THERMODYNAMIC ANALYSIS OF VAPOR ABSORPTION REFRIGERATION SYSTEM USING LOW-GRADE HEAT RECOVERY SYSTEM

Capstone Project Report Submitted in Partial Fulfilment for the Award of the Degree of

BACHELOR OF TECHNOLOGY

In

MECHANICAL ENGINEERING

Submitted By

Ayush Sharma (18SCME1010009)

Kshitij Kashyap (18SCME1010043)

In

Department of Mechanical Engineering

Galgotias University, Greater Noida

Under the Supervision of

Dr. K.K. Dubey

Associate Professor, D/O Mechanical Engineering

Galgotias University, Greater Noida

May 2021-2022

DEPARTMENT OF MECHANICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this project report entitled **"THERMODYNAMIC ANALYSIS OF VAPOR ABSORPTION REFRIGERATION SYSTEM USING LOW-GRADE HEAT RECOVERY SYSTEM"** submitted to **DOME, Galgotias University, Greater Noida**, is a bonafide record of work done by **"Ayush Sharma (18SCME1010009) & Kshitij Kashyap (18SCME1010043)"** under my supervision from **"17/07/2021" to "25/05/2022".**

Project Guide

____

Dean

____

Date: ____________

Place: __________

DECLARATION

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Student Name & Signature

____

____

Date: - ________________

APPROVAL SHEET

This thesis/dissertation/project report entitled titled **THERMODYNAMIC ANALYSIS OF VAPOR ABSORPTION REFRIGERATION SYSTEM USING LOW-GRADE HEAT RECOVERY SYSTEM** by **AYUSH SHARMA - 18SCME1010009, KSHITIJ KASHYAP – 18SCME1010043** approved for the degree of Bachelor of Technology in Mechanical Engineering.

Examiners

____

Project Guide

____

Dean

____

Date: - __________

Place: ___________

GALGOTIAS
UNIVERSITY

Statement of Project Report Preparation

1. Project report title: “THERMODYNAMIC ANALYSIS OF VAPOR ABSORPTION REFRIGERATION SYSTEM USING LOW-GRADE HEAT RECOVERY SYSTEM”.
2. Degree for which the report is submitted: BACHELOR DEGREE OF TECHNOLOGY.
3. Project Supervisor was referred to for preparing the report.
4. Specifications regarding the thesis format have been closely followed.
5. The contents of the thesis have been organized based on the guidelines.
6. The report has been prepared without resorting to plagiarism.
7. All sources used have been cited appropriately.
8. The report has not been submitted elsewhere for a degree.

(Signature of the student)

Name: Ayush Sharma

Enrollment No: 18021011943

GALGOTIAS
UNIVERSITY

Statement of Project Report Preparation

1. Project report title: “THERMODYNAMIC ANALYSIS OF VAPOR ABSORPTION REFRIGERATION SYSTEM USING LOW-GRADE HEAT RECOVERY SYSTEM”.
2. Degree for which the report is submitted: BACHELOR DEGREE OF TECHNOLOGY.
3. Project Supervisor was referred to for preparing the report.
4. Specifications regarding thesis format have been closely followed.
5. The contents of the thesis have been organized based on the guidelines.
6. The report has been prepared without resorting to plagiarism.
7. All sources used have been cited appropriately.
8. The report has not been submitted elsewhere for a degree.

(Signature of the student)

Name: Kshitij Kashyap

Enrollment No: 18021011972

ACKNOWLEDGEMENT

I have taken efforts in this project. However, it would not have been possible without the kind support and help of many individuals and organizations. I would like to extend my sincere thanks to all of them.

I am highly indebted to Dr. P.K.S. NAIN (DEAN D.O.M.E., G.U.) for providing all support and guidance being as head of the department during my academic progress.

I am highly obliged to Dr. K.K Dubey (Associate Professor D.O.M.E., G.U.) for their guidance and constant supervision as well as for providing necessary information regarding the project & also for their support in completing the project.

My thanks and appreciations also go to my colleague in developing the project and the people who have willingly helped me out with their abilities.

AYUSH SHARMA (18SCME1010009)

KSHITIJ KASHYAP (18SCME1010043)

(DOME, GALGOTIAS UNIVERSITY)

GALGOTIAS
UNIVERSITY

Abstract

Fossil fuel-based power plants generate more than 65 percent of total energy generation. As a result of this situation, the cooling sector consumes more than 40% of total energy output. The importance of new refrigerant trends for alternative cooling systems is discussed in this paper. Low operating expenses and an effective cooling process are all advantages of using energy-efficient refrigerant ingredients.

VARS (Vapor absorption refrigeration system) is a well-known cooling technology that uses low-grade heat energy sources and has no harmful side effects. In the research of cooling machine performance, the coefficient of performance is an important parameter. The maximum and minimum limits of the coefficient of performance (COP) of absorption cooling cycles are defined using the fundamental laws of energy and entropy formation. It is investigated the thermodynamics of a LiBr–H2O–based absorption refrigerator with a cooling capacity of 5TR. The principal heat source for operation is the VARS generator, which has a considerable impact on the COP.

Keywords: - ODP, GWP, Tri-generation Systems, Absorbents, Absorption, Energy Performance Ratio.

Table of Contents

List of Abbreviations

CCHP stands for Combined Cooling, Heating, and Power.

CHP stands for Combined Heat and Power.

CHRP stands for Combined Heat and Refrigeration Power.

CFC stands for Chlorofluorocarbon.

GWP stands for Global Warming Potential.

IWH stands for Industrial Waste Heat.

KCS (Kalina Cycle System) is an acronym for "Kalina Cycle System".

ORC stands for Organic Rankine Cycle.

ODP (Ozone Depletion Potential) is a term used to describe the potential for ozone depletion.

TEC stands for Thermo Electric Cooling.

Qref – Evaporator Heat

Qgen – Generator Heat

Qabs – Absorber Heat

Qhex – Heat Exchanger heat

Qcond – Condenser Heat

Ta – Absorber Temperature

Tg – Generator Temperature

Te – Evaporator Temperature

Tc – Condenser Temperature

List of Tables

List of Figures

CHAPTER – 1

INTRODUCTION

The additional power consumption from industry and household cooling demand (600 TWh/yr) is expected to absorb more than half of the entire generation. Increased electricity use would put a lot of strain on countries’ power grids. The rise of HVACs causes environmental difficulties due to the GHG emissions emitted during the production of energy needed to power HVACs, as well as the refrigerants used in their systems. CFC and HFC refrigerants are used in mechanical compression-based cooling systems; these types of cooling materials have a significant influence on the environment in terms of ozone layer depletion and global warming. The potential for heat re-use of discarded heat from industry, such as refineries, steel mills, and power plants, is enormous with new age cooling materials. The use of dumping heat recovery systems for combined heating, cooling, and power generation, as well as the use of new refrigerant trends.

Refrigeration technologies have become more important in recent advances in thermal engineering in today's industrial applications, but significantly raising the COP of these refrigeration systems has always been a challenge for academics. Because they are both vapour cycles, the vapour absorption refrigeration system is comparable to the vapour adsorption refrigeration system. Unlike steam adsorption refrigeration, absorption refrigeration requires heat as an energy source. As a result, thermal drive or thermal energy drive systems are widely used to describe these systems. Heat is removed by evaporating the refrigerant at low pressure in both the vapour absorption and adsorption refrigeration cycles, and heat is removed by condensing the refrigerant at higher pressures in both. The main distinction is that the vapour adsorption system uses a mechanical compressor to create the pressure difference needed to circulate the refrigerant, whereas the absorption system relies on heat. The absorption system works with little or no effort because of this difference, but the energy must be delivered in the form of heat. If low-cost heat sources such as solar heat, electricity, and waste heat from heat are available, the system becomes more appealing.

Vapor Absorption Systems have a number of benefits, including the capacity to create cooling using any form of low-grade, low-cost heat energy, resulting in significant cost savings. It can run on steam or any other waste heat source instead of pricey and unstable electric power. Because there are no moving parts, the system is silent, vibration-free, and trouble-free to use. Furthermore, maintenance costs are low when compared to power-driven mechanical devices. To provide the cooling effect, a pure refrigerant is employed instead of ozone-depleting chlorine-based compounds.

The current thesis examines several cooling materials in terms of environmental safety, future refrigerant, ultra-cooling achievement, commercial application in all aspects, and enormous plant rejected heat utilization. In addition, an energy study of a LiBr–H2O based absorption refrigerator with a refrigeration effect of 5TR in which the VARS generator is the primary heat source for operation and its significant impact on VARS performance is calculated, as well as the influence of generator temperature (T_ gen) on VARS performance. The data show that the cooling machine’s COP increases as T_ gen increase, but that it drops after 100°C (343°K). For optimal COP values, the operational T_gen must shut off the generator temperature.

CHAPTER -2

LITERATURE REVIEW

Present literature work explain recent research and development of alternative and eco-friendly refrigeration system. The significant research work on all types of refrigerants has been discussed in same chapter in terms of Alternative refrigerants future, Commercialization of refrigerants and its technological implementation.

Won and Lee compared a double-effect absorption cooling cycle utilising a new working pair of H_2O-LiCl to a cycle using the traditional H_2O-LiBr solution. The use of H_2O-LiCl created better system performance than the H_2O-LiBr mixture, according to the findings. Won et al. conducted a simulation analysis on a double-effect absorption cooling cycle using a ternary mixture of H_2O-LiBr-LiSCN and compared the system COP when two other pairs, H_2O-LiBr and H_2O-LiCl, were used.

According to the scientists, the system that employed the H_2O-LiBr-LiScN solution performed better than those that used H_2O-LiBr and H_2O-LiCl individually. The COP of the system improved by 3% when compared to the system using H_2O-LiBr, according to the findings. Lee et al. presented a quintuple mixture of H_2O-LiBr-$LiNO_3$-LiI-LiCl as the solution in a double-effect absorption system in a serious flow scheme (mole ratio of LiBr:$LiNO_3$:LiI:LiCl = 5:1:1:2). Using this recommended method, no crystallisation issues were detected in the air-cooled absorption equipment.

The authors noted how using renewable energies to operate refrigeration systems (e.g., waste heat from industrial processes, wind, and solar energy) has become a more intriguing subject of research in recent years due to their long-term and abundant availability.

Iyoki and Uemura used a ternary mixture of H_2O-LiBr-$LiNO_3$ as a better performing and less corrosive working fluid pair than the traditional binary mixture of H_2O-LiBr.

In an experimental study, Cai et al. studied the efficiency of a single-effect absorption machine cooled with air. NH_3–$LiNO_3$ and NH_3–NaSCN were the two types of working pairings we used. The COP values produced with NH_3–NaSCN ranged from 0.20 to 0.35, which were greater than those obtained with NH_3–$LiNO_3$ under similar conditions. The findings of this study's tests were crucial in the creation of a superior NH3–salt absorption refrigeration system. Patel and his associates

Yang et al. used a mixture of 20 different types of nanoparticles and 10 different types of dispersants to evaluate the diffusion stability of interruption in the NH3-H2O absorption system.

According to the authors, low-grade heat sources (such as engine exhaust) and renewable energy sources can be used to power absorption refrigeration systems (e.g., solar energy). As a result, the system is very effective in reducing CO2 emissions and very promising in terms of energy savings.

Absorption refrigeration systems account for over 60% of all thermally driven refrigeration systems deployed in Europe, according to Henning. Some of the advantages of absorption refrigeration systems are as follows:

1. Absorption refrigeration uses environmentally friendly refrigerants such as water, which have a low impact on the ozone layer and global warming;
2. Because there are few high-speed moving parts in absorption refrigeration systems, they are quiet. This also makes their upkeep low-cost and straightforward.
3. Absorption refrigeration systems can recover heat from virtually any system.
4. An absorption refrigeration system produces minimal cycling loss during on-off operation, which is known to produce a lot of waste heat with traditional VCRSs;
5. Absorption refrigeration systems have a 20–30-year life expectancy.

CHAPTER -3

METHODOLOGY

The present chapter discusses the methods used for the proposed project on Libr H2o-based cooling techniques for heat recovery purposes. The following steps have been implemented for completion of the current project work

1. Complete state of art Literature work on alternative cooling systems and refrigerants.
    - Review of all cooling systems and novel heat recovery thermodynamic systems
    - Review refrigerants in terms of alternative refrigerants, eco-friendly refrigerants, and commercialization.
    - Review on Vapor Absorption Refrigeration cooling system
2. Detail Discussion of Libr -H2O Vapor Absorption Refrigeration system and its layout.
3. Mathematical modeling of Vapor Absorption Refrigeration system.
4. Data Collection of Vapor Absorption Refrigeration as per latest research publications.
5. Thermodynamic Analysis
6. Result and Conclusion
7. Publications

CHAPTER -4

THERMODYNAMIC MODELS

Under the heading of thermodynamic models, we will discuss about Different Cooling Techniques, Waste Energy Recovery Thermal System, and Alternative Cooling Materials.

- **Different Cooling Techniques**
    1. Mechanical Compression Refrigeration System (VCRS)
    2. Vapor Absorption Refrigeration Systems (VARS).
    3. Vapor Adsorption Vapor.
    4. Thermo-Electric Cooling System.
    5. Solar-Refrigeration System (Solar Thermal-VARS)

Vapor Mechanical Compression Refrigeration System (VCRS)

The mechanical compression-based cooling technique are commonly known as vapor compression refrigeratisystemstem (VCRS). The working refrigerant material undergoes phase change twice from liquid to vapor the at evaporator and again back to vapor to liquid at condenser side. The four basic components of VCRS are linked via a conduit through which refrigerant flows. The evaporator is a fixed location where heat is extracted by the refrigerant in order to accomplish cooling. Low pressure and temperature were maintained via the evaporator. The liquid refrigerant turns in to low pressure vapor. After evaporator vapor refrigerant transferred to compression, here refrigerants will be compressed and convert into high pressure and temperature. Thermodynamically compression process is isentropic compression. The compressed superheated refrigerant vapor enters into condenser for heat rejection at same compression pressure. The vapor refrigerants return to a liquid state after leaving the heat. The saturated liquid refrigerant is transferred from the condenser to the expansion valve in an isenthalpic throttling operation. The refrigerants reach low pressure and temperature before returning to the evaporator. The VCRS system is widely used in applications such as ultra-low cooling solidification of gases, ice production, and HVAC.[11]

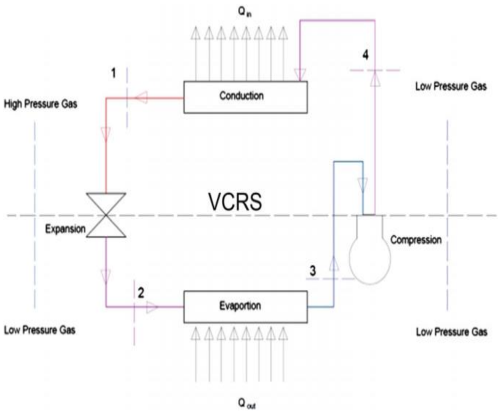


Figure 1 – Vapor Compression Refrigeration System [14]

Vapor Absorption Refrigeration System (VARS)

The evaporator sends low-pressure dry ammonia vapor into the absorber. Dry ammonia vapor is dissolved in cold water in the absorber, forming a strong ammonia solution. The heat generated during ammonia absorption is dissipated by flowing cold water through the absorber's coils. A pump then transports the highly concentrated ammonia (known as Aqua Ammonia) to the generator through a heat exchanger. The hot weak solution returning from the generator to the absorber heats the strong ammonia solution in the heat exchanger. The warm solution is heated further in the generator by steam coils, gas, or electricity, and the ammonia vapor is forced out of the solution. Ammonia's boiling point is lower than that of water. As a result, the vapors emitted by the generator are mostly ammonia. Weak aqua refers to the weak ammonia solution that is left in the generator. Through the heat exchanger, this weak solution is returned to the absorber. Water vapor may be present in the ammonia vapors emitted by the generator. If this water vapor is allowed to reach the condenser and expansion valve, it may freeze, causing the flow to get clogged. Before the condenser, the system includes an analyser and rectifiers. The analyser vapor separates ammonia from water vapor by passing ammonia vapor from the generator through a series of trays. The water vapor that had been separated was returned to the generator. After that, the ammonia vapor is rectified. Water vapor remaining present in ammonia vapor condenses in the rectifier, and the condensate is returned to the analyser. Following that, the nearly pure ammonia vapor goes through the condenser.[16]

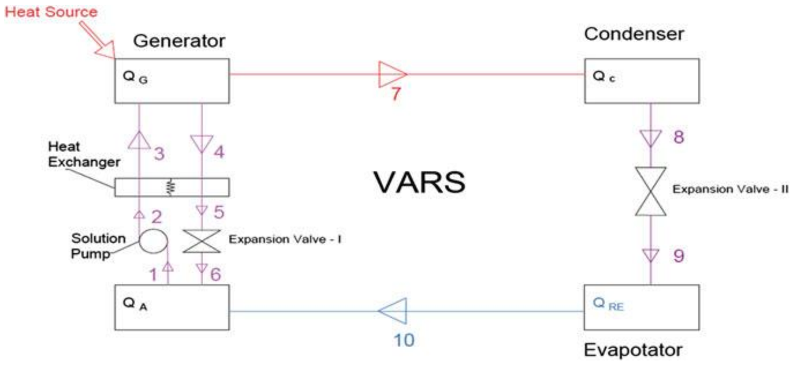


Figure 2 – Vapor Absorption Refrigeration System [14]

Vapor Adsorption System

The adsorption refrigeration system works similar to vapour compression refrigeration system. The thermal compressor is used in the adsorption system in place of mechanical compressor. It's termed a thermal compressor since it works based on temperature change. The adsorption and desorption phenomena are used to replace the compressor's function in this system. As a result, one adsorption bed will alternate between adsorption and desorption processes. The desorption process necessitates heating, while the adsorption process needs cooling.[17]

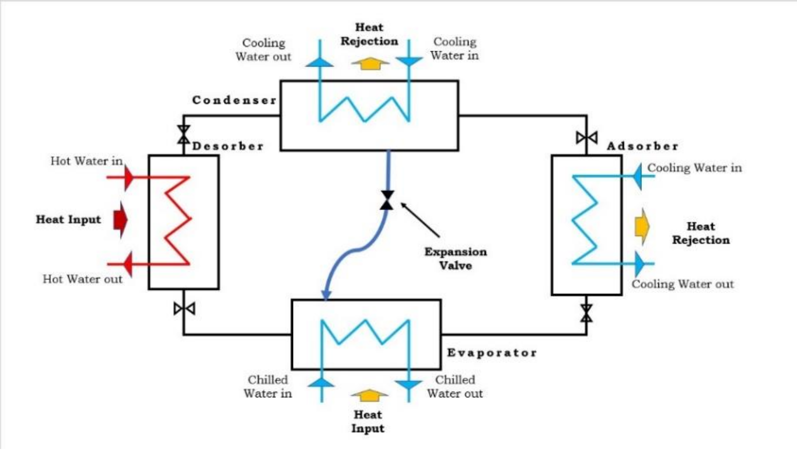


Figure 3 – Vapor Adsorption Refrigeration System [17]

Thermo-Electric Cooling System

The potential application of solid-state thermoelectric (TE) technology as green energy conversion devices has attracted a lot of interest. As a long-term cooling method, proper thermal management of thermoelectric coolers (TEC) is critical. The Peltier effect, which is used in thermoelectric technology, allows for electrical energy conversion in to temperature differential directly [34]. The thermoelectric cooler (TEC) uses the Peltier effect to distribute heat and eliminate hot spots from electrical equipment in an environmentally friendly manner. A TEC could be placed in a small space due to its capacity to be made in small sizes (micro-chips). The cooling effect of TECs varies from milli watts to watts only, it depends on the application. The refrigeration effect and energy performance ratio are significant performance parameters of TEC. [35-36]

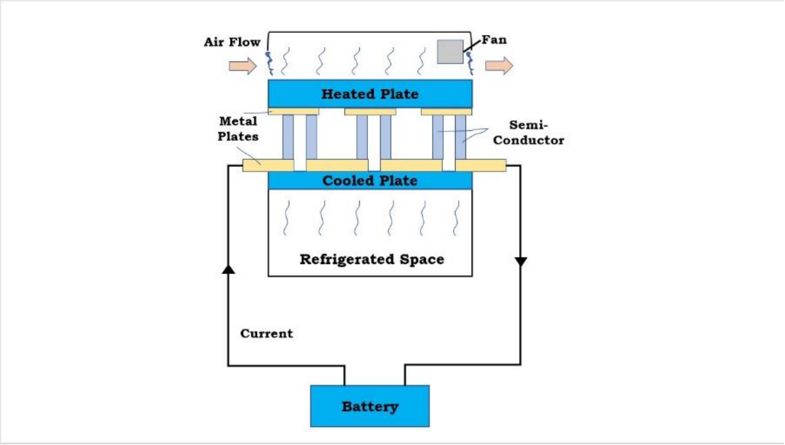


Figure 4 – Concept of Thermo Electric Cooling [37]

Solar Thermal Cooling system using vapor absorption refrigeration.

