in energy efficiency. It is still possible to make significant progress in the domain of waste heat recovery, even if industrial energy use continues to fall.

Flue gases from boilers, kilns, ovens, and furnaces create large quantities of heat in the process industries. It would save a significant amount of gasoline and money to recover part of this heat.

1.3.2 Recovering Waste Heat Energy serves a purpose.

The rise in energy prices, as well as environmentally friendly policies, are the primary driving forces towards energy recovery. No matter how thoroughly the thermal components and processes of an industrial plant are optimised, there will always be some heat loss because of the process. Therefore, the vast majority of this low-grade heat energy is released into the atmosphere, creating a significant waste of energy and resources.

Effluent streams that are discharged into the environment contain a considerable quantity of thermal energy that may be recycled for energy conservation and conservation of natural resources (Lamb, 1982). In the majority of cases, the use of waste streams from industrial processes to generate renewable energy is becoming the most important benefit of investing in energy recovery equipment, surpassing all other benefits. Studies have shown that energy recovery systems may have a remuneration phase of under five years, even though they need a significant initial investment to be put in place. That energy recovery technology may be economically viable for businesses is shown by this case study.

Process industries are motivated by environmental regulations as well as the desire to save money and resources on energy use. Because of energy recovery, the environment is in a better state. An increase in CO_2 emissions has been linked to an increase in energy waste, It is a key source of greenhouse gas emissions associated to climate change. Examples include the fact that, for every unit of useable energy that is wasted in the process sector, hundreds of tonnes of CO_2 are discharged into the environment because of the burn up of fossil fuels to produce electricity to replace the lost energy. Although carbon dioxide (CO_2) is not the most potent greenhouse gas, its statement into the atmosphere in large quantities as a result of the combustion of fossil fuels is a cause of interest.

In addition to being beneficial economically and environmentally, the recovery of process industry waste heat is also beneficial from a thermodynamic aspect. On a thermal level, recycling waste heat contributes to increased energy use while simultaneously decreasing entropy production. The thermodynamic notion of entropy generation minimization is based on the second law of thermodynamics and is a relatively new concept in the field of thermodynamics, having emerged in the 1980s. According to the second law of thermodynamics, the entropy of a closed system can never decrease in an isolated system if the system is closed.

1.4. Energy and Exergy

1.4.1 Energy - Every equipment or process conserves energy. It can't be taken away. Energy is introduced into a system by fuel, electricity, and moving streams of matter, and it is quickly accounted for in the products and by-products. However, the concept of energy conservation alone is insufficient to describe several key features of resource usage.

Global warming and environmental degradation are being caused by rising energy use and fast industrialisation. The development of energy systems is necessary to meet energy demand while reducing greenhouse gas emissions and fossil fuel dependence. Studies show that almost half of all industrial heat is of poor quality and ends up as thermal pollution.

Energy Efficiency (η_{en})

$$\eta_{en} = \frac{W_{net}}{Q_{solar}}$$

Where W_{net} and Q_{solar} are the net power output of ORC cycle and solar heat input,

1.4.2 Exergy - We start with exergy (also known as availability), which is the most valuable work that a system can obtain in a given state in a given environment, and then go on to reversible work, which is the most beneficial work that can be gained when a system transitions between two states. Next, irreversibility (also known as exergy destruction or final work) is explored and characterised as a second-law efficiency, which refers to lost work potential throughout a process because of irreversibility.

Exergy Efficiency (η_{ex})

$$\eta_{ex} = \frac{W_{net}}{E_{x,\,solar}}$$

Where E_x, Incoming exergy connected with sun radiation falling on heliostat is referred to as solar. and W_{net} are the net power output of ORC.

1.5. Objective of the thesis

The main objectives of the thesis are as follows:

- Using the first and second low approaches, determine the cycle's realistic performance.
- To investigate for irreversibility in the Organic Rankine Cycle's many components.
- To examine the impact of different operational parameters on the Organic Rankine Cycle, researchers are developing an Organic Rankine Cycle simulation.
- Using various fluids, determine the impact of a vapour compression device.

1.6. Structure of thesis

We discussed here chapters descriptions of all thesis structure

Chapter 1- In the following chapter we have studied about solar heat, Organic Rankine Cycle, energy, exergy and working fluids.

Chapter 2- In the following chapter various literatures have been reviewed in support of thesis work.

Chapter 3- In this chapter, we have discussed about the working of ORC and VCR, energy equation, exergy equation and various refrigerant.

Chapter 4- In this chapter, we have studied about the refrigerant R245fa and R600, R602 for better energy and exergy efficiency along with exergy destruction. And we have also described the effect of various operating parameters on the performance of Organic Rankine Cycle.

Chapter 5- In this following chapter we have concluded that R600, R602 is better as compared to R245fa and it is best suited for production of power.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

An electric system creates work that is utilised in a refrigeration system to move heat from one location to another where it is required (cooling) or to heat one location from another one (place to be heated). A cooling effect is accomplished in the region being cooled by using low-temperature boiling fluids, which are referred to as refrigerants. When assessing the advantages and disadvantages of various cooling methods, the operating temperature and the COP are the two most important elements to consider. It is feasible to investigate these systems via the use of energy and exergy studies that are In keeping with thermodynamics' first and second laws, which were comprehensively discussed in the chapter before this one. Throughout this chapter, a broad variety of refrigeration and heat pump systems have been discussed. The primary purpose was to map out a possible future research route for the team. The review of the literature has been divided into the following categories:

- Vapor Absorption Refrigeration Systems.
- VCRS.
- VCRAS.

2.2 Vapor Absorption System

Direct cooling of low-grade energy is now possible with the Vapor Absorption System. Vapour compression technique, which consumes high-grade energy, has a substantial disadvantage here. Additionally, these systems have no moving elements other than a small liquid pump. This is a significant aspect of these systems. Evaporator, absorber (on the low-pressure side), generator and compressor are all components of a vapour absorption system (on the high-level-density side) (located on high pressure side). While the absorbent travels back and forth between the generator and evaporator, the refrigerant goes from the condenser and evaporator to the absorber and the generator, and then back again. It is important to have as minimal a pressure differential as possible between the low and high- pressure sides of the pump. Operation costs may be lower if absorption and distillation can be optimised, and these costs may be further decreased with more efficient systems. However, the price of these systems has gone up. It is crucial to thoroughly investigate these qualities to build an effective absorption refrigeration cycle, thermodynamic characteristics of the refrigerant–absorbent combination determine the efficiency of these processes.

LiBr-H2O and NH3-H2O are two examples of working pairs that have been researched extensively by researchers in the field of vapour absorption refrigeration. How to develop and optimise a water-lithium bromide refrigeration cycle theoretical research. Their findings showed them that a greater heat exchange surface and cheaper cost for the same refrigerating capacity could be achieved by increasing the temperature of the generator. Due to the difficulties of crystallisation, water lithium bromide cycles are limited. For both single and lithium bromide adsorption systems that use a sequence of water flows, availability and irreversibility were examined.

Jiarui Liu, et. al. (2021) This research suggests a modified trans-critical CO2 refrigeration cycle with a dual-ejector and dual-evaporator design for retail use. One of the two ejectors and a flash tank in the modified cycle is based on the traditional trans critical CO2 refrigeration cycle. There are two methods for raising the compressor suction pressure: The first method uses a liquid-vapor ejector to remove the flash vapour from a low-temperature condenser; the second method uses the vapour from a higher temperature condenser to entrain flash vapour from the lower-temperature condenser. Compressor pressure ratio may be reduced by up to 19.1 percent under typical operating conditions, and COP and exergy effectiveness can be improved by up to 15.9 percent, 27.1 percent and 15.5 percent, 27.5 percent. A lower gas cooler pressure of 8.15 MPa is used in the modified cycle, as opposed to the standard cycle's 8.3 MPa. This redesigned cycle has shown to save energy in comparisons, and it might be used in supermarket refrigeration.

Sahar Safarian et. al. (2015) A hypothetical structure developed in this research was used to evaluate the energy and exergy production of a basic Organic Rankine Cycle and three improved versions (ORCs). The modified ORCs were used to study turbine bleeding, restoration, and a combination of the two. The statistics demonstrate that raising the pressure of the evaporator aids in exergy deterioration. Integrated ORCs with turbine regeneration have the best thermal and exergy efficiencies (22.8 percent and 35.5 percent, respectively), as well as the lowest exergy loss (25.5 percent). This is due to decreased cold utility demand and high power output (42.2 kW). In terms of efficiency, the ORC (d) has the highest thermal and exergy efficiency (22.8 percent and 35.5 percent, respectively) because of the decreased cold service demand and the high-power output it offers over the other analysed cycles. Thus, the total exergy loss is decreased to 42.2 kW, and the thermodynamic perfection level rises to 76 percent.

Guanglin Liu et. al. (2020) Exergy analysis was used in this work to examine the two-stage ORC power generating system with a geothermal fluid temperature between 100 and 150 degrees Celsius. Studying the subcritical saturation organic Rankine cycle system at temperatures between 100 and 150 °C, four distinct organic working fluids are tested. Single and two-stage systems, heaters, and condensers are all evaluated for their exergy efficiency in relation to the temperature of the heat source. With regard to exergy efficiency, geothermal fluid mass split ratio and heater exergy efficiency are studied in the preheaters. The following are some of the most significant results: Temperatures of organic working fluid evaporation impact the exergy effectiveness of the two-stage system, which reaches a maximum at both high and low temperatures. Two-stage systems have a higher exergy efficiency than single-stage systems when the same heat sink and heat source characteristics are used. At 130 degrees Celsius, a two-stage system's energy efficiency is 9.4% more than that of a single-stage system.

Naveen Kumar, et. al. (2019) A detailed examination of the exergy consumption of a VCRS using the refrigerants 134a and HC (combined R-290/R600a) is presented in this paper in agonising detail. As the name suggests, the key objectives of this research are to examine the effects of energy on performing, as well as the exergetic efficiency, energy product, exergy destruction ratios (EDR), performance coefficients, and second-law efficiency. This investigation will focus on the system's most important components, such as the compressor, condenser, evaporator, and throttle valve (throttle valve). An exergy analysis of a hydrocarbon refrigerant that might be utilised in lieu of R-134a is the aim of this research. With R134a, the effects of evaporation temperature on cooling capacity (COP), energy efficiency (EE), and EDR will be studied and compared to those of hydrocarbon refrigerant gas. Because they have a lower global warming potential, refrigerants such as hydrocarbon and R-134a are chosen for use in household refrigerators (Global Warming Potential).

Tao Bai et. al. (2015) Using a two-stage ejector modified dual-evaporator, the MDRC is a CO2 trans critical refrigeration cycle. Recovering expansion work from throttled cycles, increasing system performance, and achieving dual-temperature refrigeration may all be accomplished using a two-stage MDRC ejector. An energetic and exergetic simulation of the redesigned cycle's thermodynamic performance may be performed theoretically. Simulations show that the two-stage ejector beats the single ejector in terms of boosting system performance in CO2 dual-temperature cooling systems, increasing the maximum system COP and exergy efficiency by 37.61 percent and 31.9 percent respectively. The gas cooler, compressor, two-stage ejector, and expansion valves account for the bulk of total system exergy destruction, with the two-stage ejector accounting for 16.91 percent of the total system exergy input when each component is run at its optimum discharge pressure. In terms of performance metrics, the suggested cycle can operate in a double-evaporator refrigeration system.