Non-Toxic and zero global warming index-based refrigeration system integrated with solar thermal system. Solar heating operated this cooling machine is thermo-compression-based machine. The mechanical compression refrigeration system is replaced by the refrigerant pump for pressure of cycle and generator unit provide high temperature to refrigerant. The popularly LiBr-H_2O and H_2O-NH_3 vars system is commercially available which give the sufficient cooling (about 5 ^{0}C of cooling temperature) for food preservation, milk storage, water chilling etc. It is a one-time investment with minimum running expenses. It is a pollution free system with very low maintenance cost. The components of a Solar Powered Vapor Absorption System are absorber, generator. [39-42]

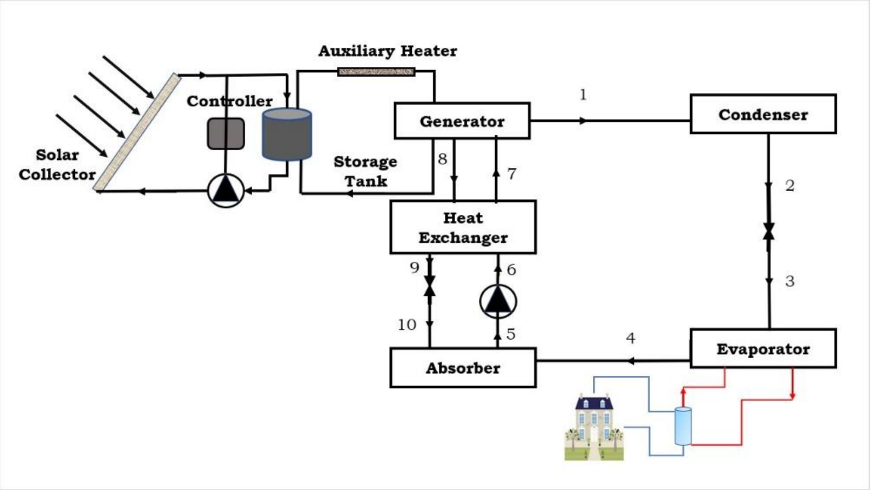


Fig 5 – Solar VARS System Schematic [40]

- **Waste Energy Recovery Thermal System**

Co-generation system

Combined output power and heat process is defined as co-generation system. It that includes joint effect of two different power cycles at the same time, such as gas turbines and steam turbine systems, to simultaneously generate power and usable heat or process heat. The considerable quantity of energy is discarded from the power plant. Maidment and Tozer studied on different thermodynamic system which gives collective results of energy in form of heating and power in same thermal system. They looked at a number of different ways for combining energy generation, including cooling and engine technologies. [1,2] Bureau of energy efficiency summarized the well-known topping and bottoming cycle co-generation concept, which is suitable for manufacturing operations in which high-temperature heat is required in furnaces and kilns and high-temperature heat is rejected. Cement, steel, ceramics, gas, and petrochemical industries are examples of typical application sectors. Plants in the bottoming cycle are far less prevalent than those in the topping cycle. The furnace’s waste gases are utilized to make steam, which is subsequently used to power the turbine, which provides electricity. [3,4]

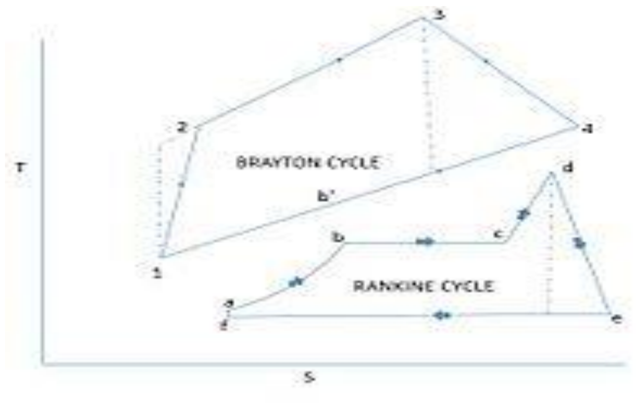


Figure 6 – Combined Power Cycle [13]

TRIGENERATION SYSTEM

Three forms of energy are produced via tri-generation techniques: electrical power, heating, and cooling. RI-generation systems combine a thermally powered refrigeration system with a CHP (Combined Heat and Power) or cogeneration system to provide cooling, electricity, and heat. This innovative thermal system has higher thermal efficiency with multiple effect of energy, and employable in power generation plants. [4,5]

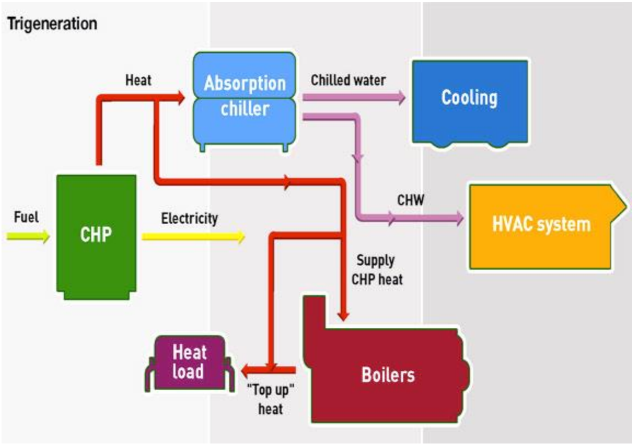


Figure 7 – Trigeneration System [13]

ORGANIC RANKINE CYCLE (ORC)

Chen and Goswami discussed many thermodynamic methods for utilizing waste heat, such as the Organic Rankine Cycle (ORC). This novel thermal system similar to vapour power Rankine cycle, but low boiling temperature alternative working fluid is employed in place of steam. This organic fluid able to recover the discharged heat from low grade energy source. The cycle includes an expansion turbine, condenser, pump, boiler, and superheated water (provide superheat is needed). HCFC123 (CHCl2CF3), PF5050 (CF3(CF2)3CF3), HFC-245fa (CH3CH2CHF2), HFC 245ca (CF3CHFCH2F), isobutene ((CH3)2C=CH2), n-pentane, and aromatic hydrocarbons have all been used to study organic Rankine cycles. Power plants, cement plants, desalination plants, processing plants, and manufacturing plants are all examples. There are three types of working fluids: dry, wet, and isentropic. An isentropic or dry fluid was recommended for ORC to avoid liquid droplet impingement in turbine blades during expansion. If the fluid is excessively dry, the expanded vapor will exit the turbine with a lot of superheats, which is a waste and will increase the cooling load. [6,7-10]

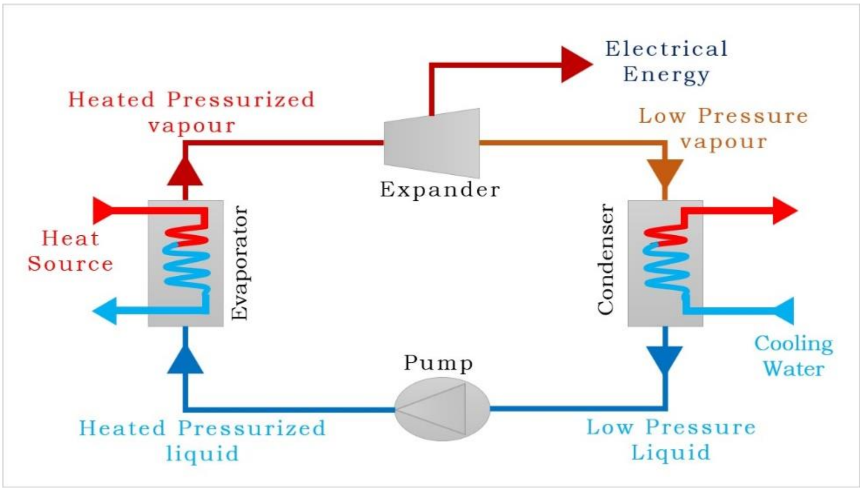


Figure 8 – Organic Rankine Cycle [12]

- **Alternative Cooling Materials (Nano-Fluids & Thermo-Electric Materials)**

In advanced materials technology a particle is defined as a small item that has the same transport properties as a full unit. Nanoparticles range in size from 1 to 100 nanometres (1x109 and 1x107 m). Nanoparticles include tubes and fibres with only two dimensions less than 100 nm. At a threshold length scale of 100 nm, novel features that distinguish particles from bulk material often emerge. Ceramics, metals, and metal oxides are used to create them. [33]

Nano-Refrigerants

Nanofluids are nanoparticle colloidal suspensions in base fluids that have been tailored to improve their properties at low concentrations. Nanofluids feature 1) greater heat transfer between particles and fluids than regular solid-liquid suspensions due to the increased surface area of nanoparticles. 2) Improved dispersion stability with Brownian motion as the main motion in comparison to the base fluid, there was less particle blockage and less pumping power.

The lubricant nanoparticles mixture is known as nano lubricant, and it can be added to the lubricant (compressor oil). Nanoparticles can also be added to refrigerant, and the refrigerant nanoparticles mixture is referred to as nano refrigerant. Pure refrigerant can be mixed with nano lubricant to make nano lubricant-refrigerant. Nanofluids include nano lubricant, nano refrigerant, and nano lubricant-refrigerant. Nano lubricant enhances tribological properties in refrigeration systems, boosting compressor performance; thermo-physical characteristics of nano refrigerants are improved., increasing cooling effect. The addition of nanoparticles improves the solubility of oil and refrigerant, allowing more oil to be returned to the compressor. [33]. Table 4 all the Nano-refrigerants are mentioned in this table.

Thermo-Electric Materials

Thermoelectric material specifications.

- Because of their room-temperature functioning, semiconductors with narrow band gaps have a high electrical conductivity (to reduce electrical resistance, a source of waste heat)
- Low thermal conductivity (i.e., heat does not flow back from the heated to the cold side); this typically means heavier components.
- Complex structure with a large unit cell.
- Compositions that are complex.
- Extremely anisotropic or symmetric

Bismuth telluride, lead telluride, silicon germanium, and bismuth-antimony alloys are common thermoelectric materials used as semiconductors. Bismuth telluride is the most often utilised of them [35].

Table 1 – Commercial & 21st century refrigerants [38-42]

Refrigerants Designation	**Refrigerants**	**Temp_boiling (K)**	**Temp_freezing (K)**	**Temp _critical (K)**	**Pressure _critical (bar)**	**ODP**	**GWP**
Chlorofluorocarbons							
R113	Trichlorofluoromethane	320.73	238.16	487.3	34.4	0.9	5200
R11	Trichlorofluoromethane	296.98	162.05	471.2	44.1	1	4000
R114	Dichlorotetrafluoroethane	276.94	179.27	418.9	32.6	0.7	16600
R12	Dichlorodifluoromethane	243.37	115.38	385.2	41.2	1	12200
R115	Chloropentafluoroethane	233.83	167.05	353.1	31.5	0.6	39200
Hydrochlorofluorocarbons							
R141b	Dichlorofluoromethane	305.16	-	483.35	46.4	0.15	600
R123	Dichlorodifluoromethane	301.03	166.01	457.15	36.76	0.02	80
R22	Chlorodifluoromethane	232.40	113.16	363.15	49.78	0.05	1480
Hydrofluorocarbons							
R245fa	Pentafluoro propane	288.44	166.49	383.4	31.5	0	790
R134a-21st century refrigerants	Tetrafluoroethane	247.00	176.55	374.25	40.67	0	1160
R507	Azeotrope- Blend	226.05	255.38	344.05	37.92	0	1400
R125	Pentafluoro ethane	224.59	170.01	339.25	36.2	0	3360
R32	Difluoromethane	221.44	137.05	351.4	58.08	0	440
R23	Triflouromethane	191.10	118.16	298.75	48.37	0	24000
Hydrofluoroellifins							
R1234yf-21st century refrigerants	2,3,3,3-Tetrafluoropropene	244.15	220.00	367.85	33.82	0	4
Fluorocarbons/ Perfluorocarbons							
R218	Octofluoropropane	241.66	113.16	344.95	26.8	0	9300
R14	Tetrafluoromethane	145.22	89.27	227.65	37.43	0	6500
Hydrocarbons							
R600	Butane	272.66	134.66	425.12	37.7	0	0
R290-21st century refrigerants	Propane	231.07	85.49	369.83	42.1	0	0
R170	Ethane	184.35	90.38	305.32	48.5	0	0
R1150	Ethylene	169.44	104.27	282.34	50.3	0	0
R50	Methane	111.66	90.94	190.56	45.9	0	0
Inorganic Compounds							
R718	Water	373.16	273.16	647.13	219.4	0	0
R717	Ammonia	239.83	195.44	405.65	113.0	0	0
R744	Carbon Dioxide	194.72	216.55	3.4.21	73.9	0	1
R728	Nitrogen	77.38	63.16	126.2	33.9	0	0
R702n	Hydrogen	20.38	13.99	33.19	13.2	0	0
R50	Helium	4.22	-	5.2	2.3	0	0
Hydrofluoroether							
HFE-7100	Methoxynonafluorobutane	334.16	138.16	468.45	22.3	0	320
HFE-7200	Ethoxynonafluorobutane	349.16	135.16	482.0	19.8	0	55
HFE-7000	Methoxyheptafluoropropane	307.16	150.38	438.15	24.8	0	400

Table 2 – List of nano materials-based cooling agents [19-32]

Research Conducted	**Cooling materials**	**Nano-materials and base materials**	**Research Outcome**
Maheshwari [19]	R-134a	ZnO	The heat conduction of spherical nanoparticles increased by 25.26 per cent, whereas cubic nanoparticles increased by 42.5 per cent.
Rezaeinjoybari [20]	R600a	CuO / POE oil	Between 1.5 and 2 percent concentration, the heat transfer coefficient was increased.
Kumar [21]	R134a, R12, R22, R600, R600a	Al2O3 / POE	11.5 % reduction in energy use.
Coumaressin and Palaniradja [22]	R134a	CuO	With nano refrigerant, the evaporator heat transfer coefficient is enhanced. R134a/CuO is an excellent refrigerant to utilize.
Diao [23], Peng [26]	R141b	Cu – SDBS	Boiling's heat transmission coefficient increased as the volume increased.
Sanukrishna [24]	R134a	SiO2 – Poly alkaline glycolnano lubricant	Heat conduction improves and reducing friction with SiO2 – PAG lubricant.
Tang [25]	R141b POE	δ- Al2O3 with SBDS as surfactant	The heat transmission coefficient of a pool that is boiling has been improved.
Wang [27]	R410a	NiFe2O4 – MNRO as lubricant	By changing the lubricant, the energy efficient ratio (EER) was increased by 6%.
Kumar [28]	R134a	Al2O3 – PAG	The co-efficient of performance is increased by 9-10% less energy use when 0.2% is applied.
Peng [29]	R113	Diamond	Nucleate pool boiling heat transfer coefficient increased by 63.3%.
Trisaksri and Wongwises [30]	R141b	TiO2	The energy rate fell as the volume fraction increased.
Bi [31]	R600a	TiO2	With nano-refrigerant, the performance enhanced. There was a 9.6% reduction in energy consumption.
Adelekan [32]	R600a	Graphene	The smallest power consumption was 65W, the highest PPTR was 5.22, and the maximum increased COP was 0.76.

CHAPTER – 5

THERMODYNAMIC ANALYSIS

Energy Calculation for the System

Energy Calculation of the system entails calculating the system Coefficient of Performance (COP) by determining critical parameters such as enthalpy, mass flow rates of absorbent & absorbate, and circulation ratio for the entire system. These values will subsequently be used in the system's design. First, by applying mass and energy balance to each component, a set of thermodynamic equations in terms of mass flow rates and enthalpy has been generated. The actual system conditions, such as temperature, pressures, and enthalpies, are then substituted into the equations to produce the system's COP value.

The following assumptions are used to conduct the system's thermodynamic analysis.

Let Mr =Refrigerant mass flow rate, (kg/s)
Mss =Strong solution mass flow rate, (kg/s)
Mws=Weak solution mass flow rate, (kg/s)

Mass (M)balance for the system: -Mss = Mr + Mws

ƛ = Mws/Mr Therefore, Mss = Mr(1+ƛ) { Where ƛ is the circulation Ratio }

Heat (Q) balance for each component :-

S No.	Component	Heat (Q)	Heat (Q) balance Equations for each component
1.	Absorber	Qabs	Qabs = Mrh10 + ƛMrh6 – Mr(1+ƛ)h1
2.	Heat Exchanger	Qhex	Qhex = Mr(1+ƛ)(h3-h2)
3.	Generator	Qgen	Qgen = Mrh7 + ƛMrh4 – Mr(1+ ƛ)h3
4.	Condenser	Qcond	Qcond = Mr(h7-h8)
5.	Evaporator	Qref	Qref = Mr(h10-h9)

Coefficient of Performance (COP) :-

The heat absorbed by the refrigerant in the evaporator is the net refrigerating effect in this system. The sum of the work done by the pump and the heat supplied by the generator is the total energy given to the system. As a result, COP1= Heat Absorbed in Evaporator / (Work Done by Pump + Heat provided to Generator) is the system's Coefficient of Performance (COP1).

Or COP1 = Qref / (Qgen + Wp)

Now, Neglecting the pump work

Therefore**,** **COP 1 = Qref / Qgen** Also **COP 2 = COP 1 / COPcarnot**

Thermodynamics of 5-ton LiBr-H2O Vapor Absorption Refrigeration Plant

Operating Temperatures :-

1. Absorber Temperature (Ta) – 20° - 30°C [293 – 303]°K
2. Generator Temperature (Tg) – 60° - 110°C [333 – 383]°K
3. Condenser Temperature (Tc) – 25° - 50°C [298 – 323]°K
4. Evaporator Temperature (Te) – 2° - 10° C [275 – 283]°K

COP Carnot :-

A Carnot refrigeration cycle's COP is solely determined by the cycle's upper and lower temperatures, and it is true that the reversed Carnot cycle is the most efficient refrigeration cycle while running between these two temperature ranges.

COPcarnot = [(Te/Tc-Te)*(Tg-Ta/Tg)]

Capacity of the system or Refrigerating effect :-

Cooling Plant Refrigeration Effect (Qref) = 5TR (Also 1TR = 3.5 KW)

Therefore, **Qref = 5TR = 5*3.5 = 17.5 KW**

Calculation of Enthalpy (h) at each of the system's designated points :-

- At any temperature, steam tables can be used to compute the enthalpy of pure water and superheated water vapors.
- The LiBr-H2O (P-T-ξ-h) Chart is used to calculate the enthalpies of solutions.

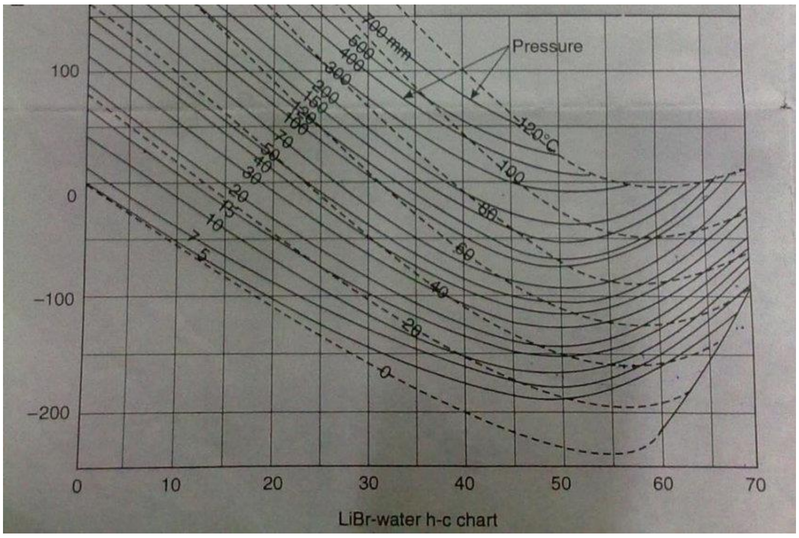


Fig – 9 LiBr-H2O (P-T-ξ-h) Chart

LiBr-H2O Enthalpy – Pressure – Temperature – Concentration Tables

Table 3

State Points	Temperature (°K)	Pressure (bar)	Enthalpy (h) (Kj/Kg)	Concentration (ξ)
1.	295	0.00933	-165	0.48
2.	295	0.05199	-165	0.48
3.	323	0.05199	-120	0.48
4.	343	0.05199	-100	0.57
5.	298	0.05199	-185	0.57
6.	295	0.00933	-185	0.57
7.	343	0.31162	2626.9	-
8.	306	0.05199	138.2	-
9.	277	0.00813	2508.9	-
10.	293	0.02337	2538.2	-

Table 4

State Points	Temperature (°K)	Pressure (bar)	Enthalpy (h) (Kj/Kg)	Concentration (ξ)
1.	295	0.00933	-165	0.48
2.	295	0.06399	-165	0.48
3.	323	0.06399	-80	0.48
4.	353	0.06399	-72	0.59
5.	298	0.06399	-185	0.59
6.	295	0.00933	-185	0.59
7.	353	0.47360	2643.8	-
8.	311	0.06624	159.1	-
9.	277	0.00813	2508.9	-
10.	293	0.02337	2538.2	-

Table 5

State Points	Temperature (°K)	Pressure (bar)	Enthalpy (h) (Kj/Kg)	Concentration (ξ)
1.	295	0.00933	-165	0.48
2.	295	0.07999	-165	0.48
3.	323	0.07999	-72	0.48
4.	363	0.07999	-65	0.62
5.	298	0.07999	-185	0.62
6.	295	0.00933	-185	0.62
7.	363	0.70109	2660.1	-
8.	316	0.08639	180.0	-
9.	277	0.00813	2508.9	-
10.	293	0.02337	2538.2	-

Table 6

State Points	Temperature (°K)	Pressure (bar)	Enthalpy (h) (Kj/Kg)	Concentration (ξ)
1.	295	0.00933	-165	0.48
2.	295	0.09865	-165	0.48
3.	323	0.09865	-68	0.48
4.	373	0.09865	-56	0.65
5.	298	0.09865	-185	0.65
6.	295	0.00933	-185	0.65
7.	373	1.0133	2676.0	-
8.	321	0.11162	200.9	-
9.	277	0.00813	2508.9	-
10.	293	0.02337	2538.2	-

CHAPTER – 6

RESULT AND DISCUSSION

- We have devised a computation approach based on simple analytical data that relates the thermodynamic variable of the H2O-LiBr fluid couple in this study.
- We have calculated the heat transfer for each component and the COPcarnot, COP1, and COP2 for the system, all the calculated values are mentioned in Tables 7 & 8.

Table 7 – Calculated values of COPcarnot, COP1, and COP2 for different conditions

Conditions	**COP Carnot**	**COP 1**	**COP 2**
Case 1 Tg =343°K, Te = 277°K, Tc = 306°K, Ta = 295°K	1.33668	0.01026	0.007681
Case 2 Tg =353°K, Te = 277°K, Tc = 311°K, Ta = 295°K	1.33861	0.01062	0.007933
Case 3 Tg =363°K, Te = 277°K, Tc = 316°K, Ta = 295°K	1.33050	0.01063	0.007990
Case 4 Tg =373°K, Te = 277°K, Tc = 321°K, Ta = 295°K	1.31647	0.01054	0.008006

Table 8 – Heat Transfer Calculated for each Components with Circulation Ratio

Conditions	**ƛ (Circulation Ratio)**	**Qref (KW)**	**Qhex (KW)**	**Qgen (KW)**	**Qabs (KW)**	**Qcond (KW)**
Tg =343°K	5.33	17.5	170.12	1704.28	1550.84	1486.40
Tg =353°K	4.36	17.5	272.11	1647.64	1562.43	1484.01
Tg =363°K	3.42	17.5	245.50	1646.07	1573.66	1481.26
Tg =373°K	2.82	17.5	221.30	1659.09	1587.27	1478.27

Graphs

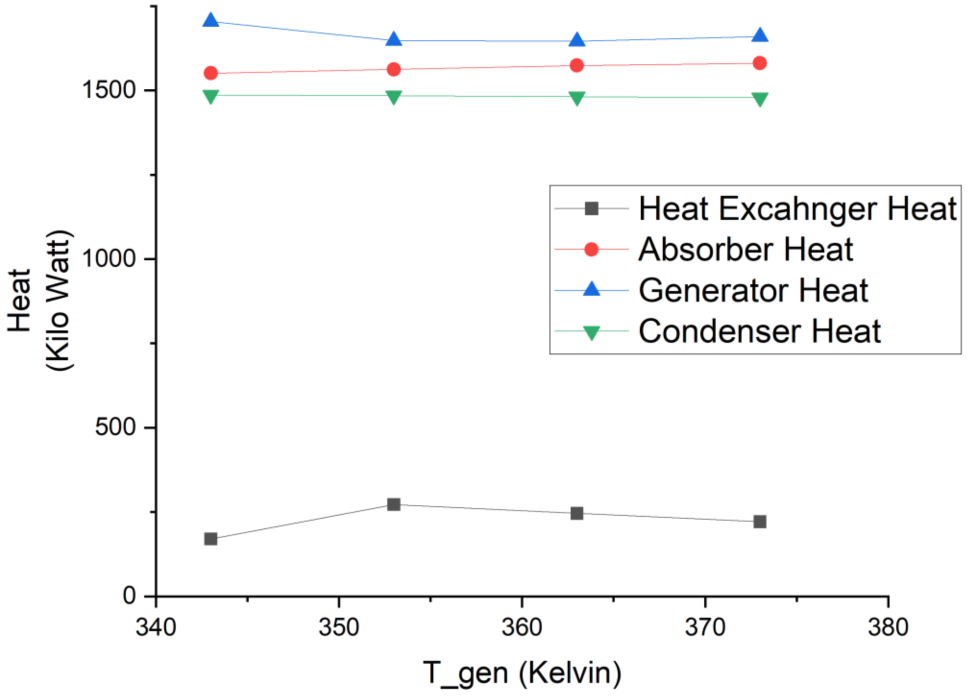


Fig 10 – Generator temperature (Tg) Versus Heat Transfer for each Component

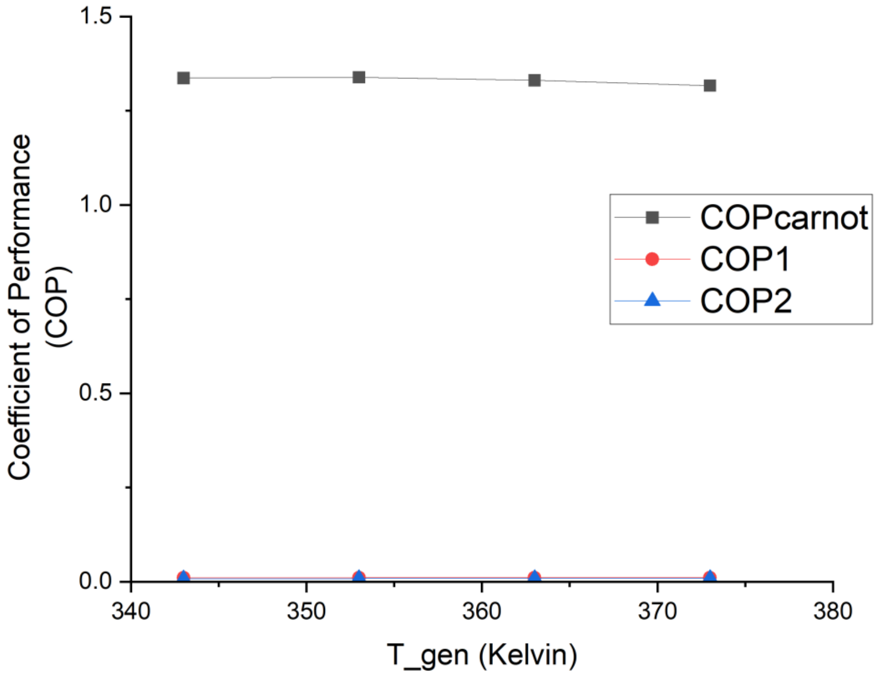


Fig 11 – Generator temperature (Tg) Versus Coefficient of Performance (COPs)

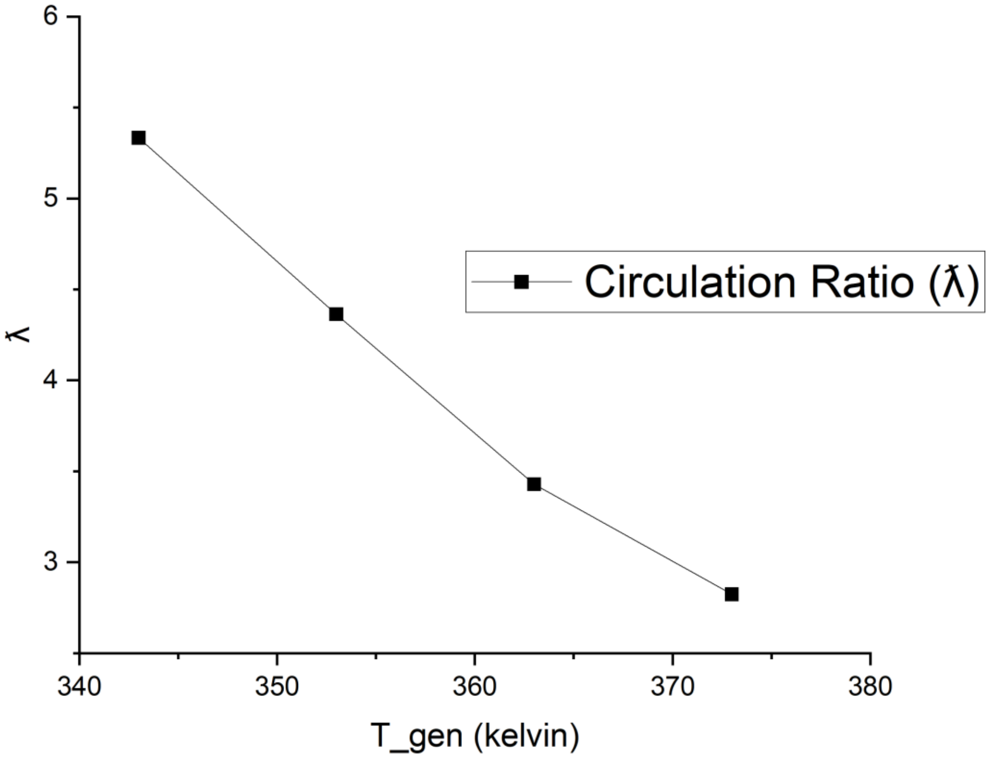


Fig 12 - Generator temperature (Tg) Versus Circulation Ratio (ƛ)

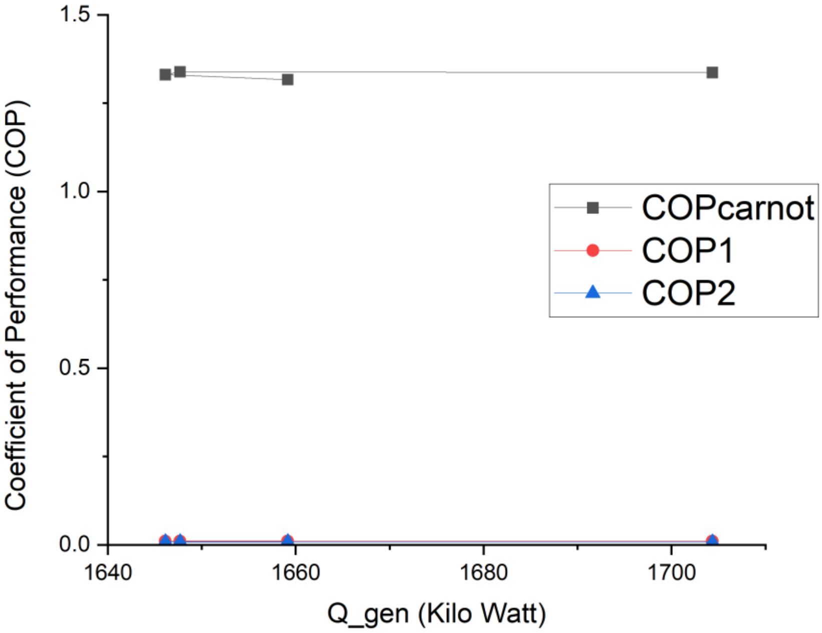


Fig 13 – Generator Heat (Qgen) Versus Coefficient of Performance (COPs)

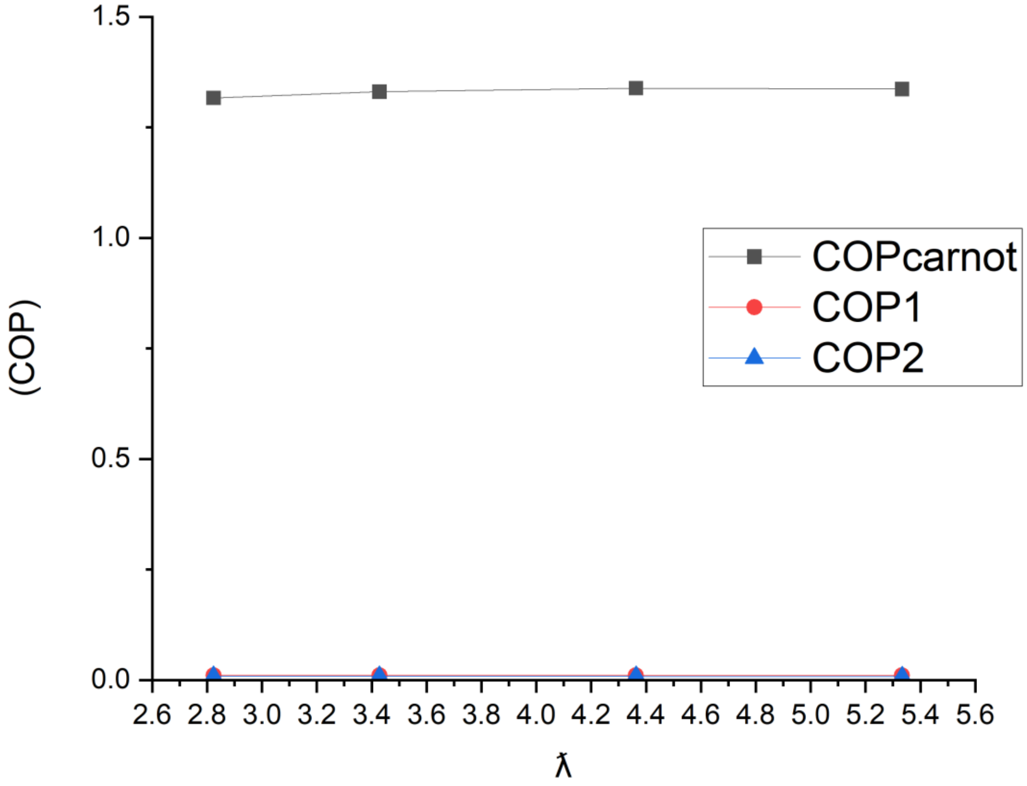


Fig 14 – Circulation Ratio (ƛ) Versus Coefficient of Performance (COPs)

CHAPTER – 7

CONCLUSION

- The powerful greenhouse gas emissions CFCs, HCFCs, and halons deplete the world's protective ozone layer, which protects the globe from damaging ultraviolet (UV-B) radiation released by the sun. These synthetic refrigerants also cause global warming and have a significant impact on climate change. The current review study looks at the advancement of low-GWP and low-ODP refrigerants. Natural refrigerants like CO_2, NH_3, and H_2O, as well as hydrocarbons like R290, R600, R600a, and blends of hydrocarbons, are potential answers to this problem and are being used in a variety of cooling techniques. The following are some of the most noteworthy observations.

1. Because of their great energy efficiency, good thermodynamic properties, low price, and excellent co-efficient of performance, HCs are a feasible solution for medium-scale cooling applications.

2. Many refrigerants have been used in auto-mobile air-conditioning systems for electric vehicles, including Propane, Iso-butane, Propylene, Ethyl fluoride, Tetrafluoro propylene, and Tetrafluoro propene. The literature on electric vehicles (EVs) suggests propane and tetrafluoro propylene as promising 21st-century refrigerants, particularly for cooling and millage issues.

3. The use of nano-refrigerants with improved thermo-physical and heat-transfer capabilities. Heat conduction of TiO_2-R134a based nano-refrigerant increases by 30-32 percent when nano-particle concentration is 1.5-2 percent, according to studies. There are limited research in the open literature on the use of nanoparticles with natural refrigerants like hydrocarbons, NH_3, and CO_2. Commercial and industrial uses necessitate these studies.

4. Because there is little study on the usage of an oil and refrigerant combination, more research with different oil concentrations is needed.

5. The advantages of thermoelectric cooling systems over typical refrigeration machines are compact size, light weight, high dependability, lack of motorised parts, no refrigerants required, direct power supply, and ease of switching between heating and cooling modes. New high-performance TEC materials are currently being developed.

6. In the rural livelihood industry, the use of solar thermal energy for alternative cooling systems such as vapour absorption, vapour adsorption, and ejector cooling can play a vital role in low cooling applications without the use of high-grade energy. By reusing discharged heat from captive industries, the refrigeration systems stated above can offer significant cooling.

7. New age cooling materials with a tri-generation thermal system, ORC, and Kalina system offer significant potential for remarkable cooling effects.

- The system's COP is heavily impacted by the temperature of the system. The effect of temperature on system COP has been investigated for the condenser, generator, absorber, and evaporator. The findings revealed that all four parameters had a significant impact on the system's COP.

References

[1] E. Bazques, D. Strom, Cogeneration and interconnection technologies for industrial and commercial use, in: Proceedings of 18th IECEC American Institute of Chemical Engineers, 1983, pp. 2060–2065.

[2] G.G. Maidment, R.M. Tozer, Combined cooling heat and power in supermarkets, Applied Thermal Engineering22 (2002) 653–665.

[3] Yunus A. Cen gel, Michael A. Boles, Thermodynamics: An Engineering Approach, 4th edition, McGraw-Hill, 2002.

[4] https://beeindia.gov.in/sites/default/files/2Ch8.pdf

[5] *Renewable Energy Institute*: Trigeneration Technologies Available. [online], [cited: June 2011], Available on internet< http://www.trigeneration.com/ >

[6] Chen H, Goswami DY, Stefanakos EK. A review of thermodynamic cycles and working fluids for the conversion of low-grade heat. Renewable and Sustainable Energy Reviews 2010; 14:3059–67.

[7] Goswami, D. Y., 1995, ―Solar Thermal Power: Status of Technologies and Opportunities for Research,‖ *Heat and Mass Transfer '95, Proceedings of the 2ndASME-ISHMT Heat and Mass Transfer Conference*, Tata-McGraw Hill Publishers, New Delhi, India, pp. 57-60.

[8] Lu, S., and D. Y. Goswami, 2003, ―Optimization of a Novel Combined

Power/Refrigeration Thermodynamic Cycle,‖ *Journal of Solar Energy Engineering*, 125, pp. 212-217.

[9] Tamm, G., D. Y. Goswami, S. Lu, and A. A. Hasan, 2003, ―Novel Combined Power and Cooling Thermodynamic Cycle for Low Temperature Heat Sources, Part I: Theoretical Investigation,‖ *Journal of Solar Energy Engineering*, 125, pp. 218-222.

[10] Tamm, G., and D. Y. Goswami, 2003, ―Novel Combined Power and Cooling Thermodynamic Cycle for Low Temperature Heat Sources, Part II: Experimental Investigation,‖ *Journal of Solar Energy Engineering*, 125, pp. 223-229.

[11] Jain, Vaibhav, S. S. Kachhwaha, and Gulshan Sachdeva. "Thermodynamic performance analysis of a vapor compression–absorption cascaded refrigeration system." *Energy conversion and management* 75 (2013): 685-700.

[12] Quoilin, Sylvain, Martijn Van Den Broek, Sébastien Declaye, Pierre Dewallef, and Vincent Lemort. "Techno-economic survey of Organic Rankine Cycle (ORC) systems." *Renewable and sustainable energy reviews* 22 (2013): 168-186.