B. Saleh, et, al. (2016) The ORC cycle and the VCR cycle are utilised in low-grade thermal energy production facilities where the temperature ranges between 80 C and 40 C. It is computed by multiplying the entire system coefficient of performance, m_ total, by the cooling capacity in kilowatts (COPS). The research of system performance includes the collection of operational parameters such as “evaporator, condenser, and boiler temperatures”. In spite of the fact that the R600 has the lowest total m_ in the operating parameters that were investigated, the findings show that the R245fa and R600 are the best options for COPS, despite the fact that the R600 has the lowest total m_ in the operating parameters that were reviewed. For the ORC-VCR system, the R600 is the optimum option from an environmental and system performance aspect. However, the fact that it's combustible should be all that people need to notice. At a condenser temperature of 30 C, the maximum COPS using R600 is calculated to be 0.718, with the fundamental values for the other parameters.

Ertugrul Cihan et. al. (2016) Exergy and energy efficiency were studied for an organic Rankine cycle powered by waste heat and refrigeration. The compressor in the refrigeration cycle was fed the kinetic energy that had been collected throughout the refrigeration process to put the operation to a conclusion. In the power cycle, the turbine was propelled by the “high temperature and pressure of the natural operating fluid that leaves the boiler”. To verify that the proposed system works as expected, five various organic fluids were utilized to evaluate its theoretical performance. Thermal and exergy efficiency was also evaluated by altering the temperatures of boiling, condensation, and evaporation. Based on the suggested system's energy and exergy study, R141b was found to be the best organic working fluid.

Amin Nabati et. al. (2021) Here, the best organic Rankine-vapor compression cycle for generating cold water from solar energy for hospital air conditioning is shown. In Esfarayen, where the hospital is located, sun radiation levels are monitored year-round. A new study found that Esfarayen city gets the most solar radiation from May through September (apart from December and January). Using everyday sun energy to chill water is being researched over the next five months. About solar irradiance and refrigerant, the ORC-VCC system's cooling water temperature output and cycle performance, organic Rankin cycle efficiency and VCC cycle performance coefficient, and exergy efficiency are all being studied. Increases in boiler thermal energy (solar radiation) decreases the evaporator temperature and system exergy efficiency, while increasing organic Rankin cycle efficiency and cycle performance.

R. Lizarte et. al. (2017) A new model for a stand-alone refrigeration method based on a combination of an organic Rankine cycle and a cascade refrigeration system are examples of such systems (ORC-CRS) was described in this research (from 55 0C to 30 0C). A combination of toluene and The organic Rankine cycle and the cascade refrigeration system used NH3/CO2 as a coolant, respectively. The system's overall performance coefficient (COPoval) and exergetic efficiency (gex oval) were projected using a parametric analysis and a regression analysis. At 315 degrees Celsius, the ORC's evaporation temperature was the highest COP oval and (gex_oval) determined at 0.79 percent and 31.6 percent, respectively. As a result, fossil fuel and CO2 emissions may be reduced by using renewable thermal energy sources between 100 and 350 degrees Celsius. In regions where the power supply is unpredictable, this stand-alone facility seems to be a viable choice for exploiting low- and medium-grade thermal energy.

B. Saleh et. al. (2019) ORC–VCR integrated system performance and working fluid selection are analysed using renewable energy to evaluate the system's performance and fluid selection. Coefficient of performance (COPS) and mass flow rate of refrigerant per kilowatt refrigeration capacity (m total) define the system's overall performance. The integrated system is suggested to use fluids made up of twenty-three pure components. Using the suggested working fluids, the fundamental integrated system performance is evaluated and compared. Both the basic VCR cycle and the basic ORC cycle operate between 35 and 0 degrees Celsius. ORC–VCR system performance is also analysed in terms of the evaporator, boiler, and condenser temperatures, as well as other operational parameters. Under all working circumstances, the cyclopentane achieved the maximum system performance. From an environmental and system performance standpoint, cyclopentane ranks highest among the 23 working fluids that were analysed for this integrated system. Further limits should be implemented because of its severe flammability.

M. Aslam Siddiqi et. al. (2012) Waste heat from high, middle, and low-temperature heat sources (e.g. 773.15, 623.15, and 523.15 K) has been studied for hydrocarbons in various temperature ranges (viz., 773.15, 623.15 and 523.15 K). Benzene and toluene were tested against water, n-pentane and n-dodecane, among other hydrocarbons. Model simulations were run at varying boiler pressures. Improved boiler efficiency is a by-product of higher boiler pressures. Low-temperature hydrocarbons, such as n-hexane and n-pentane, have a lot of promise (523.15 K). Higher temperatures (773.15 K) allow n-dodecane and toluene to be used as heat transfer fluids (773.15 K). Cogeneration systems may use octane, heptane, and water as working fluids under a variety of conditions, according to case studies in the intermediate temperature range (623.15 K). The statistics for heat exchanger surface area and total heat recovery efficiency have been analysed.

Nan Wang et. al. (2018) In this work, the ORC ejector refrigeration system with integrated power and cooling was discussed in depth. Traditional ORC systems may not be able to reuse exhaust heat for refrigeration, but the combination system may be able to do so. Because of its simplicity, the ejector refrigeration system is an excellent choice for those who want to save money and time. The parametric model was used to assess and analyse the system's operation. REFPROP and MATLAB are utilized to calculate thermodynamical qualities and replicate the findings. For example, generator temperature, condenser, and evaporator temperatures as well as their impact on system efficiency have been studied. System efficiency and entrainment ratio might be improved by raising generator and condenser temperatures while reducing condenser temperature. It is possible to boost the efficiency of this combination system by altering thermodynamic parameters.

Xingyang Yang et. al. (2015) The idea of combining a power and cooling cycle is being investigated. An ejector connects the organic Rankine cycle with the refrigeration cycle in the proposed cogeneration system. The combined cycle's performance is evaluated while the system is operating in various working fluids, such as R245fa and R600a pure working fluids and R245fa/R600a zeotropic mixes. Even at mass fractions as low as 10% and as high as 70% by volume, mixes outperform pure working fluids in some conditions. The influence of each of the other thermodynamic parameters, such as the temperatures of the evaporator and condenser, the boiler, and the turbine output, on the system is also examined.

Youyuan Shao et. al. (2018) Energy systems were studied for their thermal and exergy efficiency relationships. Steam boilers and steam turbines, two common pieces of thermal equipment, were selected as the basis for this case study. Exergy efficiency may not always be desirable, even if a process is very efficient in terms of thermal efficiency. When it comes to conserving energy, thermal efficiency alone is not enough. Thermal and exergy efficiency should be thoroughly evaluated, and a variety of energy levels should be used in a cascade to get the maximum possible energy savings for a thermal system or piece of machinery.

Shafiee and Topal (2009) The primary sources of energy supply in the globe, crude oil, coal, and natural gas, were discussed in depth.. When it comes to determining when non-renewable sources of energy will be depleted, there is no easy solution. New methods for assessing fossil fuel reserves before they are exhausted and an econometrics model for demonstrating the link between fossil fuel reserves and several key factors are presented in this study.

Asif and Muneer (2007) Many aspects of energy resources were examined, which are essential to human survival and have grown more important for the sustainability of current civilization. Fossil fuel users face a long list of challenges. The effects of climate change and other environmental issues, geopolitical and military conflicts, and lately, a significant increase in fuel costs have all contributed to the reduction of fossil fuel reserves. These factors indicate to a dangerous situation. No one can deny that renewable energy sources are the best bet for meeting our nation's soaring energy demands. Renewable energy resources, such as solar, wind, biomass, wave, and tidal energy, have no upper limit. This article gives the statistics to give readers a clear picture of the current and future state of the energy industry. This research focused on five major can have an influence on the global energy supply and demand: China, India, Russia, the United Kingdom, and the United States.

Quoilin et al. (2013) The ORC is a heat engine that generates electricity from low-temperature heat sources by using natural liquids with low boiling temperatures as working fluids instead of steam. ORC technology can transform low-grade thermal energy sources such waste heat recovery, geothermal and solar thermal energy sources, biomass cogeneration (CHP), and ocean thermal energy (OTE) to electricity.

Lecompte et al. (2015) Low-temperature heat may be converted into electricity without the need for human involvement using ORC technology. In addition, it needs little care and performs at optimal pressures. In comparison to using fossil fuels for the same amount of energy output, installing an ORC system helps to minimise greenhouse gas emissions.

Rayegan and Tao (2011) Organic chemicals such as ethanol are utilized as the working fluid in ordinary Rankine cycle (ORC) power systems instead of water in classic Rankine cycle systems. The ORC-based system has also been studied for use in geothermal heat recovery and solar thermal applications, in adding to waste heat recovery and biomass utilisation. There are a number of factors to take into consideration while selecting an operating fluid, including efficiency and net power production, as well as environmental effect.

He et al. (2012) As a key source of electricity, solar power has been thoroughly studied and integrated into the ORC system. We've done some preliminary research on the impact of several critical parameters on the collector field and the overall system performance using numerical simulations of a an Organic Rankine Cycle (ORC)-based solar power generating system.

Wei et al. (2007) If an ORC is used for waste heat recovery, the net power production and system efficiency must be assessed. For example, exhaust mass flow rate and air mass flow rate are included in this category, as well as ambient temperature. They found that adjusting the system's nominal state to maximise net power generation and efficiency was a great idea.

Quoilin et al. (2011) A rural electrification ORC was described in detail, with a wide range of characteristics. This model has been used to examine and optimise the working fluids of a wide variety of systems under a variety of operating situations.

Kerma and Orfi (2015) Modeling and simulation have been used to study the thermodynamics of an ORC powered by parabolic troughs and solar collectors. In order to evaluate the ORC, it was used with eight different fluids. The link between the turbine intake temperature and the primary energy and exegetical performance measures was studied. Other factors that affect turbine size, flow rate and growth ratio are also observed in this study. Also included in this study were the irreversibility ratio and the overall exergy destruction rate.

Ozdil et al. (2015) examined the thermodynamics of a modest power plant in southern Turkey's Organic Rankine Cycle (ORC). An evaporator, pump, generator, and turbine are all part of the system under investigation. Analyzing the system's many components is made possible thanks to the performance cycle and plant data. The efficiency of exergy and the pinch point are linked. The lower the pinch point temperature, the lower the rate at which exergy degradation occurs. In the real world, ORC energy and exergy efficiency in saturated liquid is 9.96% and 47.22%, respectively.

Brown et al. (2015) Five renewable/alternative energy sources have been examined to determine "ideal" working fluids for an Organic Rankine Cycle (ORC). ORCs operating in fluids that are not well specified empirically or by high-accuracy equations of state are also screened and compared using the thermodynamic performance potential method. A wide range of "theoretical" working fluids are studied to uncover feasible substitute running fluids and guide future work fluid study and progress.

Tchanche et al. (2009) Organic Rankine cycle fluids have been theoretically investigated for their thermodynamic and environmental characteristics at low temperatures. Efficiency, volume flow rate, mass flow rate and pressure ratio were used to compare the various goods. R134a seems to be the best fluid for small-scale solar applications out of the 20 fluids studied. These chemicals are very flammable and need safety measures. Many chemicals, including refrigerants, contribute to global warming by depleting the ozone layer. For the sake of the ecology, it is imperative to look for alternatives that are less destructive. Due to their high ODP and GWP, R12, R114, and R500 cannot be harvested. GWP of about 10250 was the reason for its removal from the list of eligible chemicals. Soon, only a few compounds with low ODP or GWP will remain on the market. R141b, R123, R407, R134a, R407C, and R32 are among the many other options. Eco-friendly alkanes and water families are alkanes.

Mago et al. (2008) There is a huge influence on the thermal control of ORC systems when a working fluid is used. There are three types of organic working fluids: dry and wet. We picked a range of both dry and wet fluids depending on the heat source and assessed the system performing using the parameters of thermal efficiency and exergy loss. According to the findings, dry fluids performed better in the system than moist ones.

Yang et al. (2014) compared the ORC recovery system's performance with six different kinds of combination working fluids. Using combinations of R245fa and R152a, the case study found that the power output could be increased. Using R141b and R11, The retardants were selected because of their high critical temperatures and huge molecular weights.

Linke et al. (2015) To ensure a sustainable energy future, low- and medium-grade thermal power producing efficiency must be addressed. Organic Rankine cycles (ORCs), for example, are a major enabling technology that has been a hot research area in recent years. Working fluid selection and efficient heat-to-power conversion cycle design from a variety of geothermal, solar, or waste heat sources connected to hot fluid streams are among the topics under investigation. Therefore, numerous approaches to ORCs have been designed, integrated, and controlled by the use of a systematic approach to fluid efficiency selection.

Darvish et al. (2015) a computer programme has been used to model the thermodynamic performance of an organic cycle that utilises low temperature heat sources to aid in the selection of organic working fluids. To study thermodynamic factors like output power and energy efficiency, thermodynamic models are utilised (Organic Rankine Cycle). Exergo-economic analysis is also used to assess the cost of energy. During the inquiry, nine working fluids are compared to find the one that best meets the system's power and exergy requirements. Exergy efficiency and power costs are employed as measurable criteria for system improvement, and the optimal operating condition of each fluid is considered. The pressure ratio and the degree of superheat are two separate optimization variables. It has been shown that R134a and iso-butane have the greatest energy and exergy efficiency, but their output power is in the middle of the organisations employing other operational fluids, The exergy efficiencies of the R134a and iso-butane systems were 19.6 percent and 20.3 percent, respectively, when the source temperature was 120 °C. The boiler and the expander are the places where the most exergy is lost. When employing R134a as the working fluid, The system's power costs vary from 0.08 USD/kWh to 0.12 USD/kWh depending on the price of the fuel input.

Wang et al. (2011) A thermodynamic model created in Matlab and REFPROP was used to examine the performance of nine distinct pure natural working fluids operating locations, which were chosen based on their physical and chemical features. In the zones where net power outputs were limited to 10 kW, their outcomes were compared. There was also an assessment of environmental consequences and safety standards. As a result, R245fa and R245ca are the most ecologically friendly working fluids for applications involving engine waste heat recovery, based on the results of the study. Based on the analytical findings, the optimum control concept of the transitory process of ORC is discussed. Using an engine's exhaust heat to generate electricity, the organic working fluids were analysed These fluids have thus been studied for their thermal efficiency and exergy destruction rates in an adequate range determined by the vapour pressure and temperature of condensation.

Agrawal and Kumar (2015) It has been suggested to investigate the thermodynamics of a solar-powered refrigeration cycle that uses both electricity and an ejector. The Rankine cycle and the ejector cooling cycle are combined in this cycle to create both electricity and refrigeration at the same time. The cycle's performance is being evaluated using a variety of refrigerants, including R141b, R600, R601 and R601a. Cycle energy and exergy efficiency may be affected by numerous operational thermodynamic factors including turbine input pressure, back pressure, condenser and evaporator temperatures. R141b has the maximum energy efficiency (18.37 percent) and R600 has the highest exergy efficiency at a common turbine back pressure of 0.4MPa, according to the research (7.65 percent). A common evaporator temperature of 270K, R141b delivers a high energy efficiency of 17.98 percent and

R600 a high exergy efficiency of 6.69 percent. An increase in R141b turbine intake pressure of 0.5 MPa to 1.75 MPa results in a 13.8 percent gain in energy efficiency and a 3.45 percent increase in exergy efficiency.

Nobru et al. (2012) Ozone depletion and global warming are insignificant, and HFO-1234yf provides the maximum thermal efficiency of 8.8-11.4 percent for expander inlet temperatures of (180-160oC) in the Supercritical Organic Rankine cycle, a viable working material, according to a study on First Law efficiency (Energy analysis). The study and destruction of exergy in the expansion of distinct components, pumps, condensers, and evaporators employing HFO-1234yf as a working ingredient have not been studied to date in the Organic Rankine cycle (ORC).

Marin et al. (2014) The exergy performance for an Organic Rankine Cycle is shown using several components of energy and exergy analysis (ORC). An existing building with a recognised design is considered in this system's electrical energy supply. Several working fluids were used in the simulations for the ORC system's operation. Using an exergetic analysis, the optimal working fluid may be selected that would minimise the damage of exergy to the system's critical components. As a result, reducing exergy degradation while simultaneously boosting overall system efficiency necessitates thoughtful fluid selection. There is no doubt in our minds that this solar-powered Organic Rankine Cycle arrangement can meet the demands of consumers, as shown throughout this project. To make mechanical work from low-grade heat sources, an ORC is an excellent choice.

2.2. Outcomes of the literature review

During the survey of literature, it is observed that operated ORC will be more useful to produce power by using the low boiling point fluids in the Organic Rankine Cycle (ORC). The organic fluid for Organic Rankine Cycle may be taken as R600, R602, R245fa, R141b, R152a.

2.3 Proposed work

With the help of outcomes of literature review solar assisted Organic Rankine Cycle and vapour compression system is proposed for production of power by using low boiling temperature working fluid R600, R602 and R245fa. The performance of cycle is evaluated from viewpoint of energy and exergy by using first and second law approach.

CHAPTER 3

MATERIALS AND METHODOLOGY

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3.1 INTRODUCTION

Because thermal comfort is so important in both the home and industrial sectors, air conditioning comes at a high price. In order to reduce power consumption and make air conditioning more effective and environmentally friendly, the most important problem is to use less energy. All plant components must be studied to determine the irreversibility of a process.. The full knowledge of diverse thermodynamic processes in any conversion system is critical for successful utilisation and optimal optimization. A detailed thermodynamic study is necessary to optimise their design. As a rule, engineering applications rely on the first law of thermodynamics, which only deals with energy conservation and cannot explain how and when irreversibility occurs in a system or process. The application of the second law of thermodynamics, on the other hand, is a well-established approach for determining the irreversibility of any procedure.

Unlike the first law (energy), the study based on the second law (exergy) qualitatively indicates the extent of irreversibility linked with a process and therefore offers a hint of where the engineers should focus more to enhance the performing of this thermodynamic system [1-3]. [4].

3.2. Description and working of Organic Rankine Cycle (ORC)

Many components make up the solar-powered Subsystems of the ORC system, such as the ORC subsystem and the solar energy collecting subsystem The schematic diagram of the ORC system is shown in Fig 1. The Organic Rankine Cycle consists of a heat recovery vapour generator (HRVG), a turbine, a condenser, and a pump. (ORC) subsystem. Central receiver aperture region at the summit of tower receives solar waves that fall on the heliostat ground. The concentrated waves which fall on the central receiver (CR) makes the central receiver temperature high, which is result heat the Refrigerant. This refrigerant travels via pipes from the central receiver (CR) to the HRVG, transferring heat energy. For power production, the superheated refrigerant vapour develops in the turbine. In the condenser, the turbine exhaust is condensed. The saturated liquid has now been poured into the Rankine Cycle's HRVG. The main part of solar operated ORC collecting system is an arrangement of heliostat field and central receiver (CR).

Heat transfer fluid travels via the centre receiver. To reduce heat loss, a vacuum annulus is positioned outside this receiver. The heat transfer fluid preferred for the ORC system with is R600 and R602. This Refrigerants has been preferred since has better heat transfer assets and temperature management.

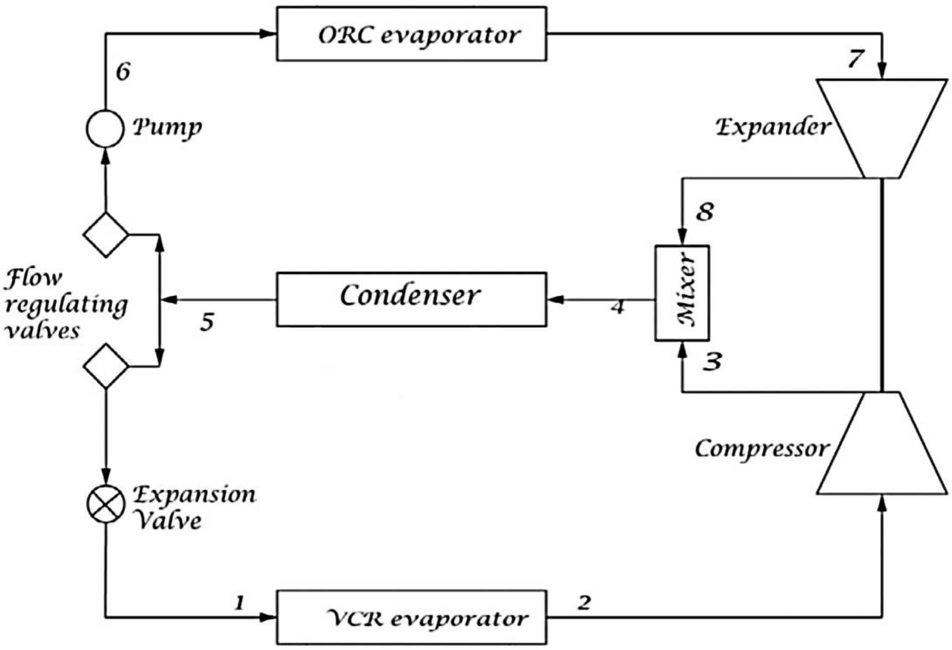

Figure 3.1: Schematic Diagram of ORC and VCR evaporators system

The schematic and T-s diagram of a basic ORC–VCR system are shown in Figures 3.1 and 3.2, respectively. The condenser's cooling water stream condenses the zeotropic mixture at the mixer's output (state 4) into a subcooled liquid as a result of the cooling water stream. (state 5). It is divided into two portions by flow controlling valves. A portion of it is throttled (from stage 5 to state 1) Before the superheated vapour (state 2) departs the VCR evaporator and reaches the compressor, it is compressed to state 3 by the compressor. The ORC evaporator's heat source fluid heats the second half of the zeotropic mixture, while the ORC pump raises the second half's pressure to that of the ORC evaporator (at state 6). When the REFRIGERANT enters the expander, it expands at a high temperature and pressure (at state 7). The exhaust from both the expander (State 8) and the compressor is blended using a mixer (State 3). As a consequence, the cycle continues to repeat itself.