[13] Kaushalendra.Kr Dubey,R.S.Mishra, Industrial And Power Plant Waste Heat Recovery Systems For Combined Cooling-Heating And Power Generation**,** International Journal of Advance Research and Innovative Ideas in Education,Vol-3,Issue-3, ISSN NO (O):2395-4396,pp-3682-94,june 2017. 16.0415/IJARIIE-5742

[14] Dubey K.K., Sharma K., Mishra R., Singh S.K., Agarwal B.N. (2021) Theoretical Analysis of Isentropic and Alternative Refrigerant Based Cooling System and Low Carbon Economy. Advances in Industrial and Production Engineering. Lecture Notes in Mechanical Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-33-4320-7_28. Advances in Industrial and Production Engineering pp 307-321.Feb 2021

[15] Kalina, A. I., 1984, ―Combined Cycle System with Novel Bottoming Cycle,‖ *ASME Journal of Engineering for Gas Turbines and Power*, 106, pp. 737-742.

[16] Soteris Kalogirou, George Florides, Savvas Tassou, Louis Wrobel" Design And Construction Of A Lithium Bromide Water Absorption Refrigerator" Clima 2000/Napoli 2001 World Congress – Napoli (I), 15-18 September 2001.

[17] Dubey, Kaushalendra Kumar, and R. S. Mishra. "Thermodynamic (Energy-Exergy) Analysis of Combined Coal based Thermal Power Plant and Solar Integrated Double Bed Vapor Adsorption System for Heat Recovery and Space Cooling." *Saudi Journal of Engineering and Technology* 2, no. 7 (2017): 286-298.

[18] Dubey, Kaushalendra Kumar, and R. S. Mishra. "Solar integrated combined cooling-power generation systems for waste heat recovery using different energy efficient materials." *International Journal of Digital Signals and Smart Systems* 5, no. 2 (2021): 125-136.

[19] P.B. Maheshwari, C.C. Handa, K.R. Nemade, Effect of shape on thermophysical and heat transfer properties of ZnO/R-134a nanorefrigerant, Mater. Today Proc. 5 (2018) 1635–1639.

[20] B. Rezaeianjouybari, M. Sheikholeslami, A. Shafee, H. Babazadeh, A novel Bayesian optimization for flow condensation enhancement using nanorefrigerant: a combined analytical and experimental study, Chem. Eng. Sci. 215 (2020) 115465, https://doi.org/10.1016/j.ces.2019.115465.

[21] R.R. Kumar, K. Sridhar, M. Narasimha, Heat transfer enhancement in domestic refrigerator using R600a/mineral oil/nano-Al2O3 as working fluid, Int. J. Comput. Eng. Res. 3 (2013) 42–50.

[22] T. Coumaressin, K. Palaniradja, Performance analysis of a refrigeration system using nano fluid, Int. J. Adv. Mech. Eng. 4 (2014) 459–470.

[23] Y.H. Diao, C.Z. Li, Y.H. Zhao, Y. Liu, S. Wang, Experimental investigation on the pool boiling characteristics and critical heat flux of Cu-R141b nanorefrigerant under atmospheric pressure, Int. J. Heat Mass Transf. 89 (2015) 110–115.

[24] S.S. Sanukrishna, M. Shafi, M. Murukan, M. Jose Prakash, Effect of SiO2 nanoparticles on the heat transfer characteristics of refrigerant and tribological behaviour of lubricant, Powder Technol. 356 (2019) 39–49.

[25] X. Tang, Y.-H. Zhao, Y.-H. Diao, Experimental investigation of the nucleate pool boiling heat transfer characteristics of d-Al2O3-R141b nanofluids on a horizontal plate, Exp. Therm. Fluid Sci. 52 (2014) 88–96

[26] H. Peng, G. Ding, H. Hu. Influences of refrigerant-based nanofluid composition and heating condition on the migration of nanoparticles during pool boiling. Part II: model development and validation, Int. J. Refrig. 34 2011 1833-1845.

[27] R. Wang, Q. Wu, Y. Wu, Use of nanoparticles to make mineral oil lubricants feasible for use in a residential air conditioner employing hydro-fluorocarbons refrigerants, Energy Build. 42 (11) (2010) 2111–2117.

[28] D.S. Kumar, R. Elansezhian, Experimental study on Al2O3-R134a nano refrigerant in refrigeration system, Int. J. Mod. Eng. Res. 2 (2012) 3927– 3929.

[29] H. Peng, G. Ding, H. Hu, W. Jiang, D. Zhuang, K. Wang, Nucleate pool boiling heat transfer characteristics of refrigerant/oil mixture with diamond nanoparticles, Int. J. Refrig. 33 (2) (2010) 347–358.

[30] V. Trisaksri, S. Wongwises, Nucleate pool boiling heat transfer of TiO2–R141b nanofluids, Int. J. Heat Mass Transf. 52 (5-6) (2009) 1582–1588.

[31] S. Bi, K. Guo, Z. Liu, J. Wu, Performance of a domestic refrigerator using TiO2- R600a nano-refrigerant as working fluid, Energy Convers. Manage. 52 (1) (2011) 733–737.

[32] D.S. Adelekan, O.S. Ohunakin, J. Gill, I.P. Okokpujie, O.E. Atiba, Performance of an Iso-Butane driven domestic refrigerator infused with various concentrations of graphene based nanolubricants, Procedia Manuf. 35 (2019) 1146–1151

[33] *Kirloskar Pneumatic Co. Ltd, India*, amey.majgaonkar@gmail.com.

[34] Giri, J.M., Nain, P.K.S. Performance optimization of thermoelectric cooler using genetic algorithm. Mathematical Modelling of Engineering Problems, Vol. 7, No. 3, (2020) pp. 427-435.

[35] Giri, J.M., Nain, P.K.S.Review of Recent Progresses in Thermoelectric Materials.

Advances in Engineering Materials. Lecture Notes in Mechanical Engineering. Springer, Singapore. . (2021). pp. 269-280.

[36] Giri, J.M., Nain, P.K.S. Maximisation of energy and exergy efficiencies for a sustainable thermoelectric cooling system by applying genetic algorithm. International Journal of Exergy, Vol. 37, No. 1, (2022). pp. 57-73.

[37] D.Ponnamma, G.J.Ogunleye, P. Sharma, M.A.Al Madeed,12 - Piezo- and Thermoelectric Materials From Biopolymer Composites, Biopolymer Composites in Electronics, Elsevier , (2017), Pages 333-352

[38] https://www.ashrae.org/file%20library/technical%20resources/refrigeration/factsheet_ashrae_english_20200424.pdf

[39] Saurabh Yadav, Jie Liu, Sung Chul Kim. "A comprehensive study on 21st-century refrigerants - R290 and R1234yf: A review", International Journal of Heat and Mass Transfer, 2022

[40] E.W. Lemmon , I.H. Bell , M.L. Huber , NIST Standard Reference Database 23: Reference Fluid Thermodynamic and Transport prop- erties-REFPROP, Version 10.0, National institute of standards and technology, standard reference data program, Gaithersburg, 2018 https://trc.nist.gov/refprop/10-PATCH/REFPROP.XLS .

[41] M. Richter , M. O Mclinden , E.W. Lemmon , Thermodynamic Properties of 2,3,3,3-Tetrafluoroprop-1-ene (R1234yf), Vapor Pressure and p- ρ-T Measure- ments and an Equation of State 56 (2011) 3254–3264 .

[42] X. Konga , M. Zhang , Y. Yang , Y. Li , D. Wang , Comparative experimental anal- ysis of direct-expansion solar-assisted heat pump water heaters using R134a and R290, Sol. Energy 203 (2020) 187–196 .

Publications

Paper 1 - Review on energy efficient cooling materials for alternative cooling and waste heat recovery technology

Paper 2 - Effect of Heat Generation on Performance of LiBr-H2O Vapor Absorption Refrigeration System

Review on energy efficient cooling materials for alternative cooling and waste heat recovery technology

[1]Kaushalendra Kumar Dubey, [2]Lavepreet Singh [3]Ayush Sharma [4]Kshitij Kashyap

[1]Associate Professor, Department of Mechanical Engineering, Galgotias University

[2] Assistant Professor Department of Mechanical Engineering, Galgotias University

[3,4]UG student, Department of Mechanical Engineering, Galgotias University

*Corresponding author-dubey.kaushalendra@gmail.com

Abstract

More than 65 percent of overall energy generation comes from fossil fuel-based power plants. As a consequence of this circumstance, the cooling sector consumes more than 40% of all energy generated. This study discusses the significance of new refrigerant trends for alternative cooling technologies. The use of energy-efficient refrigerant materials has a minimal environmental impact, as well as low operating costs and an efficient cooling process. The employment of new age refrigerant capable to recover the waste heat for tri-generation effect (cooling heating and power). The thermo-electric cooling techniques can play the essential role in micro-electronics industry with its efficient cooling. The present state of the art review, as well as a technical appraisal of each technology's potential to reach the market as a complement to or replacement of conventional and high energy paid cooling systems in the future.

Keywords – ODP, GWP, WHR, Eco-friendly Refrigerant, ORC,Tri-Generation systems, TEC

1. Introduction

The additional power consumption from industry and household cooling demand (600 TWh/yr) is expected to absorb more than half of the entire generation. This increased electricity consumption would put significant strain on countriespower sectors. Due to the GHG emissions released during the production of energy needed to power HVACs, as well as the refrigerants utilized in their systems, the rise of HVACs creates environmental challenges. The mechanical compression-based cooling system uses CFC & HFC refrigerants, these category of cooling materials have severe impact on environment in terms of ozone layer degradation and global warming. The new age cooling materials have tremendous potential for heat re-utilization of discarded heat from industry such as refineries, steel industry, power generation, etc. The employment of dumped heat recovery systems for combined heating-cooling and electricity production, including the involvement of new refrigerant trends.

The present research work discusses the comprehensive review of various cooling materials in terms environment safety aspect, future refrigerant,ultra-cooling achievement, commercial application in all aspectand discarded heat utilization of massive plant.

2. Cooling Techniques

All cooling systems function by transporting heat from one location to another, chilling that location and reversing the natural flow of heat with the use of external energy. The following refrigeration systems have been developed and commercialized for food preservation, maintaining low temperature, solidification of gases, Micro-Chip manufacturing, Tele communication, cryogenics and industrial cooling process.

A- Mechanical Compression Refrigeration System (VCRS)
B- Vapor Absorption Refrigeration Systems (VARS).
C- Vapor Adsorption Vapor.
D- Ejector Cooling System.
E- Thermo-Electric Cooling System.
F- Solar-Refrigeration System (Solar Thermal-VARS)

2.1. Vapor Mechanical Compression Refrigeration System (VCRS)

The mechanical compression-based cooling techniques commonly known as vapor compression refrigeration system (VCRS). The working refrigerant material undergoes phase change twice from liquid to vapor at evaporator and again back to vapor to liquid at condenser side. The four basic components of VCRS are linked via a conduit through which refrigerant flows. The evaporator is a fixed location where heat is extracted by the refrigerant in order to accomplish cooling. Low pressure and temperature were maintained via the evaporator.The liquid refrigerant turns in to low pressure vapor.After evaporator vapor refrigerant transferred to compression, here refrigerants will be compressed and convert into high pressure and temperature. Thermodynamically compression process is isentropic compression. The compressed superheated refrigerant vapor enters into condenser for heat rejection at same compression pressure. The vapor refrigerants return to a liquid state after leaving the heat. The saturated liquid refrigerant is transferred from the condenser to the expansion valve in an isenthalpic throttling operation. The refrigerants reach low pressure and temperature before returning to the evaporator. The VCRS system is widely used in applications such as ultra-low cooling solidification of gases, ice production, and HVAC. [11]. Fig 1 comprises of the functioning of the vapor compression refrigeration system.

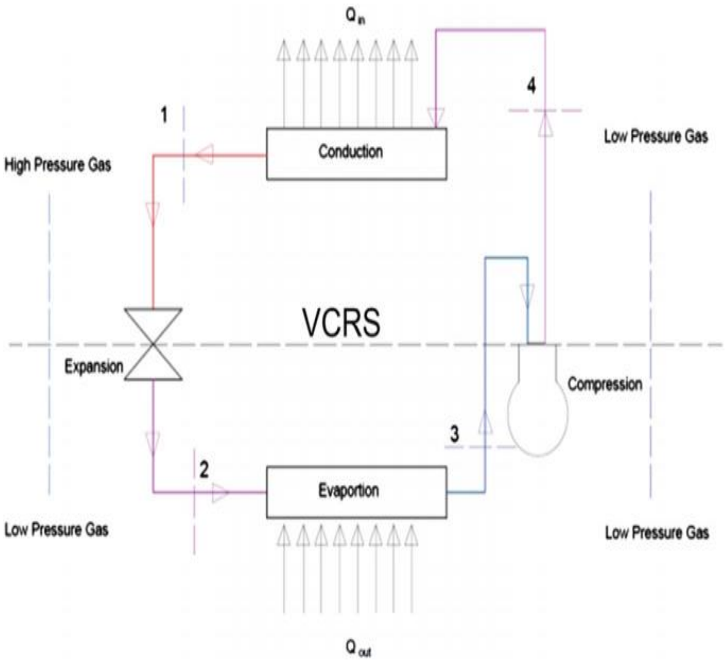


Figure 1 - Vapor Compression Refrigeration System [14]

2.2. Vapor Absorption Refrigeration System (VARS)

The evaporator sends low-pressure dry ammonia vapor into the absorber. Dry ammonia vapor is dissolved in cold water in the absorber, forming a strong ammonia solution. The heat generated during ammonia absorption is dissipated by flowing cold water through the absorber's coils. A pump then transports the highly concentrated ammonia (known as Aqua Ammonia) to the generator through a heat exchanger. The hot weak solution returning from the generator to the absorber heats the strong ammonia solution in the heat exchanger. The warm solution is heated further in the generator by steam coils, gas, or electricity, and the ammonia vapor is forced out of the solution. Ammonia's boiling point is lower than that of water. As a result, the vapors emitted by the generator are mostly ammonia. Weak aqua refers to the weak ammonia solution that is left in the generator. Through the heat exchanger, this weak solution is returned to the absorber. Water vapor may be present in the ammonia vapors emitted by the generator. If this water vapor is allowed to reach the condenser and expansion valve, it may freeze, causing the flow to get clogged. Before the condenser, the system includes an analyzer and rectifiers. The analyzer vapor separates ammonia from water vapor by passing ammonia vapor from the generator through a series of trays. The water vapor that had been separated was returned to the generator. After that, the ammonia vapor is rectified. Water vapor remaining present in ammonia vapor condenses in the rectifier, and the condensate is returned to the analyzer. Following that, the nearly pure ammonia vapor goes through the condenser. The ammonia vapor's latent heat is transferred to the cooling water pumped through the condenser, and the vapor is condensed into liquid ammonia. An expansion valve, also known as a throttle valve, controls the flow of high-pressure liquid ammonia. The high temperature of the liquid ammonia is reduced to a low value, and the liquid ammonia partially evaporates as a result. The water is then piped to the evaporator. The liquid completely vaporizes in the evaporator. The latent heat of evaporation is extracted from the brine or other cooling medium. The cycle is completed when a low-pressure ammonia vapor leaving the evaporator and pass in the absorber. The refrigerating effect is achieved by repeating this cycle.[1**6**]**.** Fig 2comprises of the functioning of the vapor absorption refrigeration system.

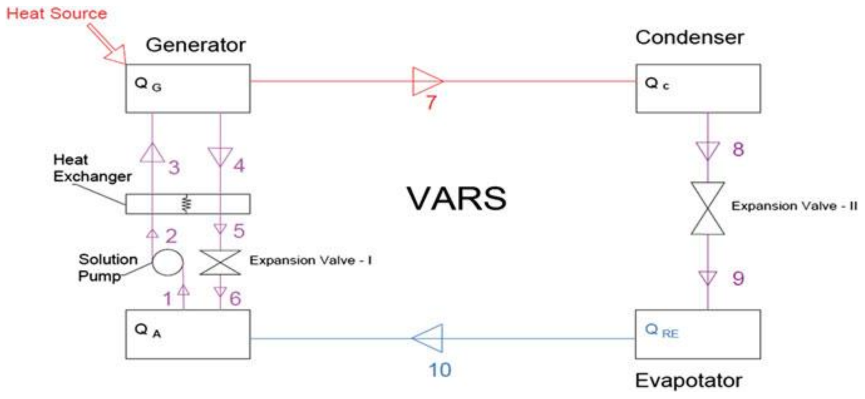


Figure 2 - Vapor Absorption Refrigeration System [14]

2.3. Vapor Adsorption System

The adsorption refrigeration system works similar to vapour compression refrigeration system. The thermal compressor is used in the adsorption system in place of mechanical compressor. It's termed a thermal compressor since it works based on temperature change. The adsorption and desorption phenomena are used to replace the compressor's function in this system. As a result, one adsorption bed will alternate between adsorption and desorption processes. The desorption process necessitates heating, while the adsorption process needs cooling.[17]. Fig 3 It represents the Vapor Adsorption Refrigeration System.

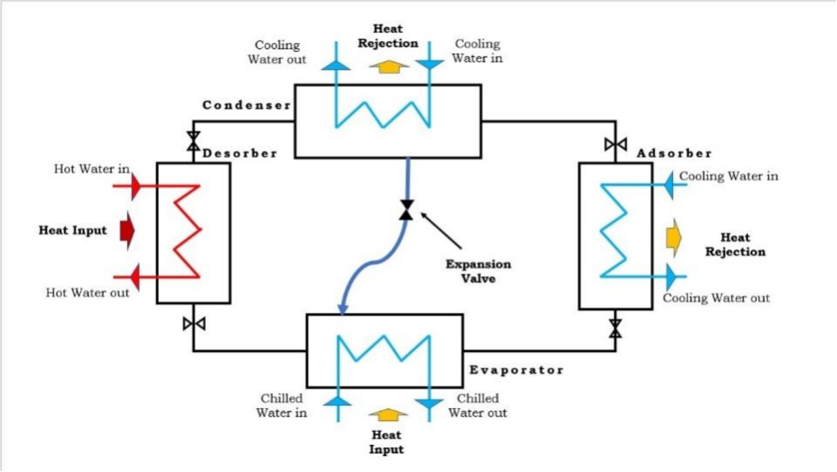


Figure 3 - Vapor Adsorption Refrigeration System [17]

2.4. Ejector Cooling

A vapour compression cycle with an ejector refrigeration system is a variation on the classic vapour compression cycle (VCC). An ejector replaces a compressor to pressurise and release refrigerant vapour from an evaporator to a condenser. The pressure and temperature of working fluid can be increases by thermo-compression process of ejector cooling system. The pressurised working fluid passing through the nozzle it high speed and capture the motive steam from the evaporator. The nozzle ejects the mixed vapour steams into the condenser, where they cool and condense into liquid fluids. Through an expansion valve, some of the liquid refrigerants return to the evaporator, while the rest is sent to the generator. Air conditioning in trains and large buildings can benefit from ejector cooling technology.[18]. Fig 4 It is the schematic representation of Ejector Cooling.