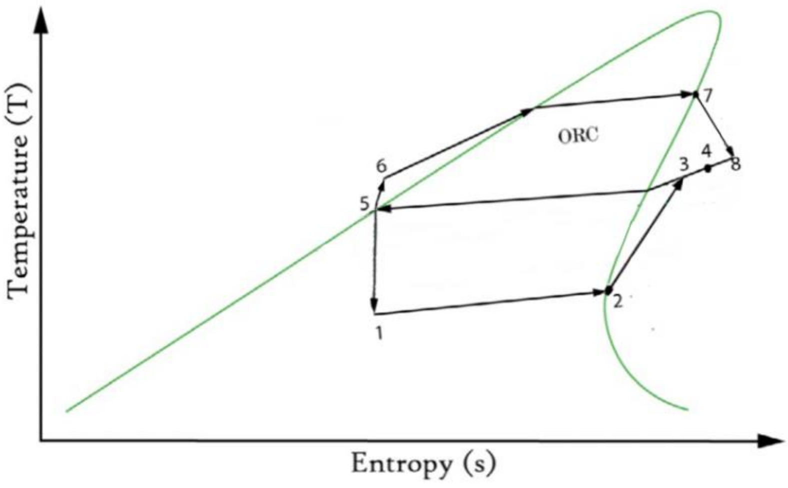

Figure 3.2: Entropy cycle of ORC system

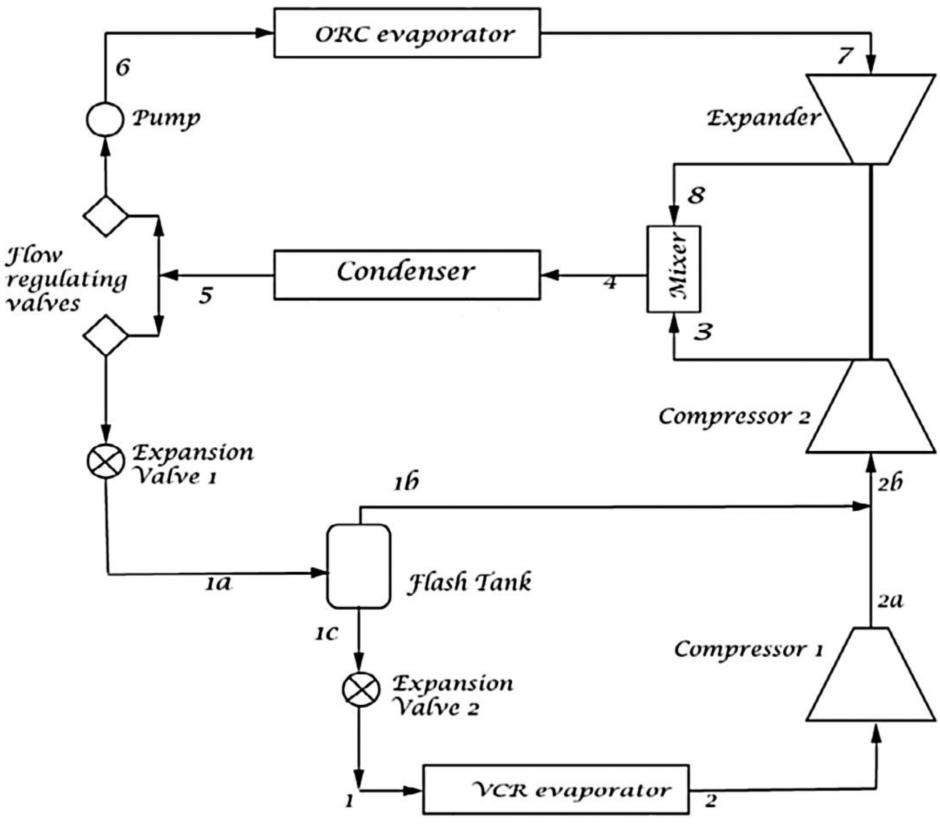

Figure 3.3: Modified ORC and VCR Cycle system

3.3. Modified ORC–VCR system

On the right are diagrams of the updated ORC–VCR system, as well as a schematic design and a T-S diagram (see Figures 3.3 and 3.4). When compared to the previous system, the ORC subcycle and its functioning are same in the new system. The only alteration was the addition of a flash tank, as well as an expansion valve and compressor, to the VCR sub-cycle. The exhaust from the condenser is received by the expansion valve 1 and the flash tank for the VCR sub-cycle (state 5) in this manner (state 1a). After escaping from the flash tank, it expands even more via the expansion valve 2 before being evaporated in the VCR evaporator, where it becomes superheated in the superheated state 1. State 2a is compressed by Compressor 2 then. One of the flash tank's saturated vapour mixtures (state 1b) is mixed with the exhaust from compressor 1 and squeezed further (to condenser pressure) by compressor 2. (state 3). Compressor 2 (stage 3) and state 8) exhaust from the condenser are mixed together in the condenser's final stage.

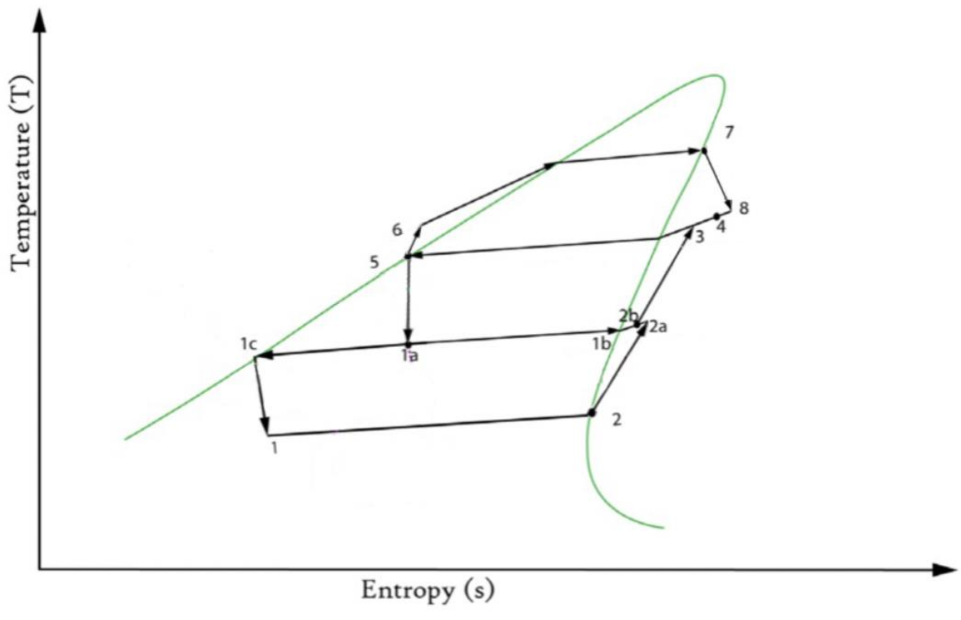

Figure 3.4: Entropy cycle of VRC system

Figure 3.4 shows the process of every step in modified ORC -VCR system working process.

3.4. Methodology

The overall thermal efficiency (energy efficiency) of a system is determined via the application of energy analysis and energy conservation since heat and work are equivalent in nature. Thermodynamics second principle based on exergy analysis (the second law of thermodynamics), exergy is a measure of the irreversible difference between heat and work (exergy destruction). A system's exergy is the highest amount of work it can do. while it is in equilibrium with a reference environment; this equation can be represented numerically as:

As shown in Table 3.1, the first rule of thermodynamics may be applied to each component of the cycle to determine its mass and energy balance.

Table 3.1: Energy Relations Used for Each Component Of The System

Components	Steady flow energy balance equations	
	ORC-VCC	**Modified ORC-VCC**
VCC evaporator	$\dot{Q}_{Evap} = \dot{m}_{VCC}(h_2 - h_1)$	$Q_{Evap} = \dot{m}_{VCC}(1-y)(h_2 - h_1)$
Compressor	$\dot{W}_{Comp} = \dot{m}_{VCC}(h_3 - h_2)$	
Compressor 1		$\dot{W}_{Comp,1} = \dot{m}_{VCC}(1-y)(h_{2a} - h_2)$
Compressor 2		$\dot{W}_{Comp,2} = \dot{m}_{VCC}(h_{3a} - h_{2b})$ $\dot{W}_{Comp} = \dot{W}_{Comp,1} + \dot{W}_{Comp,2}$
Expansion Valve	$h_5 = h_1$	
Expansion Valve1		$h_{1a} = h_5$
Expansion Valve2		$h_{1c} = h_1$
Condenser	$\dot{Q}_C = \dot{m}_{tf}(h_4 - h_5)$	$\dot{Q}_C = \dot{m}_{tf}(h_4 - h_5)$
Pump	$\dot{W}_P = \dot{m}_{ORC}(h_6 - h_5)$	$\dot{W}_P = \dot{m}_{ORC}(h_6 - h_5)$
ORC Evaporator	$\dot{Q}_b = \dot{m}_{ORC}(h_7 - h_6)$	$\dot{Q}_b = \dot{m}_{ORC}(h_7 - h_6)$
ORC Expander	$\dot{W}_{Comp} = \dot{W}_T$ $\dot{W}_T = \dot{m}_{ORC}(h_7 - h_8)$	$\dot{W}_{Comp} = \dot{W}_T$ $\dot{W}_T = \dot{m}_{ORC}(h_7 - h_8)$
Mixer	$\dot{m}_{tf} = \dot{m}_{ORC} + \dot{m}_{VCC}$ $\dot{m}_{tf}h_4 = \dot{m}_{VCC}h_8 + \dot{m}_{ORC}h_3$	$\dot{m}_{tf} = \dot{m}_{ORC} + \dot{m}_{VCC}$ $\dot{m}_{tf}h_4 = \dot{m}_{VCC}h_8 + \dot{m}_{ORC}h_3$
Flash Tank		$h_{1a} = yh_{1b} + (1-y)h_{1c}$ $P_i = \sqrt{P_C P_e}$

COP of VCC	$COP_{VCC} = \dot{Q}_{Evap}/\dot{W}_{Comp}$
COP of System	$COP_S = \dot{Q}_{Evap}/\dot{Q}_b$
Thermal efficiency of ORC	$\eta_{ORC} = \frac{\dot{W}_T - \dot{W}_P}{\dot{Q}_b}$
Useful exergy from the system	$\dot{EX}_u = -\dot{Q}_{Evap}\{1 - \left(\frac{T_0}{T_e}\right)\}$
Exergy input to the system	$\dot{EX}_{in} = \dot{Q}_b\{1 - \left(\frac{T_0}{T_b}\right)\}$
Exergetic efficiency of system	$\eta_{ex} = \dot{EX}_u/\dot{EX}_{in}$

3.5. Exergy Definitions and Balances

Exergy is defined as the quantity of theoretically usable work performed by a system in order to establish equilibrium with a certain reference environment determined by its temperature, pressure, and chemical composition, among other things. Because of this, the value of exergy is required to be at least zero, and in no case negative. Exergy is a thermodynamic property that ties a system to the environment in which it operates. The second law of thermodynamics provides an explanation for the production of entropy in a system as a result of irreversibility in the system. With the second rule of thermodynamics in mind, exergy may be considered a wide property of a system that, when paired with the first law, can help in the correct study of an energy system. Whenever an irreversible event takes place, exergy is depleted, and it is only conserved when all of the interactions between the system and its environment are reversible. In this part, we will look at the relationships that are utilised to determine the exergy of each component of the system.

As stated in the table below, just a few theories are taken into consideration in thermodynamic modelling for the thermodynamic study of the recommended systems:

- The system operates in a constant condition.
- Pipes, heat exchangers, and mixers all have low pressure losses.
- When compared to other energy changes, heat losses from the system to the environment are low.
- In comparison to enthalpy changes, kinetic and potential energy changes in the elements are minimal.

3.6. Operating fluids for ORC

3.6.1 Selection criteria of working fluid for ORC

For the Organic Rankine Cycle (ORC) system to operate at peak performance and dependability, the working fluid must be selected carefully. It is essential that working fluids have acceptable thermodynamic characteristics, high temperature stability, are non-toxic and non-corrosive, operate within a tolerable pressure range, and are environmentally benign (ODP, GWP). Based on studies available in the literature, the working fluid was selected based on the results of thermodynamic models that were used to estimate the power production and efficiency associated with various operating fluids. The safety of working fluids, as well as environmental hazards, are critical and essential considerations in the selection of equipment. Consequently, several working fluids from various published literature are studied and evaluated for their thermodynamic performance in the current thesis study. The temperature of the source side and thermodynamic performance play an essential role in the selection of working fluid in the current thesis study.

3.6.2 Commonly used operating fluids for ORC

R600, R602, R245fa are the three working fluids utilized in this modelling experiment. The relevance of employing organic substances (liquids) as working fluids stems from the fact that they have a low evaporation temperature when mixed with steam (water vapour) and have a propensity to convert vapour or superheated vapour when heated at low to medium temperatures.

Table.3.2: Physical, safety and environmental properties of the working fluid

S. No.	Substance	Physical data				Environmental Data		
		Molecular mass (g kmol)	T_{bp} (°C)	T_{crit} (°C)	P_{crit} (MPa)	Atmospheric life time (yr)	ODP	GWP (100 Yr)
1.	R600	58.12	-0.5	152	3.796	0.0 18	0	~20
2.	R245fa	134.05	15.14	154	3.651	7.2	0	1020
3.	R602	86.17	-0.5	234	3.03	0.020	0	~

n.a	=	Non available
T_b	=	Normal boiling temperature
T_{crit}	=	Critical temperature
P_{crit}	=	Critical pressure
ODP	=	Ozone depletion potential (ODP), Related / associated with R11.
GWP	=	Global Warming Potential (GWP), Related / associated with CO_2.

CHAPTER 4

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Overview

In this section, energy, exergy, exergy destruction and cause of several effective parameters on the execution of ORC are described.

4.2. Results and Discussion

The performance of a cycle may now be studied using a computer programme that has been created. Working fluids in the cycle include the refrigerants R245fa and R600. EES software version 9.224-3D was used to predict the characteristics of R245fa and R600, respectively. We have compared R245fa with R600 under same operating parameters for the evaluation of performance of ORC cycle in which we found that energy and exergy efficiency is better in R600. Therefore, we used R600 and R602 as a working fluid in ORC and VCR evaporators cycle due its better environment as well as physical properties.

Table.4.1 Input Data Utilized in the assessment

Parameters	Typical Value	Range
Mass flow rate of working fluid in refrigeration cycle	1 kg/s	
Isentropic Effectiveness of the Compressor	75%	60-90%
Isentropic Effectiveness of the expander	80%	60-90%
Isentropic Effectiveness of the Pump	80%	
ORC Evaporator Temperature	100°C	
VCC Evaporator Temperature	0°C	-15°C to 15°C
Condenser Temperature	35°C	25°C to 50°C

Table 4.2: Initial Parameters of Refrigerant

	Refrigerant	(K)	(MPa)
1	R245fa	427.13	3.65
2	R600	425.1	3.8
3	R602	507.1	3.65

As a result of decreased requirements for both Q b and Pump, R602 has superior system performance than R600. R602 is a suitable operating fluid for ORC-VCR systems because of its energetic and exergetic analysis. At Tb of 100 °C, Table 3 shows that R602 has the lowest pressure in the system, at 0.2463 MPa, compared to R601 at the same temperature. As a result, R602 as a working fluid result in a reduced total investment in the system.

Where ,

COP_S = Coefficient of performance

ETA_D = exergetic efficiency

T[4] = T[5] = condenser temperature

T[1] = evaporator temperature

Table 4.3: Performance of COP with Condenser Temperature using Refrigerants

R602			**R600**			**R245fa**		
COP_s [C]	T[4]	ETA_D	T[4] [C]	COP_s	ETA_D	T[4] [C]	COP_s	ETA_D
0.9789	25	44.89	25	0.98	47.01	25	0.9777	46.14
0.7511	30	37.54	30	0.7511	39.4	30	0.7493	38.63
0.5894	35	32.27	35	0.5886	33.93	35	0.587	33.24
0.469	40	28.29	40	0.4675	29.8	40	0.4662	29.16
0.3762	45	25.16	45	0.3742	26.57	45	0.3729	25.96
0.3026	50	22.64	50	0.3003	23.95	50	0.2991	23.37

Table 4.4: Performance of COP with Evaporator Temperature using Refrigerants

R602			**R600**			**R245fa**		
T[1] [C]	COP_s	ETA_D	T[1]	COP_s	ETA_D	T[1]	COP_s	ETA_D
-15	0.3632	33.66	-15	0.3644	35.57	-15	0.3627	34.77
-10	0.4217	33.55	-10	0.4223	35.37	-10	0.4206	34.61
-5	0.495	33.12	-5	0.4949	34.87	-5	0.4933	34.14
0	0.5894	32.27	0	0.5886	33.93	0	0.587	33.24
5	0.7156	30.78	5	0.7139	32.33	5	0.7123	31.69
10	0.8924	28.28	10	0.8898	29.69	10	0.8882	29.11
15	1.158	24.04	15	1.154	25.23	15	1.152	24.74

Table 4.5: Performance of COP with exergetic efficiency using Refrigerants

R602			R600			R245fa		
eta_T	COP_s	ETA_D	eta_T	COP_s	ETA_D	eta_T	COP_s	ETA_D
0.6	0.4421	24.2	0.6	0.4414	25.45	0.6	0.4403	24.93
0.65	0.4789	26.22	0.65	0.4782	27.57	0.65	0.477	27.01
0.7	0.5157	28.24	0.7	0.515	29.69	0.7	0.5136	29.08
0.75	0.5526	30.25	0.75	0.5518	31.81	0.75	0.5503	31.16
0.8	0.5894	32.27	0.8	0.5886	33.93	0.8	0.587	33.24
0.85	0.6262	34.29	0.85	0.6254	36.05	0.85	0.6237	35.32
0.9	0.6631	36.3	0.9	0.6622	38.17	0.9	0.6604	37.39

Table 4.6: Exergetic efficiency of Compressor using Refrigerants

R602			R600			R245fa		
eta_comp	COP_s	ETA_D	eta_comp	COP_s	ETA_D	eta_comp	COP_s	ETA_D
0.6	0.4715	25.82	0.6	0.4709	27.14	0.6	0.4696	26.59
0.65	0.5108	27.97	0.65	0.5101	29.41	0.65	0.5087	28.81
0.7	0.5501	30.12	0.7	0.5493	31.67	0.7	0.5479	31.02
0.75	0.5894	32.27	0.75	0.5886	33.93	0.75	0.587	33.24
0.8	0.6287	34.42	0.8	0.6278	36.19	0.8	0.6262	35.45
0.85	0.668	36.57	0.85	0.6671	38.45	0.85	0.6653	37.67
0.9	0.7073	38.72	0.9	0.7063	40.72	0.9	0.7044	39.89

4.3 Study Of Flash Tank Vapour Compression Refrigeration Cycle

Analysis of Energy efficiency of modified Vapour compression refrigeration cycle, table shows the refrigerant performance at every component.

Table 4.7: COP at evaporator Temperature in modified design cycle

R602			R600			R245fa		
T[1]	COP_s	eta_D	T[1]	COP_s	eta_D	T[1]	COP_s	eta_D
-15	0.4001	30.85	-15	0.4036	31.12	-15	0.4022	31.01
-10	0.4588	30.36	-10	0.4622	30.59	-10	0.4609	30.51
-5	0.5322	29.63	-5	0.5356	29.82	-5	0.5343	29.75

0	0.6268	28.55	0	0.6302	28.7	0	0.6288	28.64
5	0.7531	26.95	5	0.7565	27.07	5	0.755	27.01
10	0.9302	24.52	10	0.9337	24.61	10	0.9319	24.56
15	1.196	20.65	15	1.2	20.72	15	1.197	20.68

Table 4.8: COP with condenser temperature in modified design cycle

R602			**R600**			**R245fa**		
T[5]	COP_s	eta_D	T[5]	COP_s	eta_D	T[5]	COP_s	eta_D
25	1.019	46.43	25	1.026	46.71	25	1.023	46.59
30	0.7901	35.99	30	0.7946	36.19	30	0.7929	36.11
35	0.6268	28.55	35	0.6302	28.7	35	0.6288	28.64
40	0.5047	22.99	40	0.5072	23.1	40	0.5061	23.05
45	0.4101	18.68	45	0.4119	18.76	45	0.411	18.72
50	0.3346	15.24	50	0.336	15.3	50	0.3351	15.26

Table 4.9: COP with Compressor Efficiency in modified design cycle

R602			**R600**			**R245fa**		
eta_comp	COP_s	eta_D	eta_comp	COP_s	eta_D	eta_comp	COP_s	eta_D
0.6	0.559	25.46	0.6	0.5613	25.57	0.6	0.5604	25.52
0.65	0.5832	26.56	0.65	0.5859	26.69	0.65	0.5848	26.64
0.7	0.6057	27.59	0.7	0.6088	27.73	0.7	0.6076	27.67
0.75	0.6268	28.55	0.75	0.6302	28.7	0.75	0.6288	28.64
0.8	0.6466	29.45	0.8	0.6501	29.61	0.8	0.6487	29.54
0.85	0.6652	30.3	0.85	0.6688	30.46	0.85	0.6672	30.39
0.9	0.6828	31.1	0.9	0.6865	31.26	0.9	0.6847	31.18

Table 4.10: COP with Energy Efficiency in modified design cycle

R602			**R600**			**R245fa**		
eta_T	COP_s	eta_D	eta_T	COP_s	eta_D	eta_T	COP_s	eta_D
0.6	0.4701	21.41	0.6	0.4726	21.53	0.6	0.4716	21.48
0.65	0.5093	23.19	0.65	0.512	23.32	0.65	0.5109	23.27
0.7	0.5485	24.98	0.7	0.5514	25.11	0.7	0.5502	25.06
0.75	0.5876	26.76	0.75	0.5908	26.91	0.75	0.5895	26.85
0.8	0.6268	28.55	0.8	0.6302	28.7	0.8	0.6288	28.64
0.85	0.666	30.33	0.85	0.6696	30.49	0.85	0.6681	30.43
0.9	0.7052	32.12	0.9	0.709	32.29	0.9	0.7074	32.22

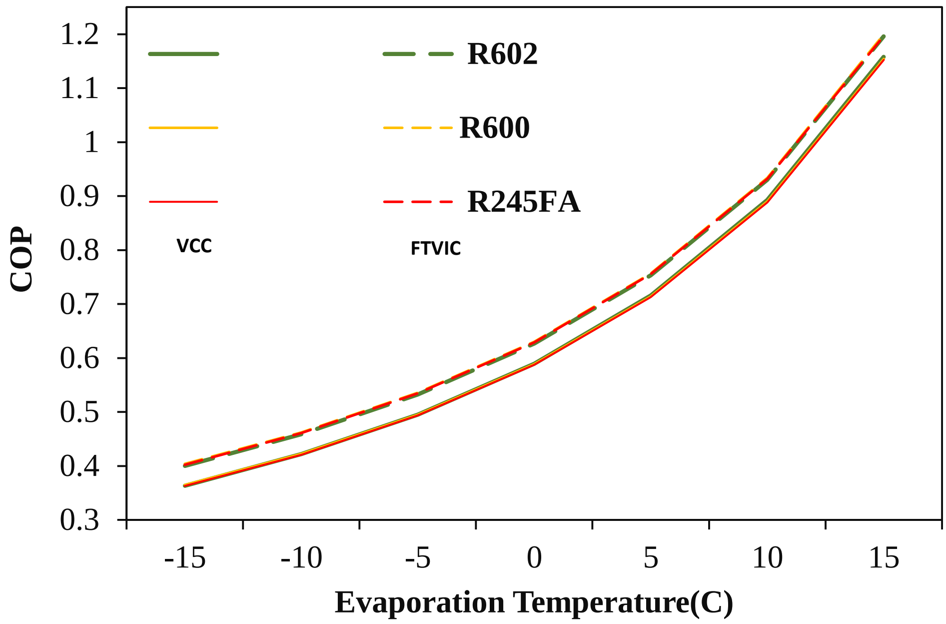

Figure 4.1: COP Performance with Evaporation temperature

As the temperature of evaporation rises, the coefficient of performance (COP) rises as well. For FTVCR, R602 has the highest police value. With a rise in T1, the expander power, WT, increases. Overall specific compressor work is unaffected by T1, nevertheless, the combined power of the compressor and expander is the same (WT). mass flow rate and the total specific compressor work. As a result, raises MVCR in direct proportion to WC, resulting in higher COPs. The system's useful exergy output increases, resulting in a rise in ex. The R602 has the highest COPs and ex.