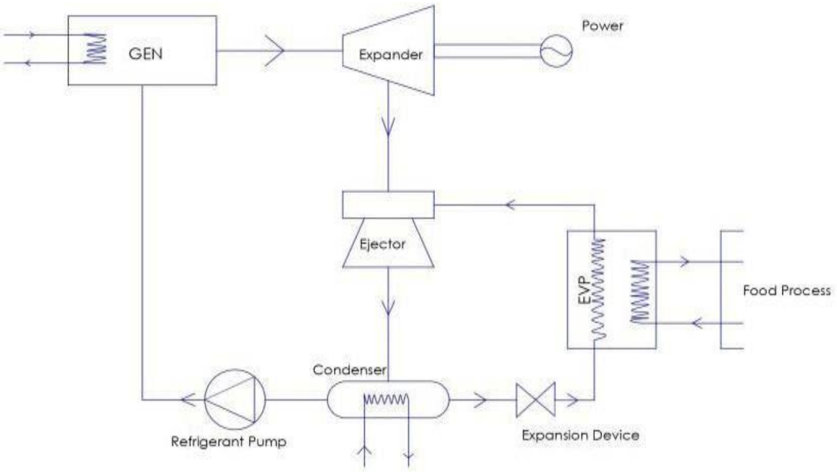


Figure 4 - Ejector Cooling System [18]

2.5.Thermo-Electric Cooling System

The potential application of solid-state thermoelectric (TE) technology as green energy conversion devices has attracted a lot of interest. As a long-term cooling method, proper thermal management of thermoelectric coolers (TEC) is critical. The Peltier effect, which is used in thermoelectric technology, allows for electrical energy conversion in to temperature differentialdirectly [34]. The thermoelectric cooler (TEC) uses the Peltier effect to distribute heat and eliminate hot spots from electrical equipment in an environmentally friendly manner. A TEC could be placed in a small space due to its capacity to be made in small sizes (micro-chips). The cooling effect of TECs varies from milli watts to watts only, it depends on the application. The refrigeration effect and energy performance ratio are significant performance parameters of TEC. [35-36]. Fig 5 It represents the concept of Thermo-Electric Cooling

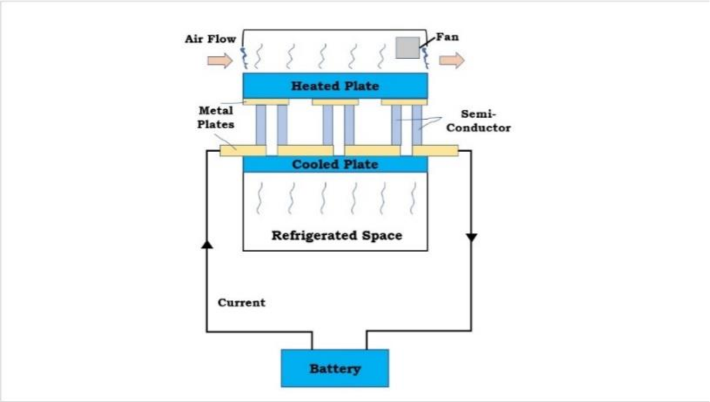


Figure 5 -Concept of Thermo Electric Cooling [37]

2.6 SolarThermal Cooling system using vapor absorption refrigeration.

Non-Toxic and zero global warming index-based refrigeration system integrated with solar thermal system. Solar heating operated this cooling machine is thermo-compression-based machine. The mechanical compression refrigeration system is replaced by the refrigerant pump for pressure of cycle and generator unit provide high temperature to refrigerant. The popularly LiBr-H2O and H2O-NH3 vars system is commercially available which give the sufficient cooling (about 5 ^{0}Cof cooling temperature) for food preservation, milk storage, water chilling etc. It is a one-time investment with minimum running expenses. It is a pollution free system with very low maintenance cost. The components of a Solar Powered Vapor Absorption System are absorber, generator. [39-42]. Fig 6 It represents the Solar – VARS system.

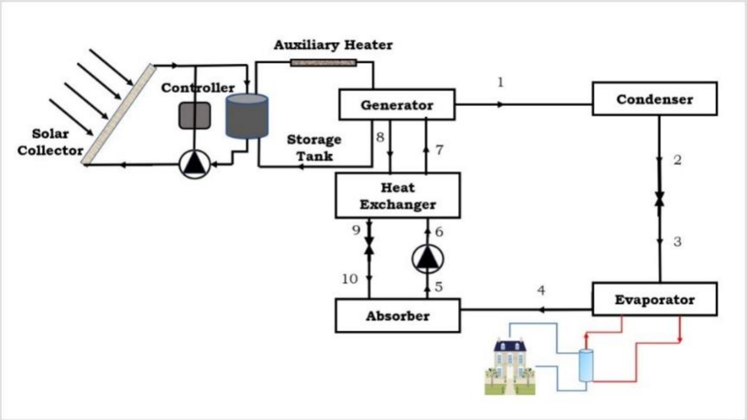


Fig 6 – Solar VARS System Schematic [40]

3. Waste Energy Recovery Thermal System

3.1. Co-generation system

Combined output power and heat process is defined as co-generation system. it that includes joint effect of two different power cycles at the same time, such as gas turbines and steam turbine systems, to simultaneously generate power and usable heat or process heat. The considerable quantity of energy is discarded from the power plant. Maidment and Tozer studiedon different thermodynamic system which gives collective results of energy in form of heating and power in same thermal system. They looked at a number of different ways for combining energy generation, including cooling and engine technologies. [1,2]Bureau of energy efficiency summarized the well-known topping and bottoming cycle co-generation concept, which is suitable for manufacturing operations in which high-temperature heat is required in furnaces and kilns and high-temperature heat is rejected. Cement, steel, ceramics, gas, and petrochemical industries are examples of typical application sectors. Plants in the bottoming cycle are far less prevalent than those in the topping cycle.The furnace's waste gases are utilized to make steam, which is subsequently used to power the turbine, which provides electricity. [3,4]. Fig 7 It shows the graphical representation of the Combined Power Cycle.

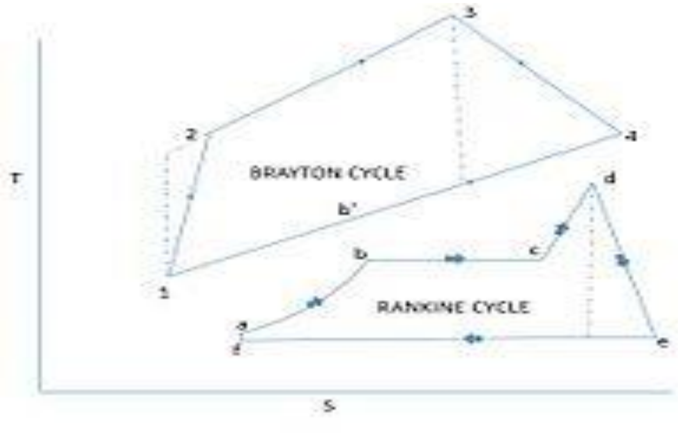


Figure 7 - Combined Power Cycle [13]

3.2. TRIGENERATION SYSTEM

Three forms of energy are produced via tri-generation techniques: electrical power, heating, and cooling. RI-generation systems combine a thermally powered refrigeration system with a CHP (Combined Heat and Power) or cogeneration system to provide cooling, electricity, and heat.This innovative thermal systemhas higher thermal efficiency with multiple effect of energy, and employable in power generation plants [4,5]. Fig 8 It is the schematic representation of the Trigeneration System.

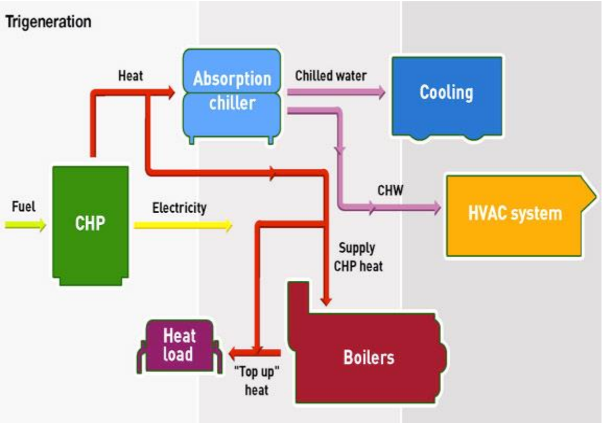


Figure 8 - Trigeneration System [13]

3.3. ORGANIC RANKINE CYCLE (ORC)

Chen and Goswami discussed many thermodynamic methods for utilizing waste heat, such as the Organic Rankine Cycle (ORC). This novel thermal system similar to vapour power Rankine cycle, but low boiling temperature alternative working fluid is employed in place of steam. This organic fluid able to recover the discharged heat from low grade energy source. The cycle includes an expansion turbine, condenser, pump, boiler, and superheated water (provide superheat is needed). HCFC123 (CHCl2CF3), PF5050 (CF3(CF2)3CF3), HFC-245fa (CH3CH2CHF2), HFC 245ca (CF3CHFCH2F), isobutene ((CH3)2C=CH2), n-pentane, and aromatic hydrocarbons have all been used to study organic Rankine cycles. Power plants, cement plants, desalination plants, processing plants, and manufacturing plants are all examples. There are three types of working fluids: dry, wet, and isentropic. An isentropic or dry fluid was recommended for ORC to avoid liquid droplet impingement in turbine blades during expansion. If the fluid is excessively dry, the expanded vapor will exit the turbine with a lot of superheats, which is a waste and will increase the cooling load. [6,7-10].Fig 9 It is the schematic representation of the organic rankine cycle.

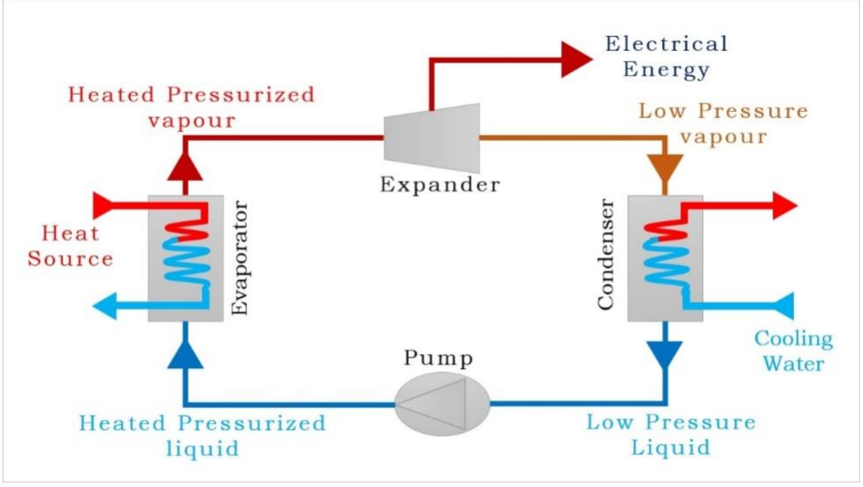


Figure 9 - Organic Rankine Cycle [12]

3.4. DUEL FLUID POWER GENERATION SYSTEM

AleksanderKalia established a two fluid-based combined power & cooling system in 1970-80s. As a source of power and cooling, the Kalina cycles system (KCS) uses a working fluid based on an ammonia-water (Binary fluid) mixture. Ammonia is the refrigerant in this cycle, while water is the solvent, because to the significant difference in their boiling temperatures and high enthalpy. The corrosivity of ammonia is another problem. Copper and zinc are highly corrosive to ammonia, and contaminants in liquid NH3, such as air or CO2, can produce stress corrosion fracture in mild steel. [5,15].Table 1, 2 and 3 are explaining all commercial refrigerants which is selected as per the environmental impact criteria and thermal properties of refrigerants. Fig 10 It is the thermodynamic representation of the Kalina Model.

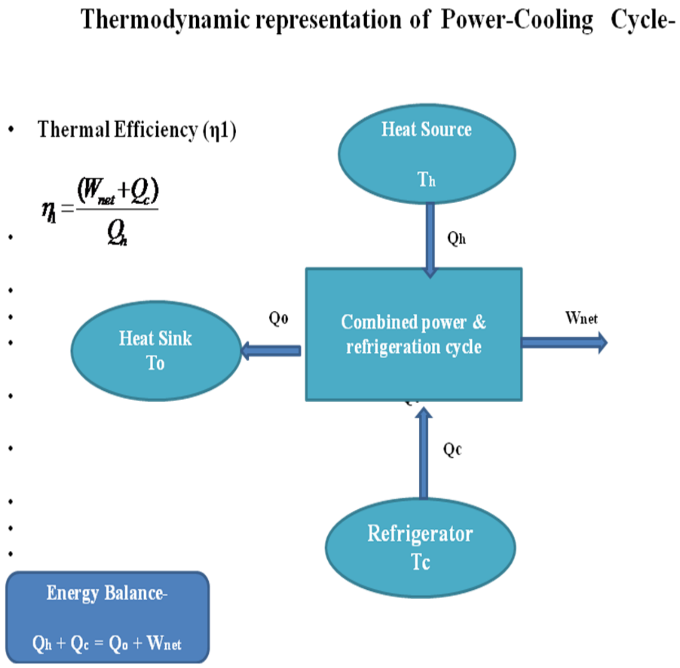


Figure 10–Kalina Thermal Model [13]

Table 1 – Commercial&21st century refrigerants [38-42]

Refrigerants Designation	Refrigerants	Temp_boiling (K)	Temp_freezing (K)	Temp _critical (K)	Pressure _critical (bar)	ODP	GWP
Chlorofluorocarbons							
R113	Trichlorofluoromethane	320.73	238.16	487.3	34.4	0.9	5200
R11	Trichlorofluoromethane	296.98	162.05	471.2	44.1	1	4000
R114	Dichlorotetrafluoroethane	276.94	179.27	418.9	32.6	0.7	16600
R12	Dichlorodifluoromethane	243.37	115.38	385.2	41.2	1	12200
R115	Chloropentafluoroethane	233.83	167.05	353.1	31.5	0.6	39200
Hydrochlorofluorocarbons							
R141b	Dichlorofluoromethane	305.16	-	483.35	46.4	0.15	600
R123	Dichlorodifluoromethane	301.03	166.01	457.15	36.76	0.02	80
R22	Chlorodifluoromethane	232.40	113.16	363.15	49.78	0.05	1480
Hydrofluorocarbons							
R245fa	Pentafluoro propane	288.44	166.49	383.4	31.5	0	790
R134a-21st century refrigerants	Tetrafluoroethane	247.00	176.55	374.25	40.67	0	1160
R507	Azeotrope- Blend	226.05	255.38	344.05	37.92	0	1400
R125	Pentafluoro ethane	224.59	170.01	339.25	36.2	0	3360
R32	Difluoromethane	221.44	137.05	351.4	58.08	0	440
R23	Triflouromethane	191.10	118.16	298.75	48.37	0	24000
Hydrofluoroellifins R1234yf-21stcentury refrigerants	2,3,3,3-Tetrafluoropropene	244.15	220.00	367.85	33.82	0	4
Fluorocarbons/ Perfluorocarbons							
R218	Octofluoropropane	241.66	113.16	344.95	26.8	0	9300
R14	Tetrafluoromethane	145.22	89.27	227.65	37.43	0	6500
Hydrocarbons							
R600	Butane	272.66	134.66	425.12	37.7	0	0
R290-21stcentury refrigerants	Propane	231.07	85.49	369.83	42.1	0	0
R170	Ethane	184.35	90.38	305.32	48.5	0	0
R1150	Ethylene	169.44	104.27	282.34	50.3	0	0
R50	Methane	111.66	90.94	190.56	45.9	0	0
Inorganic Compounds							
R718	Water	373.16	273.16	647.13	219.4	0	0
R717	Ammonia	239.83	195.44	405.65	113.0	0	0
R744	Carbon Dioxide	194.72	216.55	3.4.21	73.9	0	1
R728	Nitrogen	77.38	63.16	126.2	33.9	0	0
R702n	Hydrogen	20.38	13.99	33.19	13.2	0	0
R50	Helium	4.22	-	5.2	2.3	0	0
Hydrofluoroether							
HFE-7100	Methoxynonafluorobutane	334.16	138.16	468.45	22.3	0	320
HFE-7200	Ethoxynonafluorobutane	349.16	135.16	482.0	19.8	0	55
HFE-7000	Methoxyheptafluoropropane	307.16	150.38	438.15	24.8	0	400

Table 2 – Zoetrope's & Azeotropes Refrigerants [38]

Number	Global Warming Potential (GWP100)	Bubble Point, °F	Dew Point, °F	Bubble Point, °C	Dew Point, °C
Zeotropes					
R-407F	1670	-51.00	-39.50	-46.10	-39.70
R-407G	N/A	-20.60	-17.00	-29.20	-27.20
R-407H	N/A	-48.50	-35.70	-44.70	-37.60
R-407I	N/A	-39.60	-27.40	-39.80	-33.00
R-417B	2740	-48.80	-42.70	-44.90	-41.50
R-417C	N/A	-26.90	-20.60	-32.70	-29.20
R-419B	N/A	-35.30	-24.70	-37.40	-31.50
R-422E	N/A	-43.20	-33.50	-41.80	-36.40
R-436C	N/A	-42.70	-39.10	-41.50	-39.50
R-439A	1830	-61.60	-61.20	-52.00	-51.80
R-440A	156	-13.90	-11.70	-25.50	-24.30
R-441A	5	-43.40	-4.70	-41.90	-20.40
R-442A	1750	-51.70	-39.80	-46.50	-39.90
R-443A	4	-48.60	-42.20	-44.80	-41.20
R-444A	89	-29.70	-11.70	-34.30	-24.30
R-444B	295	-48.30	-30.80	-44.60	-34.90
R-445A	118	-58.50	-10.30	-50.30	-23.50
R-446A	461	-56.90	-47.20	-49.40	-44.00
R-447A	572	-56.70	-47.60	-49.30	-44.20
R-447B	N/A[c]	-58.20	-50.80	-50.10	-46.00
R-448A	1360	-50.60	-39.60	-45.90	-39.80
R-449A	1280	-50.80	-39.80	-46.00	-39.90
R-449B	1300	-51.00	-40.40	-46.10	-40.20
R-449C	N/A	-48.30	-36.60	-44.60	-38.10
R-450A	547	-10.10	-9.00	-23.40	-22.80
R-451A	133	-23.40	-22.90	-30.80	-30.50

Table 3 - Natural Refrigerants [38]

REFRIGERANT	ODP	GWP (<100)	BOILING TEMPERATURE	MINIMUM TEMPERATURE	CRITICAL PRESSURE
R-718 (Water)	0	0	100	373.9	217.7
R-729 (Air)	0	0	-194.5	-	-
R-717 (Ammonia)	0	0	-33	132.4	132.4
R-744 (Carbon Dioxide)	0	1	-78	31	73.8
R-170 (Ethane)	0	6	-89	32	49.7
R-600a (Isobutane)	0	3	-12	134.7	36.5
R-290-21st sanctuary refrigerants (Propane)	0	3	-42	96.7	42.5
R-1270 (Propylene)	0	2	-48	91	46.1

4. Alternative Cooling Materials (Nano-Fluids & Thermo-Electric Materials)

In advanced materials technology a particle is defined as a small item that has the same transport properties as a full unit. Nanoparticles range in size from 1 to 100 nanometres (1x109 and 1x107 m). Nanoparticles include tubes and fibres with only two dimensions less than 100 nm. At a threshold length scale of 100 nm, novel features that distinguish particles from bulk material often emerge. Ceramics, metals, and metal oxides are used to create them. [33]

4.1 Nano-Refrigerants

Nanofluids are nanoparticle colloidal suspensions in base fluids that have been tailored to improve their properties at low concentrations. Nanofluids feature 1) greater heat transfer between particles and fluids than regular solid-liquid suspensions due to the increased surface area of nanoparticles. 2) Improved dispersion stability with Brownian motion as the main motion in comparison to the base fluid, there was less particle blockage and less pumping power.

The lubricant nanoparticles mixture is known as nano lubricant, and it can be added to the lubricant (compressor oil). Nanoparticles can also be added to refrigerant, and the refrigerant nanoparticles mixture is referred to as nano refrigerant. Pure refrigerant can be mixed with nano lubricant to make nano lubricant-refrigerant. Nanofluids include nano lubricant, nano refrigerant, and nano lubricant-refrigerant. Nano lubricant enhances tribological properties in refrigeration systems, boosting compressor performance; thermo-physical characteristics of nano refrigerants are improved., increasing cooling effect. The addition of nanoparticles improves the solubility of oil and refrigerant, allowing more oil to be returned to the compressor. [33]. Table 4all the Nano-refrigerants are mentioned in this table.

4.2 Thermo-Electric Materials

Thermoelectric material specifications.

- Because of their room-temperature functioning, semiconductors with narrow band gaps have a high electrical conductivity (to reduce electrical resistance, a source of waste heat)
- Low thermal conductivity (i.e., heat does not flow back from the heated to the cold side); this typically means heavier components.
- Complex structure with a large unit cell.
- Compositions that are complex.
- Extremely anisotropic or symmetric

Bismuth telluride, lead telluride, silicon germanium, and bismuth-antimony alloys are common thermoelectric materials used as semiconductors. Bismuth telluride is the most often utilised of them [35].