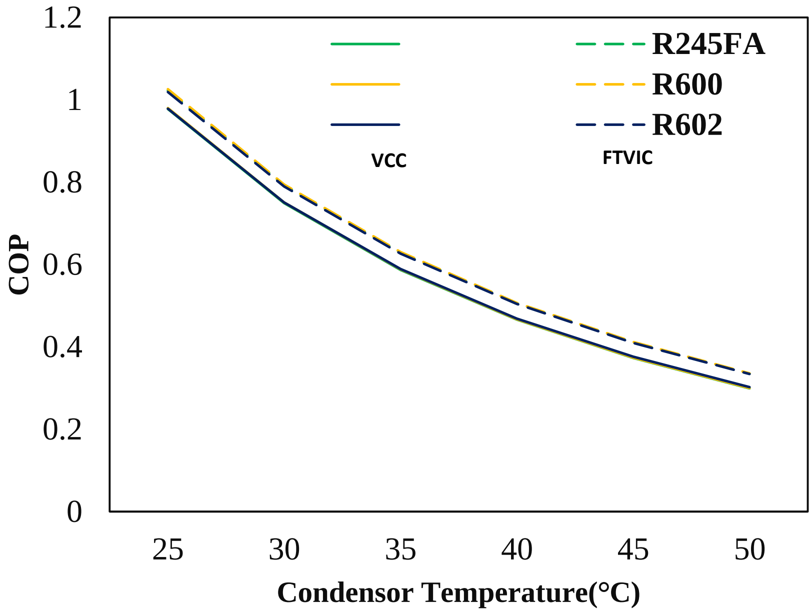

Figure 4.2: COP Performance with Condensor temperature

Figure 4.2 shows the COPs and ηoex, for all the HC fluids reduce with the growth in Tc. So, it shows the Condenser temperature dependent on the COP.

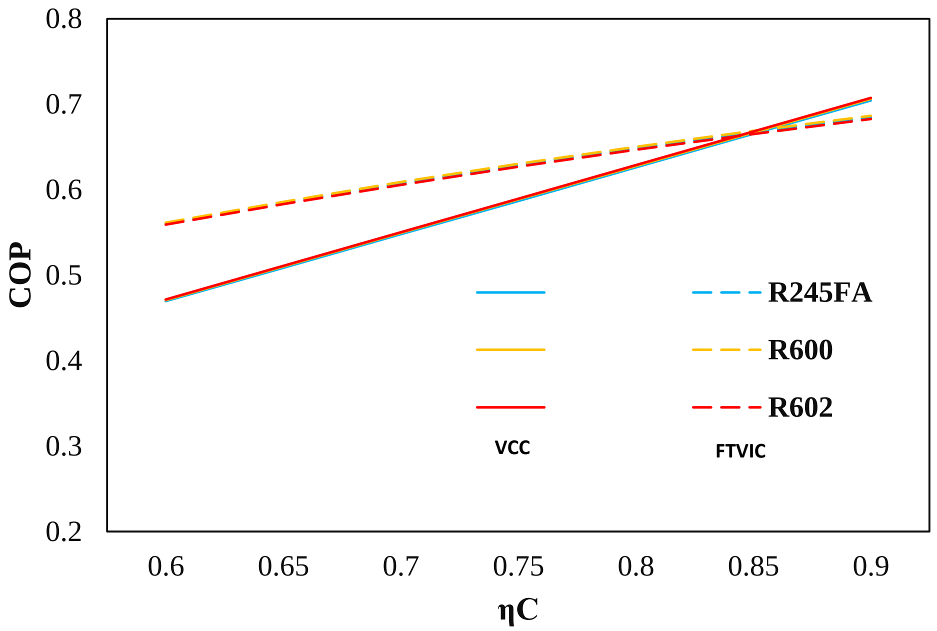

Figure 4.3: COP Performance with Efficiency of compressor

Figure 4.3 shows the growth in ηc leads to a reduction in ˙that increases COPs and ηoex. When it comes to COPs, R602 in an ftvcr system is the ideal fluid out of all those studied, ηoex for all values of ηc.

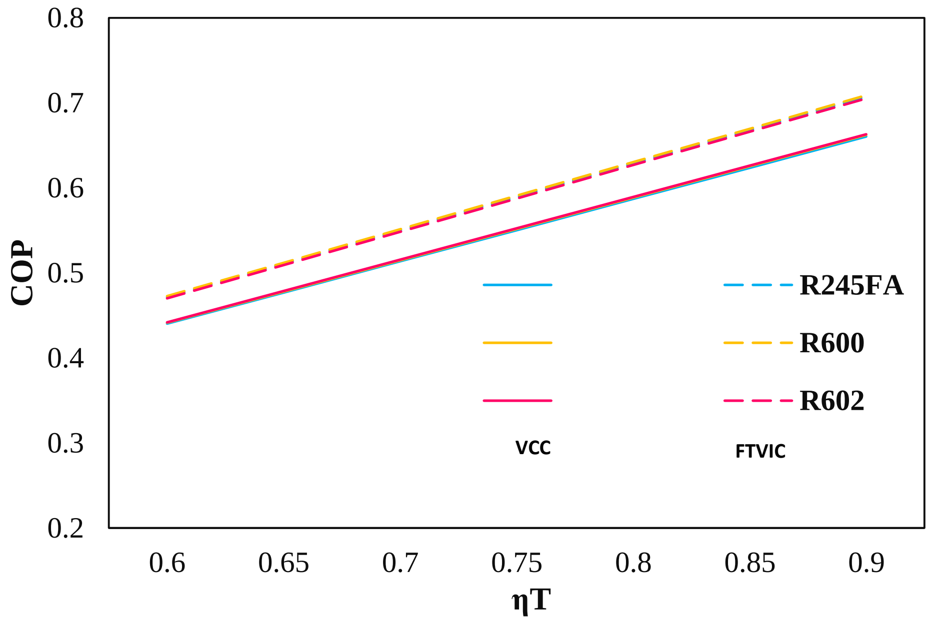

Figure 4.4: COP Performance with Efficiency of Condenser

For all fluids, the COPs and oex rise as t increases from 0.6 to 0.9, as shown in Figure 4.4. It should be noted that it has no effect on the FTVCR subsystem, hence the overall specific compressor work out is unaffected. Based on COPs and oex, R602 performs somewhat better in the FTVCR cycle than other fluids.

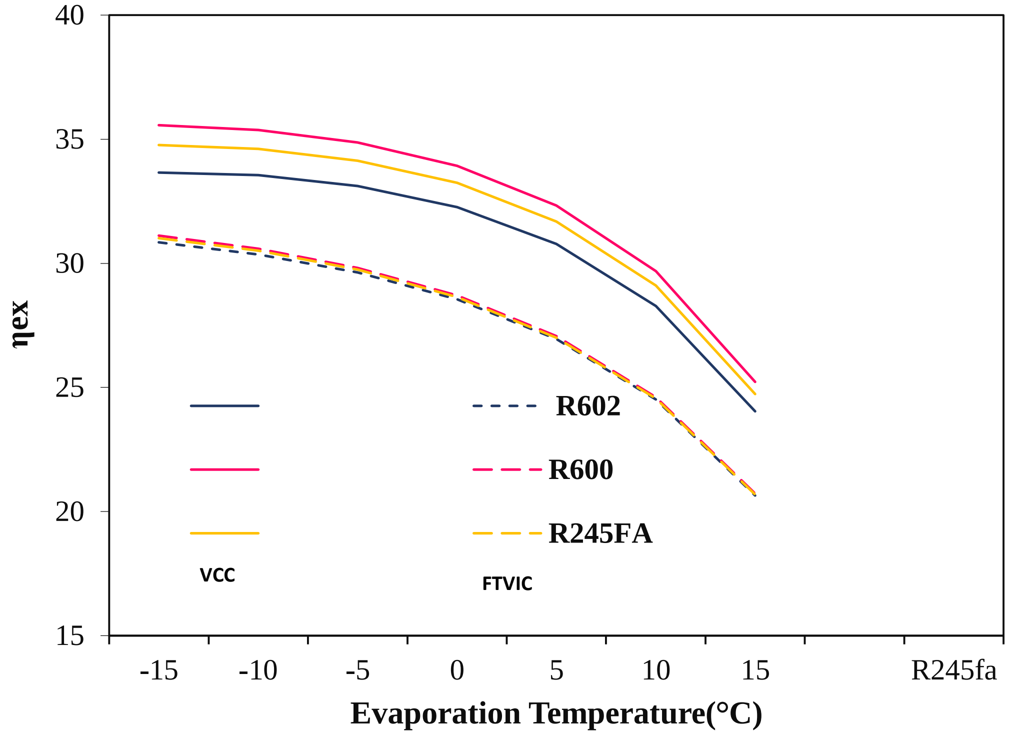

Figure 4.5: COP Performance with Evaporation Temperature

COPs are influenced favourably by evaporator variation, but ex is negatively influenced by evaporator variation for all fluids, as seen in Figure 4.5. As the temperature of T6 increases from 258 to 288 K, the evaporator pressure, Pve, increases. Because the condenser pressure, P_{cond}, remains constant for a given quantity of condenser saturated vapour temperature, Tc, this leads in a decrease in the temperature of the condenser saturated vapour. Finally, as a result of the decrease in, there is an increase in and ultimately, a decrease in COPs. The system's useable exergy production, on the other hand, reduces with T1 and hence the growth in T1 results in a reduction of ηoex.

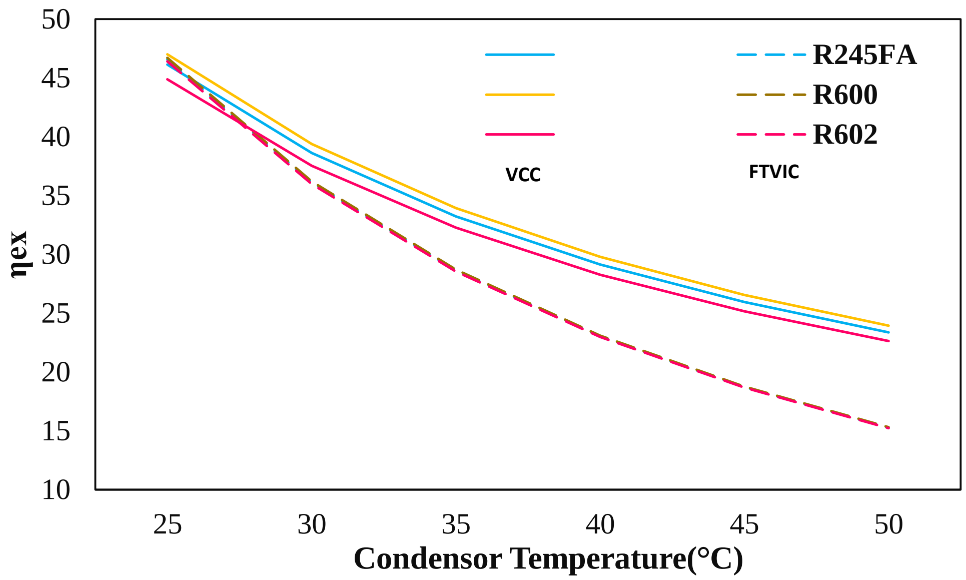

Figure 4.6: Exergy Efficiency with Condenser Temperature

Figure 4.6 shows the condenser temperature decreases with all refrigerants in process of normal VCC cycle and in modified cycle it shows more decrement in R602 in FTVIC process.

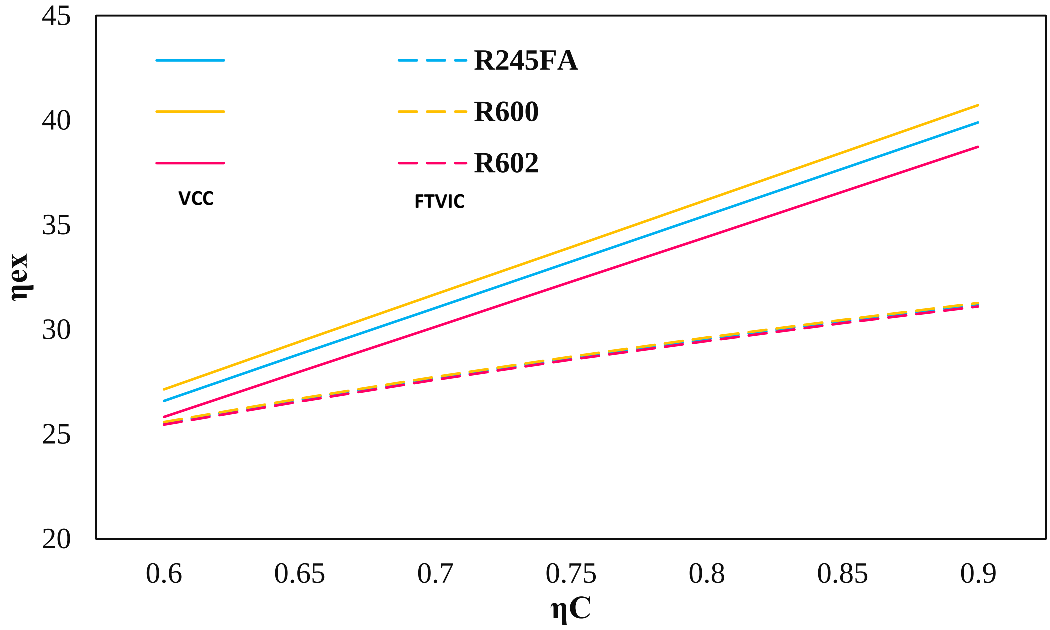

Figure 4.7: Exergy Efficiency with Condenser Efficiency

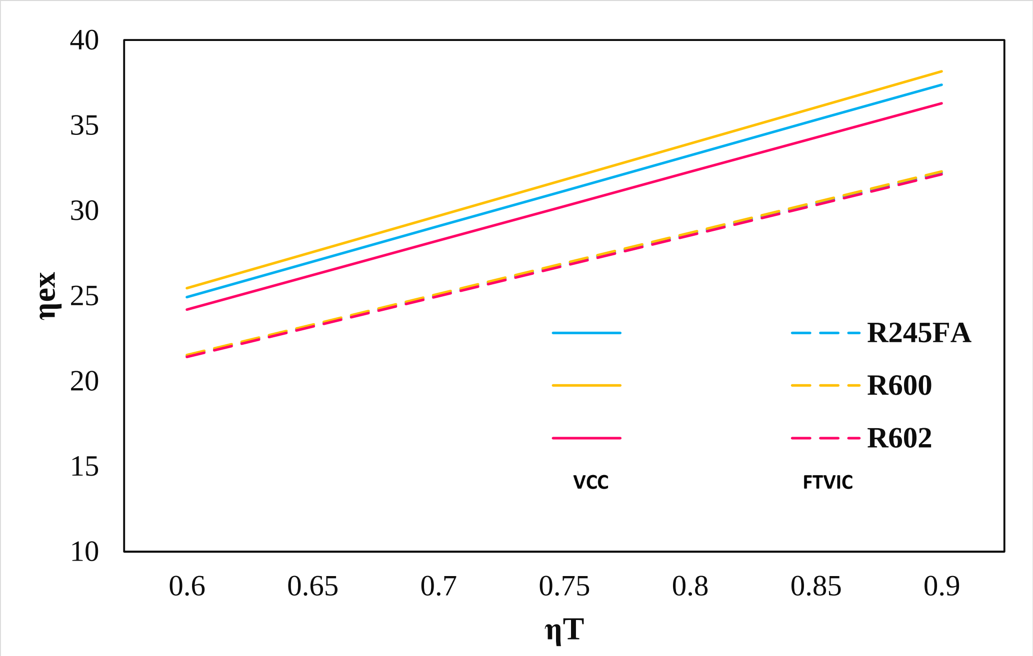

Figure 4.8: Exergy Efficiency with Evaporator Efficiency

Figure shows the comparison of fluid with R 602 fluid, we can see that **ηT** increases with decrement of η_{ex}.

4.4. Using ORC Evaporator

Table 4.11: Exergy Efficiency of ORC cycle with Refrigerant R600

R600	
COMPONENTS	**EXERGY DESTRUCTION**
ORC Evaporator	15.21
COMPRESSOR	14.32
CONDENSER	29.13
Expansion Valve	5.901
VCC Evaporator	54.9
Mixer	0.28
Pump	0.606
ORC Expander	13.72

Table 4.12: Exergy Efficiency of ORC cycle with Refrigerant R245fa

R245fa	
COMPONENTS	**EXERGY DESTRUCTION**
ORC Evaporator	8.204
COMPRESSOR	7.51
CONDENSER	15.31
Expansion Valve	3.093
VCC Evaporator	28.94
Mixer	0.1167
Pump	0.2314
ORC Expander	7.218

Table 4.13: Exergy Efficiency of ORC cycle with Refrigerant R245fa

R602	
COMPONENTS	**EXERGY DESTRUCTION**
ORC Evaporator	13.1
COMPRESSOR	14.13
CONDENSER	40.26
Expansion Valve	5.379
VCC Evaporator	54.57
Mixer	1.156
Pump	0.08535
ORC Expander	12.96

4.5. Exergy Efficiency Analysis with FTVCR modified Design

In this section we describe the efficiency of Exergy with modified FTVCR design, from we can optimize the variations in fluids as per different component of modified designed system cycle of compression system.

Table 4.14: Exergy Efficiency of ORC cycle with Refrigerant R600

FTVCR	
R600	
COMPONENTS	**EXERGY DESTRUCTION**
ORC Evaporator	20
COMPRESSOR 1	6.599
COMPRESSOR 2	7.351
CONDENSER	13.29
VCC Evaporator	27.64
Expansion Valve1	1.725
Expansion Valve 2	1.201
Flash tank	0
Mixer	0.2737
Pump	0.2576
ORC Expander	13

Table 4.15: Exergy Efficiency of ORC cycle with Refrigerant R602

R602	
COMPONENTS	**EXERGY DESTRUCTION**
ORC Evaporator	19
COMPRESSOR 1	6.487
COMPRESSOR 2	7.327
CONDENSER	12.95
VCC Evaporator	27.47
Expansion Valve1	1.448
Expansion Valve 2	1.074
Flash tank	0
Mixer	1.124
Pump	0.03607
ORC Expander	12.32

Table 4.16: Exergy Efficiency of ORC cycle with Refrigerant R245fa

R245fa	
COMPONENTS	**EXERGY DESTRUCTION**
ORC Evaporator	12.88
COMPRESSOR 1	3.438
COMPRESSOR 2	3.862
CONDENSER	10.95
VCC Evaporator	14.55
Expansion Valve1	0.882
Expansion Valve 2	0.6071
Flash tank	0
Mixer	0.1168
Pump	0.09783
ORC Expander	6.83

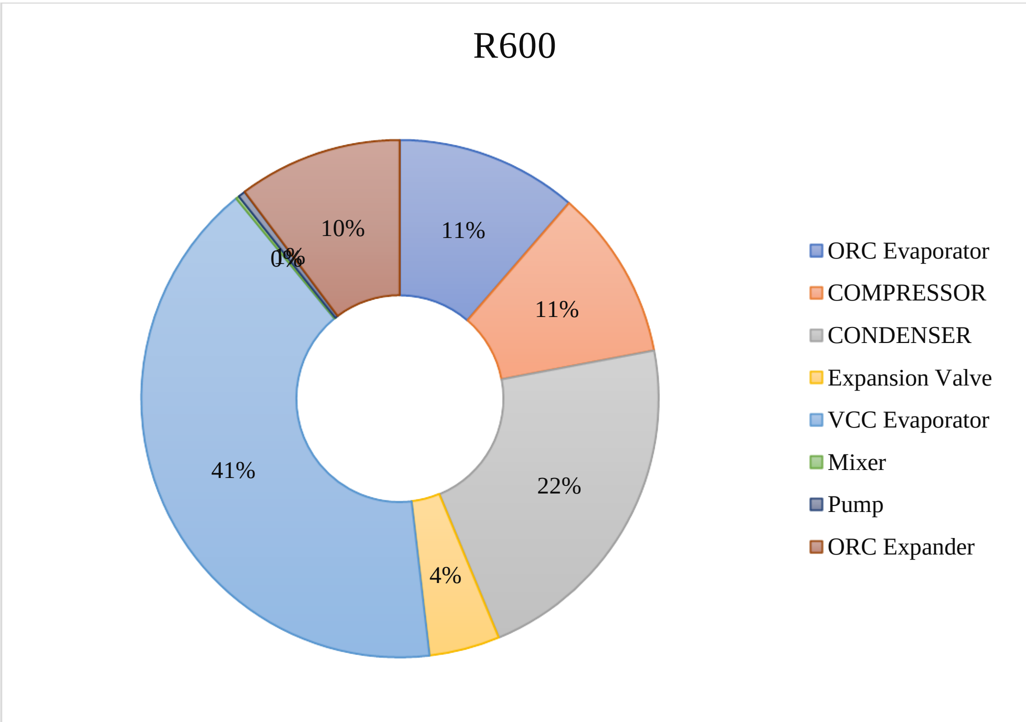

Figure 4.9: Comparison of Exergy Efficiency percentage of components with R600

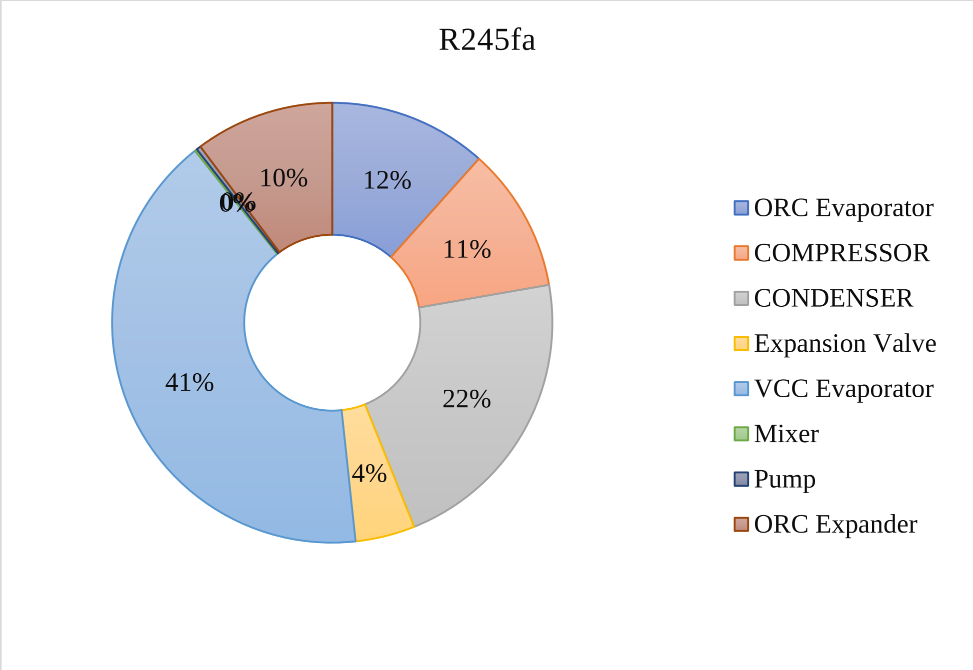

Figure 4.10: Comparison of Exergy Efficiency percentage of components with R245fa