Table 4 – List of nano materials-based cooling agents [19-32]

Research Conducted	**Cooling materials**	**Nano-materials and base materials**	**Research Outcome**
Maheshwari [19]	R-134a	ZnO	The heat conduction of spherical nanoparticles increased by 25.26 per cent, whereas cubic nanoparticles increased by 42.5 per cent.
Rezaeinjoybari [20]	R600a	CuO / POE oil	Between 1.5 and 2 percent concentration, the heat transfer coefficient was increased.
Kumar [21]	R134a, R12, R22, R600, R600a	Al2O3 / POE	11.5 % reduction in energy use.
Coumaressin and Palaniradja [22]	R134a	CuO	With nano refrigerant, the evaporator heat transfer coefficient is enhanced. R134a/CuO is an excellent refrigerant to utilize.
Diao [23], Peng [26]	R141b	Cu – SDBS	Boiling's heat transmission coefficient increased as the volume increased.
Sanukrishna [24]	R134a	SiO2 – Poly alkaline glycolnano lubricant	Heat conduction improvesand reducing friction with SiO2 – PAG lubricant.
Tang [25]	R141b POE	δ- Al2O3 with SBDS as surfactant	The heat transmission coefficient of a pool that is boiling has been improved.
Wang [27]	R410a	NiFe2O4 – MNRO as lubricant	By changing the lubricant, the energy efficient ratio (EER) was increased by 6%.
Kumar [28]	R134a	Al2O3 – PAG	The co-efficient of performance is increased by 9-10% less energy use when 0.2% is applied.
Peng [29]	R113	Diamond	Nucleate pool boiling heat transfer coefficient increased by 63.3%.
Trisaksri and Wongwises [30]	R141b	TiO2	The energy rate fell as the volume fraction increased.
Bi [31]	R600a	TiO2	With nano-refrigerant, the performance enhanced. There was a 9.6% reduction in energy consumption.
Adelekan [32]	R600a	Graphene	The smallest power consumption was 65W, the highest PPTR was 5.22, and the maximum increased COP was 0.76.

ABBREVIATIONS

CCHP stands for Combined Cooling, Heating, and Power.

CHP stands for Combined Heat and Power.

CHRP stands for Combined Heat and Refrigeration Power.

CFC stands for Chlorofluorocarbon.

GWP stands for Global Warming Potential.

HCFC stands for Hydrochlorofluorocarbons.

HFC stands for Hydrofluorocarbons.

HFO stands for Hydrofluoro-olefins.

IWH stands for Industrial Waste Heat.

KCS (Kalina Cycle System) is an acronym for "Kalina Cycle System".

ORC stands for Organic Rankine Cycle.

ODP (Ozone Depletion Potential) is a term used to describe the potential for ozone depletion.

TEC stands for Thermo Electric Cooling.

WHR stands for Waste Heat Recovery

Conclusion

The world's protective ozone layer is destroyed by the power full greenhouse gas emission CFCs, HCFCs and halons, which shelter the earth from damaging ultraviolet (UV-B) radiation released by the sun. These synthetic refrigerants also cause the warming of lower atmosphere of earth, and severe impact on climate change.The current review study discusses theevolution of refrigerants which has low GWP and ODP.The natural refrigerants such as CO2, NH3, H2O and hydrocarbons such as R290, R600, R600a, and blends of hydrocarbons are potential solutions to this problem and are now in use in a various cooling technique.The following most notable observations are discussed below.

1. HCs are a viable choice for medium scale cooling applications due to their high energy efficiency, superior thermodynamic features, minimum price, and excellent co-efficient of performance.
2. Many refrigerants, including Propane, Iso-butane, Propylene,Ethyl fluoride,Tetrafluoro propylene, andTetrafluoro propene, have been utilised in auto-mobile air-conditioning systems for electric vehicles. (EVs) literature offers propane and tetrafluoro propylene as propitious refrigerants of 21stcenturyspecially for electric vehicles cooling and millage issue.
3. The inclusion of nano-refrigerants capable to improve the thermo-physical and heat transport properties. When nano-particle concentration is 1.5-2%, studies reveal that the heat conduction of TiO2-R134a based nano-refrigerant increases by 30-32%.In the open literature, there are few studies on the utilisation of nanoparticles with natural refrigerants such hydrocarbons, NH3, and CO2. These researches are required for commercial and industrial applications.S
4. There is limited research on the use of an oil&refrigerant combination, as a result, additional research with various oil concentrations is required.
5. Compact size, light weight, high dependability, lack of motorized parts, norefrigerants required,

direct power supply, and easy to switch in heating – cooling mode are all advantages of thermoelectric cooling systems over traditional refrigeration machines. New high-performance TEC materials are in underway.

6. The utilisation of solar thermal energy for alternative cooling system such as vapour absorption, vapour adsorption and ejector cooling can play key-role for low cooling application without consumption of high-grade energy for rural livelihood industry. The mentioned refrigeration systems can provide the significant cooling by re-use of discharged heat from captive industry.
7. Using a tri-generation thermal system, ORC, and Kalina system, new age cooling materials offer tremendous potential for exceptional cooling effects.

The comprehensive review demonstrate that market participants are well attentive on the serious environmental impact as it relates to HFCs and HCFCs re, as well as the knowledge that natural refrigerants are viable alternatives. However, the risks connected with these natural refrigerants, such as HCs are high flammability, NH3 is highly toxic, and CO2 has high working pressure, are preventing their widespread use.

References

[1] E. Bazques, D. Strom, Cogeneration and interconnection technologies for industrial and commercial use, in: Proceedings of 18th IECEC American Institute of Chemical Engineers, 1983, pp. 2060–2065.

[2] G.G. Maidment, R.M. Tozer, Combined cooling heat and power in supermarkets, Applied Thermal Engineering22 (2002) 653–665.

[3] Yunus A. Cen gel, Michael A. Boles, Thermodynamics: An Engineering Approach, 4th edition, McGraw-Hill, 2002.

[4] https://beeindia.gov.in/sites/default/files/2Ch8.pdf

[5] *Renewable Energy Institute*: Trigeneration Technologies Available. [online], [cited: June 2011], Available on internet< http://www.trigeneration.com/ >

[6] Chen H, Goswami DY, Stefanakos EK. A review of thermodynamic cycles and working fluids for the conversion of low-grade heat. Renewable and Sustainable Energy Reviews 2010; 14:3059–67.

[7] Goswami, D. Y., 1995, ―Solar Thermal Power: Status of Technologies and Opportunities for Research,‖ *Heat and Mass Transfer '95, Proceedings of the 2ndASME-ISHMT Heat andMass Transfer Conference*, Tata-McGraw Hill Publishers, New Delhi, India, pp. 57-60.

[8] Lu, S., and D. Y. Goswami, 2003, ―Optimization of a Novel Combined

Power/Refrigeration Thermodynamic Cycle,‖ *Journal of Solar Energy Engineering*, 125, pp. 212-217.

[9] Tamm, G., D. Y. Goswami, S. Lu, and A. A. Hasan, 2003, ―Novel Combined Power and Cooling Thermodynamic Cycle for Low Temperature Heat Sources, Part I: Theoretical Investigation,‖ *Journal of Solar Energy Engineering*, 125, pp. 218-222.

[10] Tamm, G., and D. Y. Goswami, 2003, ―Novel Combined Power and Cooling Thermodynamic Cycle for Low Temperature Heat Sources, Part II: Experimental Investigation,‖ *Journal of Solar Energy Engineering*, 125, pp. 223-229.

[11] Jain, Vaibhav, S. S. Kachhwaha, and Gulshan Sachdeva. "Thermodynamic performance analysis of a vapor compression–absorption cascaded refrigeration system." *Energy conversion and management* 75 (2013): 685-700.

[12] Quoilin, Sylvain, Martijn Van Den Broek, Sébastien Declaye, Pierre Dewallef, and Vincent Lemort. "Techno-economic survey of Organic Rankine Cycle (ORC) systems." *Renewable and sustainable energy reviews* 22 (2013): 168-186.

[13] Kaushalendra.Kr Dubey,R.S.Mishra, Industrial And Power Plant Waste Heat Recovery Systems For Combined Cooling-Heating And Power Generation**,** International Journal of Advance Research and Innovative Ideas in Education,Vol-3,Issue-3, ISSN NO (O):2395-4396,pp-3682-94,june 2017. 16.0415/IJARIIE-5742

[14] Dubey K.K., Sharma K., Mishra R., Singh S.K., Agarwal B.N. (2021) Theoretical Analysis of Isentropic and Alternative Refrigerant Based Cooling System and Low Carbon Economy. Advances in Industrial and Production Engineering. Lecture Notes in Mechanical Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-33-4320-7_28.Advances in Industrial and Production Engineering pp 307-321.Feb 2021

[15] Kalina, A. I., 1984, ―Combined Cycle System with Novel Bottoming Cycle,‖ *ASME Journal of Engineering for Gas Turbines and Power*, 106, pp. 737-742.

[16] Soteris Kalogirou, George Florides, Savvas Tassou, Louis Wrobel" Design And Construction Of A Lithium Bromide Water Absorption Refrigerator" Clima 2000/Napoli 2001 World Congress – Napoli (I), 15-18 September 2001.

[17] Dubey, Kaushalendra Kumar, and R. S. Mishra. "Thermodynamic (Energy-Exergy) Analysis of Combined Coal based Thermal Power Plant and Solar Integrated Double Bed Vapor Adsorption System for Heat Recovery and Space Cooling." *Saudi Journal of Engineering and Technology* 2, no. 7 (2017): 286-298.

[18] Dubey, Kaushalendra Kumar, and R. S. Mishra. "Solar integrated combined cooling-power generation systems for waste heat recovery using different energy efficient materials." *International Journal of Digital Signals and Smart Systems* 5, no. 2 (2021): 125-136.

[19] P.B. Maheshwari, C.C. Handa, K.R. Nemade, Effect of shape on thermophysical and heat transfer properties of ZnO/R-134a nanorefrigerant, Mater. Today Proc. 5 (2018) 1635–1639.

[20] B. Rezaeianjouybari, M. Sheikholeslami, A. Shafee, H. Babazadeh, A novel Bayesian optimization for flow condensation enhancement using nanorefrigerant: a combined analytical and experimental study, Chem. Eng. Sci. 215 (2020) 115465, https://doi.org/10.1016/j.ces.2019.115465.

[21] R.R. Kumar, K. Sridhar, M. Narasimha, Heat transfer enhancement in domestic refrigerator using R600a/mineral oil/nano-Al2O3 as working fluid, Int. J. Comput. Eng. Res. 3 (2013) 42–50.

[22] T. Coumaressin, K. Palaniradja, Performance analysis of a refrigeration system using nano fluid, Int. J. Adv. Mech. Eng. 4 (2014) 459–470.

[23] Y.H. Diao, C.Z. Li, Y.H. Zhao, Y. Liu, S. Wang, Experimental investigation on the pool boiling characteristics and critical heat flux of Cu-R141b nanorefrigerant under atmospheric pressure, Int. J. Heat Mass Transf. 89 (2015) 110–115.

[24] S.S. Sanukrishna, M. Shafi, M. Murukan, M. Jose Prakash, Effect of SiO2 nanoparticles on the heat transfer characteristics of refrigerant and tribological behaviour of lubricant, Powder Technol. 356 (2019) 39–49.

[25] X. Tang, Y.-H. Zhao, Y.-H. Diao, Experimental investigation of the nucleate pool boiling heat transfer characteristics of d-Al2O3-R141b nanofluids on a horizontal plate, Exp. Therm. Fluid Sci. 52 (2014) 88–96

[26] H. Peng, G. Ding, H. Hu. Influences of refrigerant-based nanofluid composition and heating condition on the migration of nanoparticles during pool boiling. Part II: model development and validation, Int. J. Refrig. 34 2011 1833-1845.

[27] R. Wang, Q. Wu, Y. Wu, Use of nanoparticles to make mineral oil lubricants feasible for use in a residential air conditioner employing hydro-fluorocarbons refrigerants, Energy Build. 42 (11) (2010) 2111–2117.

[28] D.S. Kumar, R. Elansezhian, Experimental study on Al2O3-R134a nano refrigerant in refrigeration system, Int. J. Mod. Eng. Res. 2 (2012) 3927– 3929.

[29] H. Peng, G. Ding, H. Hu, W. Jiang, D. Zhuang, K. Wang, Nucleate pool boiling heat transfer characteristics of refrigerant/oil mixture with diamond nanoparticles, Int. J. Refrig. 33 (2) (2010) 347–358.

[30] V. Trisaksri, S. Wongwises, Nucleate pool boiling heat transfer of TiO2–R141b nanofluids, Int. J. Heat Mass Transf. 52 (5-6) (2009) 1582–1588.

[31] S. Bi, K. Guo, Z. Liu, J. Wu, Performance of a domestic refrigerator using TiO2- R600a nano-refrigerant as working fluid, Energy Convers. Manage. 52 (1) (2011) 733–737.

[32] D.S. Adelekan, O.S. Ohunakin, J. Gill, I.P. Okokpujie, O.E. Atiba, Performance of an Iso-Butane driven domestic refrigerator infused with various concentrations of graphene based nanolubricants, Procedia Manuf. 35 (2019) 1146–1151

[33] *Kirloskar Pneumatic Co. Ltd, India*, amey.majgaonkar@gmail.com.

[34] Giri, J.M., Nain, P.K.S. Performance optimization of thermoelectric cooler using genetic algorithm. Mathematical Modelling of Engineering Problems, Vol. 7, No. 3, (2020) pp. 427-435.

[35] Giri, J.M., Nain, P.K.S.Review of Recent Progresses in Thermoelectric Materials.

Advances in Engineering Materials. Lecture Notes in Mechanical Engineering. Springer, Singapore.. (2021). pp. 269-280.

[36] Giri, J.M., Nain, P.K.S.Maximisation of energy and exergy efficiencies for a sustainable thermoelectric cooling system by applying genetic algorithm. International Journal of Exergy, Vol. 37, No. 1, (2022). pp. 57-73.

[37]D.Ponnamma, G.J.Ogunleye, P. Sharma, M.A.Al Madeed,12 - Piezo- and Thermoelectric Materials From Biopolymer Composites, Biopolymer Composites in Electronics, Elsevier , (2017), Pages 333-352

[38] https://www.ashrae.org/file%20library/technical%20resources/refrigeration/factsheet_ashrae_english_20200424.pdf

[39]Saurabh Yadav, Jie Liu, Sung Chul Kim. "A comprehensive study on 21st-century refrigerants - R290 and R1234yf: A review", International Journal of Heat and Mass Transfer, 2022

[40] E.W. Lemmon , I.H. Bell , M.L. Huber , NIST Standard Reference Database 23: Reference Fluid Thermodynamic and Transport prop- erties-REFPROP, Version 10.0, National institute of standards and technology, standard reference data program, Gaithersburg, 2018 https://trc.nist.gov/refprop/10-PATCH/REFPROP.XLS .

[41] M. Richter , M. O Mclinden , E.W. Lemmon , Thermodynamic Properties of 2,3,3,3-Tetrafluoroprop-1-ene (R1234yf), Vapor Pressure and p- ρ-T Measure- ments and an Equation of State 56 (2011) 3254–3264 .

[42] X. Konga , M. Zhang , Y. Yang , Y. Li , D. Wang , Comparative experimental anal- ysis of direct-expansion solar-assisted heat pump water heaters using R134a and R290, Sol. Energy 203 (2020) 187–196 .

Effect of Heat Generation on Performance of LiBr-H2O Vapor Absorption Refrigeration System

[1]Kaushalendra Kumar Dubey, [2]Avinash Ranjan Patnaik [3]Ayush Sharma [4]Kshitij Kashyap
[1]Associate Professor, Department of Mechanical Engineering, Galgotias University
[2] Assistant Professor GEC, Bilaspur, Chhattisgarh
[3,4]UG student, Department of Mechanical Engineering, Galgotias University
*Corresponding author-dubey.kaushalendra@gmail.com

Abstract

The vapor absorption refrigeration system (VARS) is well-known cooling equipment that uses low-grade heat energy sources and has no hazardous side effects. The coefficient of performance is a significant parameter of cooling machines' performance study. The fundamental laws of energy and entropy generation are used to define the maximum and minimum limits of the energy performance ratio of absorption cooling cycles. The energy study of a LiBr–H2O–based absorption refrigerator with a refrigeration effect of 5TR is carried out. The VARS generator is the primary heat source for operation and its considerable impact on VARS performance. The influence of generator temperature (T_gen) on VARS performance is investigated in this work. The results indicate COP of the cooling machine is increases with the T_gen but after 100 ^{0}Cis it found that COP decreases. The operating T_gen is required to cut off the generator temperature for optimized COP values.

Keywords –Cooling System, Absorbents, Absorption, Energy Performance Ratio, Generator Temperature

1. Introduction

The vapor absorption refrigeration system is comparable to the vapor adsorption refrigeration system because it belongs to the same class of vapor cycles. In contrast to steam adsorption refrigeration systems, absorption systems require heat as an energy source. Therefore, these systems are well known as thermal drive systems or thermal energy drive systems [3-5]. Heat removal is achieved by evaporating the refrigerant at low pressure, and heat removal is achieved by condensing the refrigerant at higher pressures in both the vapor absorption and adsorption refrigeration cycles. The basic difference is that the vapor adsorption system uses a mechanical compressor to generate the pressure difference required to circulate the refrigerant, while the absorption system uses a heat source. Due to this difference, the absorption system works with little or no effort, but the energy must be provided in the form of heat. This makes the system more attractive if cheap heat sources such as solar heat, electricity and waste heat from heat are available.[1,2,6-9]

Vapor Absorption Systems provide a number of advantages, including the ability to use any type of low-grade, low-priced heat energy to create cooling, resulting in significant cost savings. Instead of using expensive and unstable electric power, it can run on steam or any other waste heat source. There are no moving parts, thus operation is quiet, vibration-free, and trouble-free. Furthermore, when compared to power-driven mechanical devices, maintenance expenses are minimal. Instead of ozone-depleting chlorine-based molecules, a pure refrigerant is used to generate the cooling effect.[13-14]

2. Refrigerant-Absorbent combinations for Vapour Absorption Cooling Systems:

On the market today, there are two basic versions of absorption machines. For applications over 50°C, the cycle uses lithium bromide/water (mainly air conditioning). For applications below 50°C, the ammonia/water cycle is used, with ammonia as the refrigerant and water as the absorbent.[15]

Desirable Properties of Refrigerant-Absorbent mixtures:

Vapour Absorption using refrigerant-absorbent combinations, the refrigerant should be more volatile than the absorbent, which means that the refrigerant's boiling point should be substantially lower than the absorbent's. The boiling temperatures of the refrigerant and absorbent must be far apart (more than 2000°C) so that the solution in the Generator only needs to be heated to the temperature required to boil off the refrigerant. This guarantees that only pure refrigerant is used in the refrigerant circuit (condenser-expansion valve-evaporator) [9-10]. The refrigerant in the absorber solution should be extremely soluble. The absorbent should be strongly attracted to the refrigerant. The amount of refrigerant that must be cycled is reduced as a result. Operating pressures should be kept as low as feasible to avoid having to use thick shells and connecting pipes. Within the system, it should not crystallise or solidify. The free flow of solution in the line will be impeded as a result of crystallisation. The mixture must be safe, chemically stable, noncorrosive, inexpensive, and simple to get. A high vaporisation heat should be present in the refrigerant. [4-5]

Refrigerant-Absorbent pairs:[5]
1. **Water-Lithium Bromide (H2O-LiBr) System –** It is employed in applications that require moderate temperatures (over 50°C), such as air conditioning. The refrigerant is water, while the absorbent is lithium bromide.
2. **Ammonia-Water (NH3 - H2O) System** – It uses ammonia as the coolant and water as the absorbent in low-temperature refrigeration applications (less than 50°C).

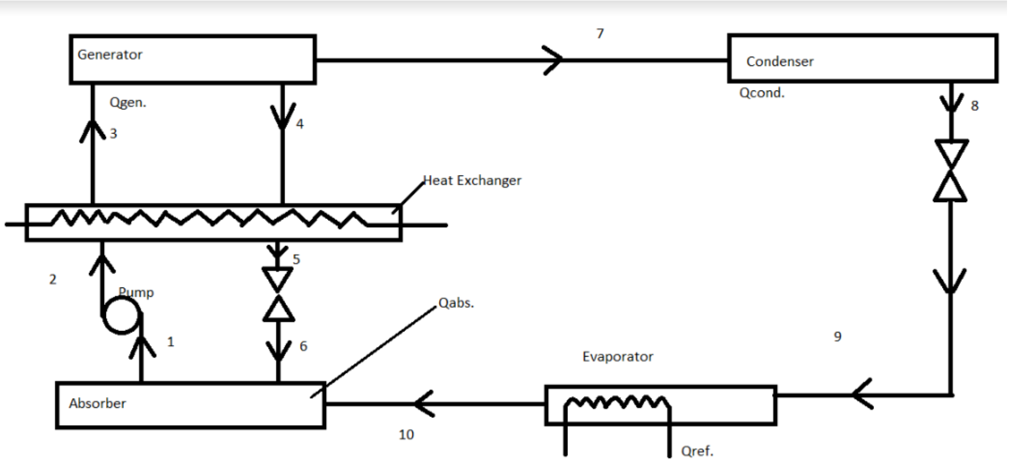


Fig – 1 Schematic of Vapor Absorption Refrigeration System

3. Energy Calculation for the System

Energy Calculation of the system entails calculating the system Coefficient of Performance (COP) by determining critical parameters such as enthalpy, mass flow rates of absorbent & absorbate, and circulation ratio for the entire system. These values will subsequently be used in the system's design. First, by applying mass and energy balance to each component, a set of thermodynamic equations in terms of mass flow rates and enthalpy has been generated. The actual system conditions, such as temperature, pressures, and enthalpies, are then substituted into the equations to produce the system's COP value.

The following assumptions are used to conduct the system's thermodynamic analysis.

Let Mr =Refrigerant mass flow rate, (kg/s)

Mss =Strong solution mass flow rate, (kg/s)

Mws=Weak solution mass flow rate, (kg/s)

Mass (M)balance for the system: -Mss = Mr + Mws

λ = Mws/Mr   Therefore, Mss = Mr(1+λ)   { Where λ is the circulation Ratio }

Heat (Q) balance for each component :-

S No.	Component	Heat (Q)	Heat (Q) balance Equations for each component
1.	Absorber	Qabs	Qabs = Mrh10 + λMrh6 – Mr(1+λ)h1
2.	Heat Exchanger	Qhex	Qhex = Mr(1+λ)(h3-h2)
3.	Generator	Qgen	Qgen = Mrh7 + λMrh4 – Mr(1+ λ)h3
4.	Condenser	QCond	Qcond = Mr(h7-h8)
5.	Evaporator	Qref	Qref = Mr(h10-h9)

Coefficient of Performance (COP) :-

The heat absorbed by the refrigerant in the evaporator is the net refrigerating effect in this system. The sum of the work done by the pump and the heat supplied by the generator is the total energy given to the system. As a result, COP1= Heat Absorbed in Evaporator / (Work Done by Pump + Heat provided to Generator) is the system's Coefficient of Performance (COP1).

Or COP1 = Qref / (Qgen + Wp)

Now, Neglecting the pump work

Therefore**,** **COP 1 = Qref / Qgen** Also **COP 2 = COP 1 / COPcarnot**

4. Thermodynamics of 5-ton LiBr-H2O Vapor Absorption Refrigeration Plant

Operating Temperatures :-

1. Absorber Temperature (Ta) - 20° - 30°C [293 – 303]°K
2. Generator Temperature (Tg) - 60° - 110°C [333 – 383]°K
3. Condenser Temperature (Tc) - 25° - 50°C [298 – 323]°K
4. Evaporator Temperature (Te) - 2° - 10° C [275 – 283]°K

COP Carnot :-

A Carnot refrigeration cycle's COP is solely determined by the cycle's upper and lower temperatures, and it is true that the reversed Carnot cycle is the most efficient refrigeration cycle while running between these two temperature ranges.

COPcarnot = [(Te/Tc-Te)*(Tg-Ta/Tg)

Capacity of the system or Refrigerating effect :-

Cooling Plant Refrigeration Effect (Qref) = 5TR (Also 1TR = 3.5 KW)

Therefore, **Qref = 5TR = 5*3.5 = 17.5 KW**

Calculation of Enthalpy (h) at each of the system's designated points :-

- At any temperature, steam tables can be used to compute the enthalpy of pure water and superheated water vapors.
- The LiBr-H2O (P-T-ξ-h) Chart is used to calculate the enthalpies of solutions.

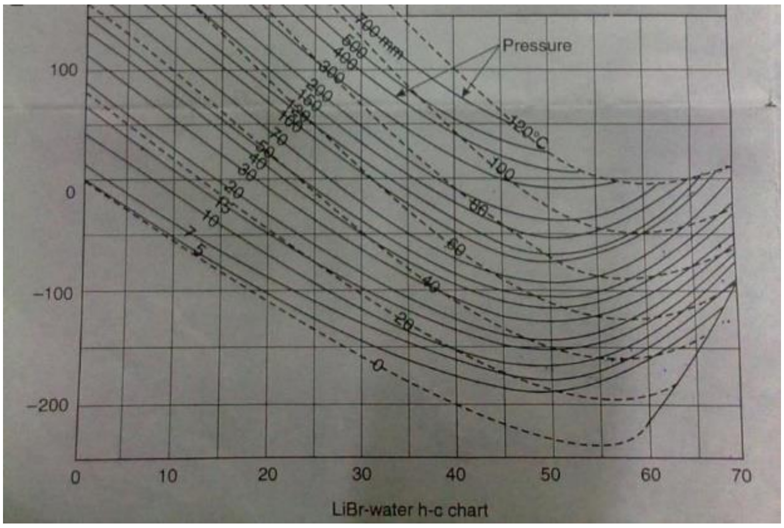


Fig – 2 LiBr-H2O (P-T-ξ-h) Chart

5. LiBr-H2O Enthalpy – Pressure – Temperature-Concentration Tables

Table 1

State Points	Temperature (°K)	Pressure (bar)	Enthalpy (h) (Kj/Kg)	Concentration (ξ)
1.	295	0.00933	-165	0.48
2.	295	0.05199	-165	0.48
3.	323	0.05199	-120	0.48
4.	343	0.05199	-100	0.57
5.	298	0.05199	-185	0.57
6.	295	0.00933	-185	0.57
7.	343	0.31162	2626.9	-
8.	306	0.05199	138.2	-
9.	277	0.00813	2508.9	-
10.	293	0.02337	2538.2	-

Table 2

State Points	Temperature (°K)	Pressure (bar)	Enthalpy (h) (Kj/Kg)	Concentration (ξ)
1.	295	0.00933	-165	0.48
2.	295	0.06399	-165	0.48
3.	323	0.06399	-80	0.48
4.	353	0.06399	-72	0.59
5.	298	0.06399	-185	0.59
6.	295	0.00933	-185	0.59
7.	353	0.47360	2643.8	-
8.	311	0.06624	159.1	-
9.	277	0.00813	2508.9	-
10.	293	0.02337	2538.2	-

Table 3

State Points	Temperature (°K)	Pressure (bar)	Enthalpy (h) (Kj/Kg)	Concentration (ξ)
1.	295	0.00933	-165	0.48
2.	295	0.07999	-165	0.48
3.	323	0.07999	-72	0.48
4.	363	0.07999	-65	0.62
5.	298	0.07999	-185	0.62
6.	295	0.00933	-185	0.62
7.	363	0.70109	2660.1	-
8.	316	0.08639	180.0	-
9.	277	0.00813	2508.9	-
10.	293	0.02337	2538.2	-

Table 4

State Points	Temperature (°K)	Pressure (bar)	Enthalpy (h) (Kj/Kg)	Concentration (ξ)
1.	295	0.00933	-165	0.48
2.	295	0.09865	-165	0.48
3.	323	0.09865	-68	0.48
4.	373	0.09865	-56	0.65
5.	298	0.09865	-185	0.65
6.	295	0.00933	-185	0.65
7.	373	1.0133	2676.0	-
8.	321	0.11162	200.9	-
9.	277	0.00813	2508.9	-
10.	293	0.02337	2538.2	-

6. Result And Graphs

We have devised a computation approach based on simple analytical data that relates the thermodynamic variable of the H2O-LiBr fluid couple in this study.

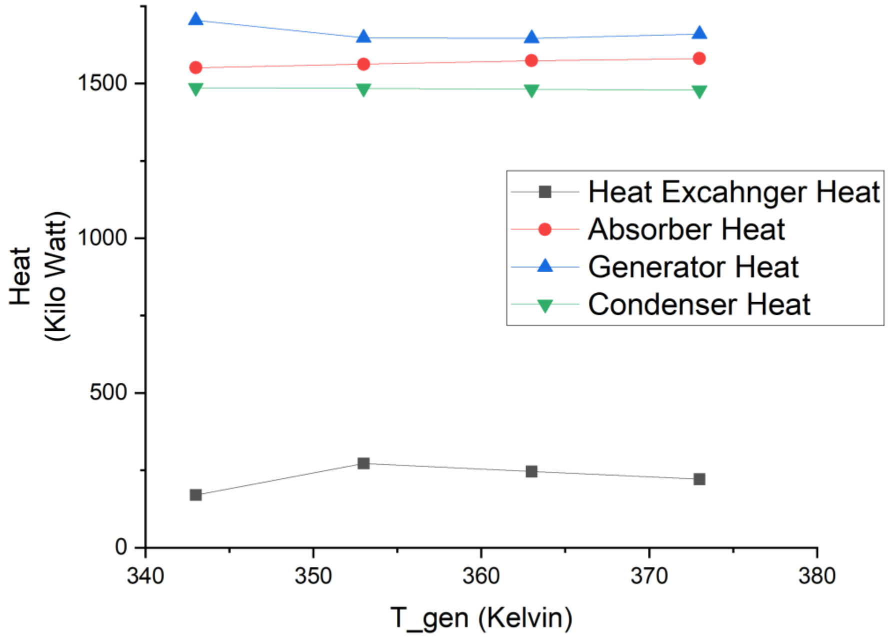
We have calculated the heat transfer for each component and the COPcarnot, COP1, and COP2 for the system, all the calculated values are mentioned in Tables 5 & 6.

Table 5 – Calculated values of COPcarnot, COP1, and COP2 for different conditions

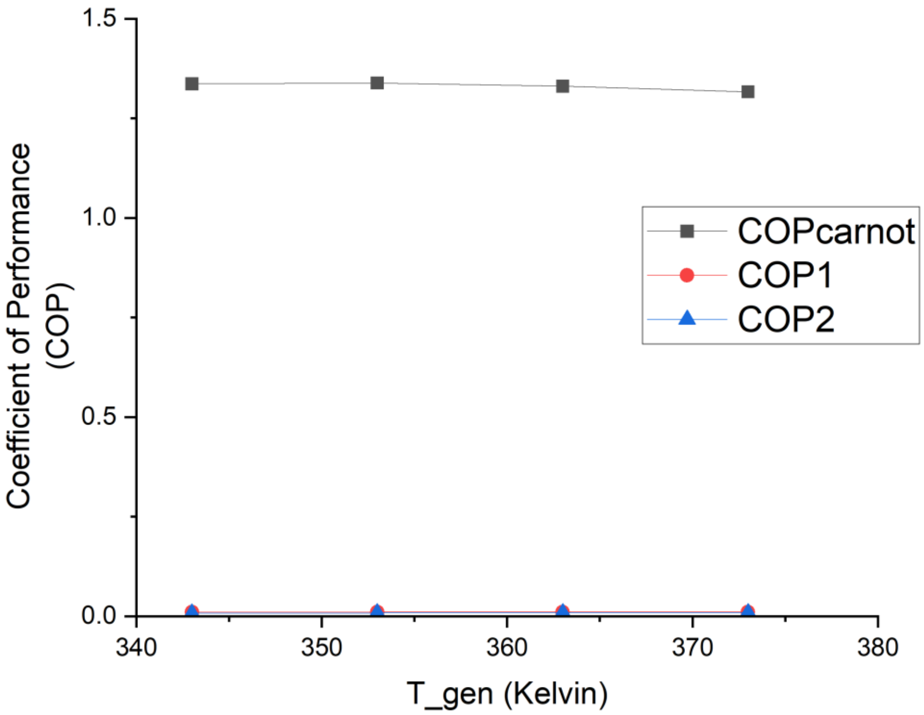
Conditions	**COP Carnot**	**COP 1**	**COP 2**
Case 1 Tg =343°K, Te = 277°K, Tc = 306°K, Ta = 295°K	1.33668	0.01026	0.007681
Case 2 Tg =353°K, Te = 277°K, Tc = 311°K, Ta = 295°K	1.33861	0.01062	0.007933
Case 3 Tg =363°K, Te = 277°K, Tc = 316°K, Ta = 295°K	1.33050	0.01063	0.007990
Case 4 Tg =373°K, Te = 277°K, Tc = 321°K, Ta = 295°K	1.31647	0.01054	0.008006

Table 6 – Heat Transfer Calculated for each Components with Circulation Ratio

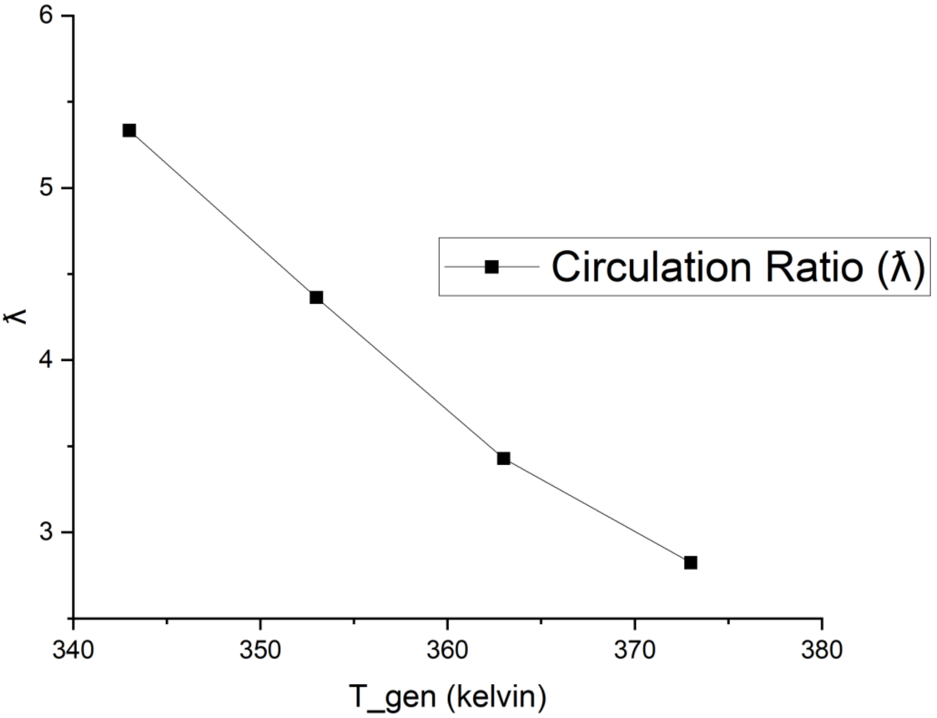
Conditions	**ƛ (Circulation Ratio)**	**Qref (KW)**	**Qhex (KW)**	**Qgen (KW)**	**Qabs (KW)**	**Qcond (KW)**
Tg =343°K	5.33	17.5	170.12	1704.28	1550.84	1486.40
Tg =353°K	4.36	17.5	272.11	1647.64	1562.43	1484.01
Tg =363°K	3.42	17.5	245.50	1646.07	1573.66	1481.26
Tg =373°K	2.82	17.5	221.30	1659.09	1587.27	1478.27



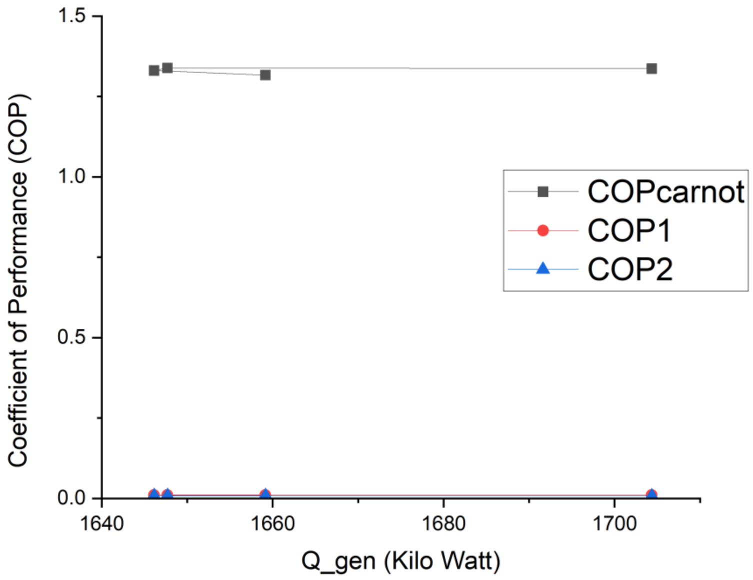
Graph 1 – Generator temperature (Tg) Versus Heat Transfer for each Component



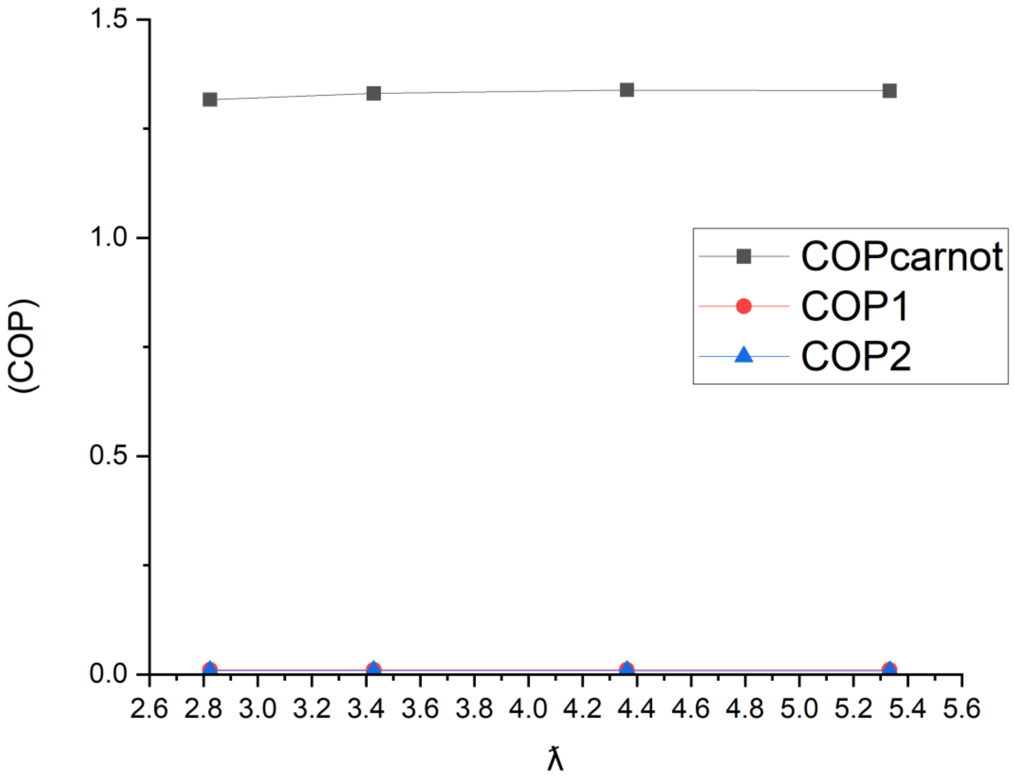
Graph 2 - Generator temperature (Tg) Versus Coefficient of Performance (COPs



Graph 3 - Generator temperature (Tg) Versus Circulation Ratio (ƛ)



Graph 4 – Generator Heat (Qgen) Versus Coefficient of Performance (COPs)



Graph 5 –Circulation Ratio (ƛ)Versus Coefficient of Performance (COPs

7. Conclusion

The system's COP is heavily impacted by the temperature of the system. The effect of temperature on system COP has been investigated for the condenser, generator, absorber, and evaporator. The findings revealed that all four parameters had a significant impact on the system's COP.

ABBREVIATIONS

Qref – Evaporator Heat

Qgen – Generator Heat

Qabs – Absorber Heat

Qhex – Heat Exchanger heat

Qcond – Condenser Heat

Ta – Absorber Temperature

Tg – Generator Temperature

Te – Evaporator Temperature

Tc – Condenser Temperature

References

[1] Mr. S. S. Mali , Prof.M.M.Wagh, Prof. N. N. Shinde, *"Review Of Design Of Single Effect Solar Powered Vapour Absorption Air Conditioning System "* International Journal Of Advance Research In Science And Engineering, Vol. No.2, Issue No.7, July, 2013, Pp 44-52.

[2] Anil Sharma, Bimal Kumar Mishra, Abhinav Dinesh, Ashok Misra, *"Configuration Of A 2 Kw Capacity AbsorptionRefrigeration System Driven By Low Grade Energy Source "*International Journal Of Metallurgical & Materials Science And Engineering (Ijmmse) Vol. 2 Issue 4 Dec - 2012 1-10, Pp 1-9.

[3] Minh, Nguyen Q.; Hewitt, Neil James; And Eames, Philip Charles, *"Improved Vapour Absorption Refrigeration Cycles:Literature Review And Their Application To Heat Pumps "*International Refrigeration And Air Conditioning Conference, 2006 Paper 795, Pp1-8.

[4] Rotchana Prapainop, K O Suen, *" Effects Of Refrigerant Properties On Refrigerant Performance Comparison: A Review"* International Journal Of Engineering Research AndApplications (Ijera) Vol. 2, Issue 4, July-August 2012, Pp.486-493.