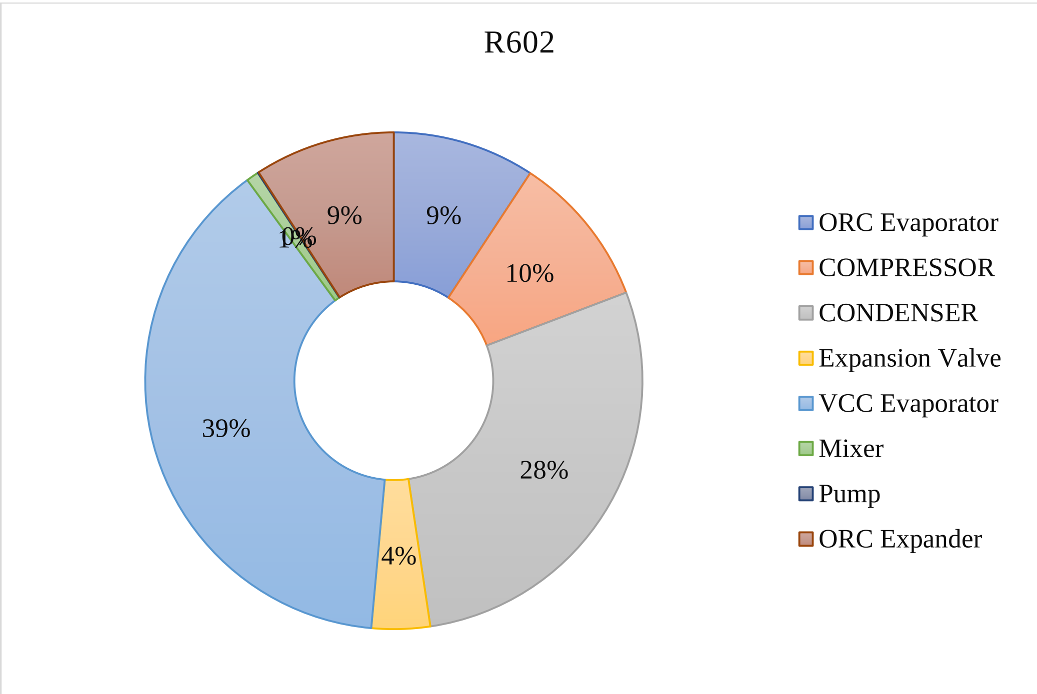

Figure 4.11: Comparison of Exergy Efficiency percentage of components with R602

4.6. OCR-VCR Modified Designed cycle

In this section we are analysing exergy efficiency with all components in modified design cycle for optimizing better performance in vapour compression system compare to previous design.

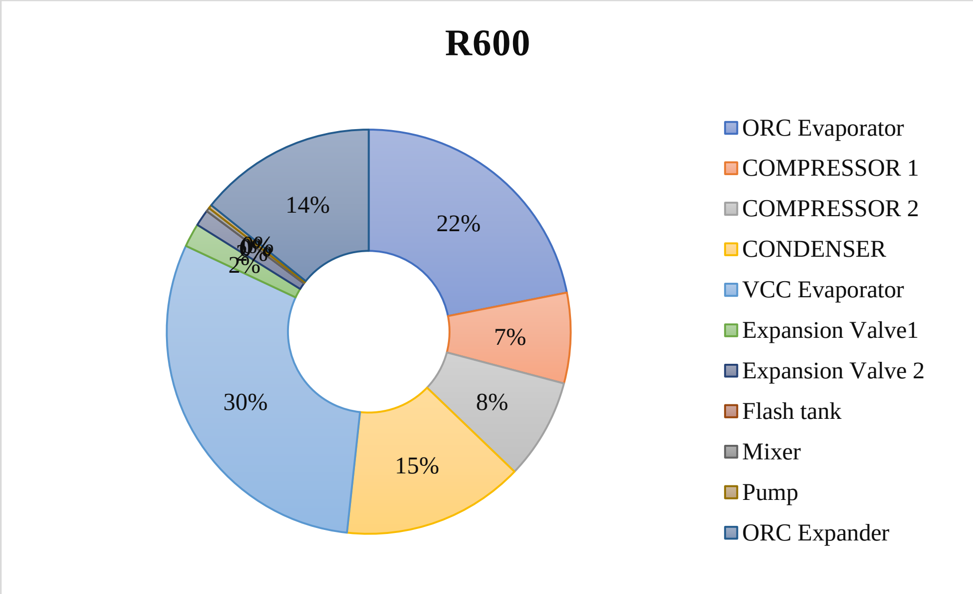

Figure 4.12: Comparison of Exergy Efficiency in modified design cycle with R600

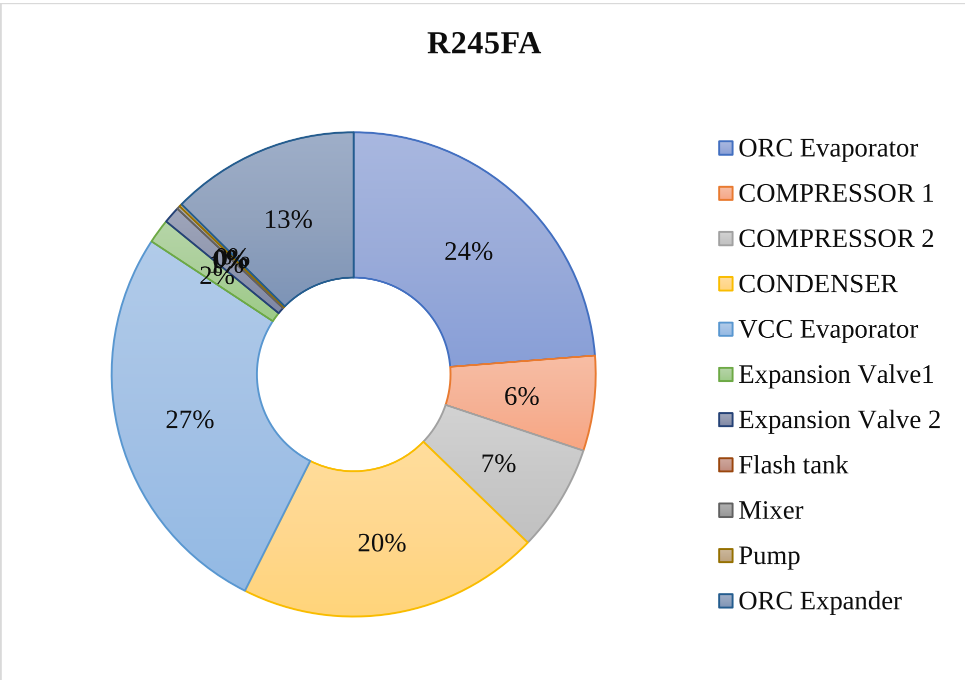

Figure 4.13: Comparison of Exergy Efficiency in modified design cycle with R600

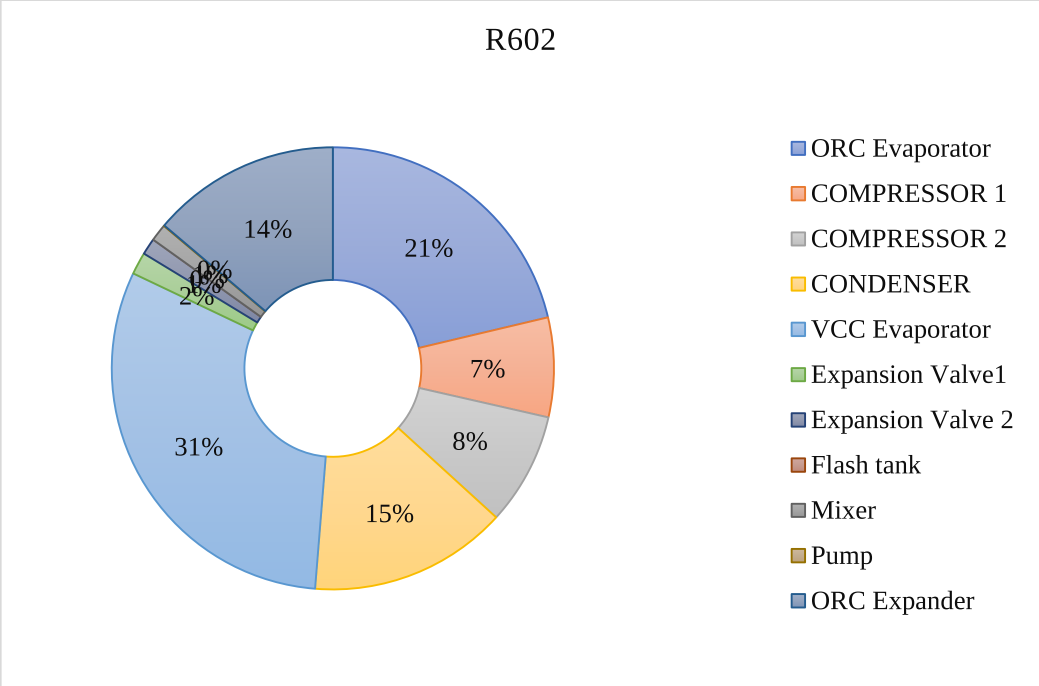

Figure 4.14: Comparison of Exergy Efficiency in modified design cycle with R602

CHAPTER 5

CONCLUSION

CHAPTER 5

CONCLUSION

5.1. Conclusion

The ORC for the generation of energy is explored in this study, employing R245fa and R600 and R602 as working fluids, respectively. The cycle's performance was evaluated by running a simulation. Same operating conditions provide a 10.59 percent energy efficiency and an 11.33 percent exergy efficiency. Heliostat field, central receiver (CR), HRVG, and condenser are the places where greatest exergy losses occur (extensive destruction of exergy).

The major conclusions during parametric analysis of ORC by using first and second law approach are as follow:

- With increase in turbine inlet pressure (1580-2380 KPa), energy (9.74%-11.3%) and exergy (10.43%-12.10%) efficiency both increases with R600 as a working fluid.
- With increase in turbine back pressure (180-260 KPa), energy (11.62%-9.802%) and exergy (12.44%-10.50%) efficiency both decreases with R600 as a working fluid.
- With increase in condenser temperature (25-33 oC) energy (10.41%-10.77%) and exergy (11.15%-11.54%) efficiency both increases with R600 as a working fluid.
- It is clearly obtained from results that R600 is a better fluid as compared to R245fa for operation of proposed ORC for production of power.
- The ODP of R600 is very less as compared to R245fa.
- The energy efficiency 10.59% and exergy efficiency is 11.33% of R600 which is greater than R245fa.
- R600 offers better performance as compared to R245fa at same operating conditions.

5.2 Recommendation for future work

For designing any thermodynamic system, cost analysis is an extremely important factor. System should be designed in such a way that it should be most economical. For that purpose, thermo economic analysis is proposed for future work.

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