[5] G. Ali Mansoori And Vinod Patel, "Thermodynamic Basis For The Choice Of Working Fluids For Solar Absorption Cooling Systems " Solar Energy, Volume 22, Issue 6, 1979, Pp 483-491.

[6] Dubey, Kaushalendra Kumar, and R. S. Mishra. "Thermo-statistical study of sustainable refrigeration system for stack flow heat recovery of combined gas turbine-steam turbine power generation." *Materials Today: Proceedings* 43 (2021): 74-83.

[7] Piyush Mahendru, S.K.Agrawal, P.Pachorkar, " Steady State Analysis Of Vapor Absorption Refrigeration System Using Li-Br-H2o As A Refrigerant " International Journal Of Emerging Technology And Advanced Engineering, Volume 2, Issue 9, September 2012, Pp 328-332.

[8] Dubey, Alok Manas. "Modified vapour absorption refrigeration cycles." *International Journal of Ambient Energy* (2020): 1-7.

[9] Ahmad, Tausif, Md Azhar, M. K. Sinha, Md Meraj, Islam Mohammed Mahbubul, and Akbar Ahmad. "Energy analysis of lithium bromide-water and lithium chloride-water based single effect vapour absorption refrigeration system: A comparison study." *Cleaner Engineering and Technology* 7 (2022): 100432.

[10] Gogoi, T. K. "Estimation of operating parameters of a water–LiBr vapor absorption refrigeration system through inverse analysis." *Journal of Energy Resources Technology* 138, no. 2 (2016).

[11] Amaris, Carlos, Manel Vallès, and Mahmoud Bourouis. "Vapour absorption enhancement using passive techniques for absorption cooling/heating technologies: A review." *Applied energy* 231 (2018): 826-853.

[12] Karamangil, M. I., S. Coskun, O. Kaynakli, and Nurettin Yamankaradeniz. "A simulation study of performance evaluation of single-stage absorption refrigeration system using conventional working fluids and alternatives." *Renewable and Sustainable Energy Reviews* 14, no. 7 (2010): 1969-1978.

[13] Mishra, R. S., and Harwinder Singh. "Detailed parametric analysis of solar driven supercritical CO2 based combined cycle for power generation, cooling and heating effect by vapor absorption refrigeration as a bottoming cycle." Thermal Science and Engineering Progress 8 (2018): 397-410.

[14] Ansari, Khursheed Afroz, Md Azhar, and M. Altamush Siddiqui. "Exergy analysis of single-effect vapor absorption system using design parameters." Journal of Energy Resources Technology 143, no. 6 (2021).

[15] Kaneesamkandi, Zakariya, Abdulaziz Almujahid, and Basharat Salim. "Selection of an Appropriate Solar Thermal Technology for Solar Vapor Absorption Cooling—An MADM Approach." Energies 15, no. 5 (2022): 1882.

Paper 1 Plagrism Report

Research Paper@ 25 feb - FINAL.docx

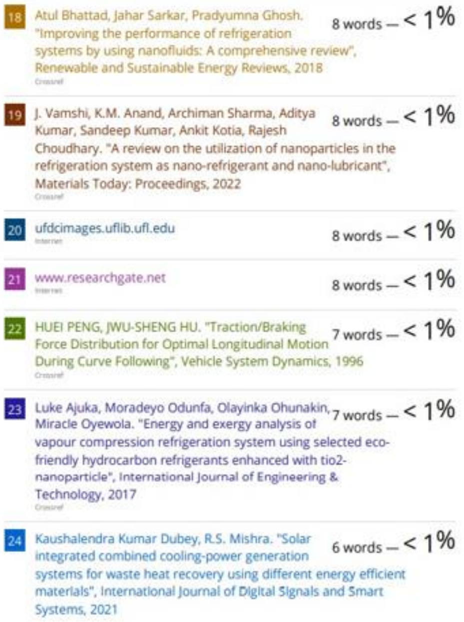
ORIGINALITY REPORT

8%
SIMILARITY INDEX

PRIMARY SOURCES

1	pdfs.semanticscholar.org Internet	44 words — 1%
2	krishisanskriti.org Internet	35 words — 1%
3	en.wikipedia.org Internet	31 words — 1%
4	scholarcommons.usf.edu Internet	30 words — 1%
5	ijari.org Internet	26 words — 1%
6	www.mechanicalwalkins.com Internet	21 words — < 1%
7	www.ias.ac.in Internet	19 words — < 1%
8	Suraj Kumar, B. Kanimozhi, M. Sunil Kumar. "Performance evaluation of refrigeration system using nano-fluid", Materials Today: Proceedings, 2021 Crossref	16 words — < 1%
9	Celen, Ali, Alican Çebi, Melih Aktas, Omid Mahian, Ahmet Selim Dalkilic, and Somchai Wongwises. "A	15 words — < 1%

	review of nanorefrigerants: Flow characteristics and applications", International Journal of Refrigeration, 2014. Crossref	
10	Hasan, A.A.. "First and second law analysis of a new power and refrigeration thermodynamic cycle using a solar heat source", Solar Energy, 200211 Crossref	15 words — < 1%
11	Saidur, R., M. Rezaei, W.K. Muzammil, M.H. Hassan, S. Paria, and M. Hasanuzzaman. "Technologies to recover exhaust heat from internal combustion engines", Renewable and Sustainable Energy Reviews, 2012. Crossref	11 words — < 1%
12	cwww.intechopen.com Internet	11 words — < 1%
13	cyberleninka.org Internet	11 words — < 1%
14	eprints.covenantuniversity.edu.ng Internet	10 words — < 1%
15	www.springerprofessional.de Internet	10 words — < 1%
16	"Handbook of Food Process Design", Wiley, 2012 Crossref	9 words — < 1%
17	Saidur, R.. "A review on the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systems", Renewable and Sustainable Energy Reviews, 201101 Crossref	9 words — < 1%



18	Atul Bhattad, Jahar Sarkar, Pradyumna Ghosh. "Improving the performance of refrigeration systems by using nanofluids: A comprehensive review", Renewable and Sustainable Energy Reviews, 2018 Crossref	8 words — < 1%
19	J. Vamshi, K.M. Anand, Archiman Sharma, Aditya Kumar, Sandeep Kumar, Ankit Kotia, Rajesh Choudhary. "A review on the utilization of nanoparticles in the refrigeration system as nano-refrigerant and nano-lubricant", Materials Today: Proceedings, 2022 Crossref	8 words — < 1%
20	ufdcimages.uflib.ufl.edu Internet	8 words — < 1%
21	www.researchgate.net Internet	8 words — < 1%
22	HUEI PENG, JWU-SHENG HU. "Traction/Braking Force Distribution for Optimal Longitudinal Motion During Curve Following", Vehicle System Dynamics, 1996 Crossref	7 words — < 1%
23	Luke Ajuka, Moradeyo Odunfa, Olayinka Ohunakin, Miracle Oyewola. "Energy and exergy analysis of vapour compression refrigeration system using selected eco-friendly hydrocarbon refrigerants enhanced with tio2-nanoparticle", International Journal of Engineering & Technology, 2017 Crossref	7 words — < 1%
24	Kaushalendra Kumar Dubey, R.S. Mishra. "Solar integrated combined cooling-power generation systems for waste heat recovery using different energy efficient materials", International Journal of Digital Signals and Smart Systems, 2021	6 words — < 1%

	Crossref	
25	Manel Taktak Meziou, Jawhar Ghommam, Nabil Derbel. "On the fast motion control of R/W head track following in hard-disc-drives", International Journal of Digital Signals and Smart Systems, 2017 Crossref	6 words — < 1%
26	ir.ymlib.yonsei.ac.kr Internet	6 words — < 1%

EXCLUDE QUOTES ON
EXCLUDE BIBLIOGRAPHY ON
EXCLUDE MATCHES < 6 WORDS

Paper 2 Plagrism Report

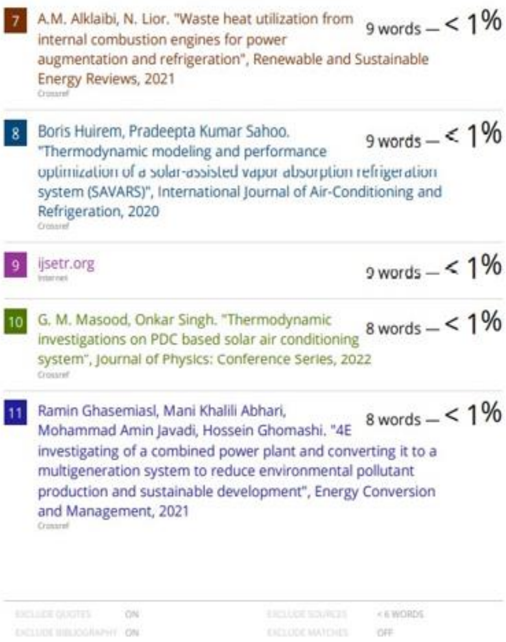
Paper 2 @20 May-FINAL.docx

ORIGINALITY REPORT

9%
SIMILARITY INDEX

PRIMARY SOURCES

1	mafiadoc.com Internet	40 words — 2%
2	Ayush Kumar, Ayush Raj, Shubham Kumar, J.P. Kesari. "Development of solar powered air conditioner using flat plate collector", Materials Today: Proceedings, 2021 Crossref	22 words — 1%
3	www.ijraset.com Internet	18 words — 1%
4	www.slideshare.net Internet	18 words — 1%
5	Horuz, I.. "Experimental investigation of a vapor absorption refrigeration system", International Journal of Refrigeration, 200401 Crossref	15 words — 1%
6	Bukola Olalekan Bolaji, Ademola Ezra Adeleke, Michael Rotimi Adu, Mabel Usunobun Olanipekun, Emmanuel Akinnibosun. "Theoretical Investigation of Energy-Saving Potential of Eco-Friendly R430A, R440A and R450A Refrigerants in a Domestic Refrigerator", Iranian Journal of Science and Technology, Transactions of Mechanical Engineering, 2017 Crossref	11 words — 1%



7	A.M. Alklaibi, N. Lior. "Waste heat utilization from internal combustion engines for power augmentation and refrigeration", Renewable and Sustainable Energy Reviews, 2021 Crossref	9 words — < 1%
8	Boris Huirem, Pradeepta Kumar Sahoo. "Thermodynamic modeling and performance optimization of a solar-assisted vapor absorption refrigeration system (SAVARS)", International Journal of Air-Conditioning and Refrigeration, 2020 Crossref	9 words — < 1%
9	ijsetr.org Internet	9 words — < 1%
10	G. M. Masood, Onkar Singh. "Thermodynamic investigations on PDC based solar air conditioning system", Journal of Physics: Conference Series, 2022 Crossref	8 words — < 1%
11	Ramin Ghasemiasl, Mani Khalili Abhari, Mohammad Amin Javadi, Hossein Ghomashi. "4E investigating of a combined power plant and converting it to a multigeneration system to reduce environmental pollutant production and sustainable development", Energy Conversion and Management, 2021 Crossref	8 words — < 1%

EXCLUDE QUOTES ON
EXCLUDE BIBLIOGRAPHY ON
EXCLUDE SOURCES < 6 WORDS
EXCLUDE MATCHES OFF

THESIS PLAGIARISM REPORT

Capstone Thesis @28 may.docx

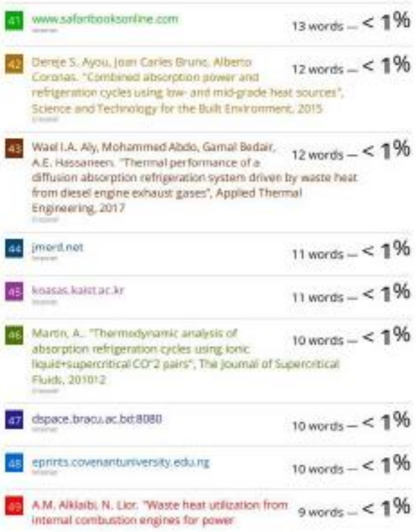
ORIGINALITY REPORT

15%
SIMILARITY INDEX

PRIMARY SOURCES

1	dx.doi.org	181 words — 1%
2	www.ijraset.com	126 words — 1%
3	coek.info	99 words — 1%
4	pdfs.semanticscholar.org	76 words — 1%
5	en.wikipedia.org	73 words — 1%
6	mafiadoc.com	64 words — 1%
7	scholarcommons.usf.edu	60 words — < 1%
8	scholarsmepub.com	54 words — < 1%
9	ijari.org	52 words — < 1%
10	www.ias.ac.in	48 words — < 1%
11	Ayush Kumar, Ayush Raj, Shubham Kumar, J.P. Kesari. "Development of solar powered air conditioner using flat plate collector", Materials Today: Proceedings, 2021	44 words — < 1%
12	ijsetr.org	38 words — < 1%
13	www.slideshare.net	36 words — < 1%
14	Touaibi, Rabah, Michel Feidt, Elena Eugenia Vasilescu, and Miloud Tahar Abbes. "Parametric study and exergy analysis of solar water-lithium bromide absorption cooling system", International Journal of Exergy, 2013.	34 words — < 1%
15	dokumen.pub	34 words — < 1%
16	www.jetir.org	34 words — < 1%
17	Suraj Kumar, B. Kanimozhi, M. Sunil Kumar. "Performance evaluation of refrigeration system using nano-fluid", Materials Today: Proceedings, 2021	32 words — < 1%
18	www.intechopen.com	32 words — < 1%
19	Zhu, Linghui. "Simulation and Development of Advanced Absorption Refrigeration Cycles.", Proquest, 2014.	28 words — < 1%
20	Bhavesh Patel, Nishith B. Desai, Surendra Singh Kachhwaha, Vaibhav Jain, Nanji Hadia. "Thermo-economic analysis of a novel organic Rankine cycle integrated cascaded vapor compression–absorption system", Journal of Cleaner Production, 2017	25 words — < 1%
21	Khelifa Salhi, Mourad Korichi, Khaled M. Ramadan. "Thermodynamic and thermo-economic analysis of compression-absorption cascade refrigeration system using low-GWP HFO fluids powered by geothermal energy", International Journal of Refrigeration, 2018	25 words — < 1%
22	worldwidescience.org	25 words — < 1%
23	uir.unisa.ac.za	23 words — < 1%
24	Saidur, R., M. Rezaei, W.K. Muzammil, M.H. Hassan, S. Paria, and M. Hasanuzzaman. "Technologies to recover exhaust heat from internal combustion engines", Renewable and Sustainable Energy Reviews, 2012.	22 words — < 1%
25	cyberleninka.org	22 words — < 1%
26	Varuneswara Reddy Panyam, N.D. Banker. "Thermodynamic assessment of a gas turbine power plant integrated with an adsorption refrigeration system", Applied Thermal Engineering, 2017	21 words — < 1%
27	www.irjet.net	21 words — < 1%
28	www.springerprofessional.de	21 words — < 1%
29	Saurabh Yadav, Jie Liu, Sung Chul Kim. "A comprehensive study on 21st-century refrigerants - R290 and R1234yf: A review", International Journal of Heat and Mass Transfer, 2022	19 words — < 1%
30	Saidur, R.. "A review on the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systems", Renewable and Sustainable Energy Reviews, 201101	18 words — < 1%
31	www.researchgate.net	18 words — < 1%
32	Atul Bhattad, Jahar Sarkar, Pradyumna Ghosh. "Improving the performance of refrigeration systems by using nanofluids: A comprehensive review", Renewable and Sustainable Energy Reviews, 2018	16 words — < 1%
33	G. M. Masood, Onkar Singh. "Thermodynamic investigations on PDC based solar air conditioning system", Journal of Physics: Conference Series, 2022	16 words — < 1%

34	J. Vamshi, K.M. Anand, Archiman Sharma, Aditya Kumar, Sandeep Kumar, Ankit Kotia, Rajesh Choudhary. "A review on the utilization of nanoparticles in the refrigeration system as nano-refrigerant and nano-lubricant", Materials Today: Proceedings, 2022	16 words — < 1%
35	Shi, Rongqi, Tianqi He, Jie Peng, Yangjun Zhang, and Weilin Zhuge. "System design and control for waste heat recovery of automotive engines based on Organic Rankine Cycle", Energy, 2016.	16 words — < 1%
36	dste.py.gov.in	16 words — < 1%
37	ufdcimages.uflib.ufl.edu	16 words — < 1%
38	Ali Celen, Alican Çebi, Melih Aktas, Omid Mahian, Ahmet Selim Dalkilic, Somchai Wongwises. "A review of nanorefrigerants: Flow characteristics and applications", International Journal of Refrigeration, 2014	15 words — < 1%
39	Gökhan Yıldız, Ümit Ağbulut, Ali Etem Gürel. "A review of stability, thermophysical properties and impact of using nanofluids on the performance of refrigeration systems", International Journal of Refrigeration, 2021	14 words — < 1%
40	Yi Chen, Wei Han, Hongguang Jin. "Thermodynamic performance optimization of the absorption-generation process in an absorption refrigeration cycle", Energy Conversion and Management, 2016	14 words — < 1%



41	www.safaribooksonline.com	13 words — < 1%
42	Dereje S. Ayou, Joan Carles Bruno, Alberto Coronas. "Combined absorption power and refrigeration cycles using low- and mid-grade heat sources", Science and Technology for the Built Environment, 2015	12 words — < 1%
43	Wael I.A. Aly, Mohammed Abdo, Gamal Bedair, A.E. Hassaneen. "Thermal performance of a diffusion absorption refrigeration system driven by waste heat from diesel engine exhaust gases", Applied Thermal Engineering, 2017	12 words — < 1%
44	jmerd.net	11 words — < 1%
45	koasas.kaist.ac.kr	11 words — < 1%
46	Martin, A.. "Thermodynamic analysis of absorption refrigeration cycles using ionic liquid+supercritical CO"2 pairs", The Journal of Supercritical Fluids, 201012	10 words — < 1%
47	dspace.bracu.ac.bd:8080	10 words — < 1%
48	eprints.covenantuniversity.edu.ng	10 words — < 1%
49	A.M. Alklaibi, N. Lior. "Waste heat utilization from internal combustion engines for power	9 words — < 1%

	augmentation and refrigeration", Renewable and Sustainable Energy Reviews, 2021	
50	Gomri, R.. "Investigation of the potential of application of single effect and multiple effect absorption cooling systems", Energy Conversion and Management, 201008	9 words — < 1%
51	Kaynakli, O.. "Theoretical study on the effect of operating conditions on performance of absorption refrigeration system", Energy Conversion and Management, 200702	9 words — < 1%
52	Meibo Xing, Hongfa Zhang, Cancan Zhang. "An Update Review on Performance Enhancement of Refrigeration Systems Using Nano-Fluids", Journal of Thermal Science, 2022	9 words — < 1%
53	Vaibhav Jain, S.S. Kachhwaha, Gulshan Sachdeva. "Thermodynamic performance analysis of a vapor compression–absorption cascaded refrigeration system", Energy Conversion and Management, 2013	9 words — < 1%
54	acd-ext.gsfc.nasa.gov	9 words — < 1%
55	eprints.staffs.ac.uk	9 words — < 1%
56	Andrew D. Chiasson. "Geothermal Heat Pump and Heat Engine Systems", Wiley, 2016	8 words — < 1%

57	Brede A.L. Hagen, Trond Andresen, Petter Nekså. "Equation-oriented methods for optimizing Rankine cycles using radial inflow turbine", Energy, 2022	8 words — < 1%
58	M. Mohanraj, S. Jayaraj, C. Muraleedharan. "Modeling of a Direct Expansion Solar Assisted Heat Pump Using Artificial Neural Networks", International Journal of Green Energy, 2008	8 words — < 1%
59	Sankarlal, T.. "Experimental investigations on ejector refrigeration system with ammonia", Renewable Energy, 200707	8 words — < 1%
60	eprints.kfupm.edu.sa	8 words — < 1%
61	link.springer.com	8 words — < 1%
62	scholar.ppu.edu	8 words — < 1%
63	www.ijritcc.org	8 words — < 1%
64	Bukola Olalekan Bolaji, Ademola Ezra Adeleke, Michael Rotimi Adu, Mabel Usunobun Olanipekun, Emmanuel Akinnibosun. "Theoretical Investigation of Energy-Saving Potential of Eco-Friendly R430A, R440A and R450A Refrigerants in a Domestic Refrigerator", Iranian Journal of Science and Technology, Transactions of Mechanical Engineering, 2017	7 words — < 1%