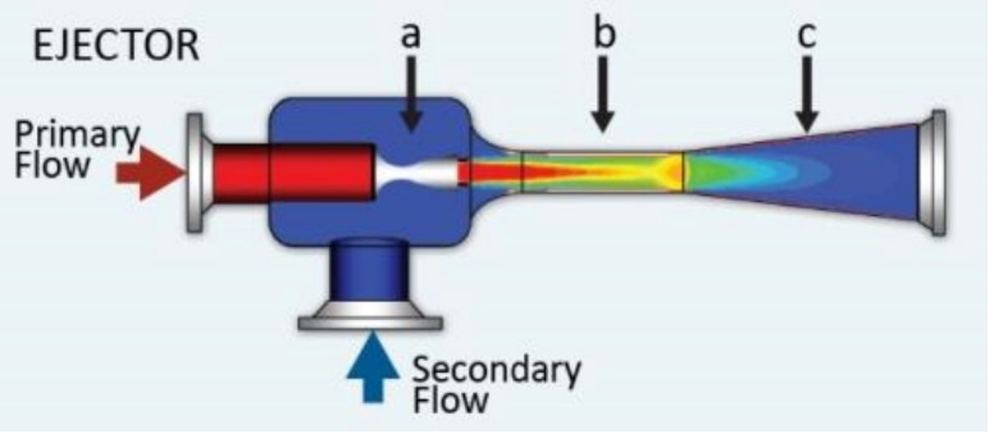
PROJECT REPORT ON

Performance Analysis of Exhaust heat powered automobile air-conditioning system based on ejector refrigeration cycle



PRESENTED BY: LOKESH BEHL

(2K12/THE/26)

UNDER THE GUIDANCE OF:

SH. N.A. ANSARI

CERTIFICATE

This is to certify that the report entitled **“PERFORMANCE ANALYSIS OF EXHAUST HEAT POWERED AUTOMOBILE AIR CONDITIONING SYSTEM BASED ON EJECTOR REFRIGERATION CYCLE”** by **LOKESH BEHL** is in fulfillment for the award of Degree of Master of Technology (M.Tech) under my supervision and guidance. He has completed his work with sincerity. The work embodied in this project has not been submitted for the award of any degree to the best of my knowledge.

NAUSHAD.A. ANSARI
(Assistant Professor)
Department of Mechanical Engineering
Delhi Technological University

ACKNOWLEDGEMENT

First of all, I would like to express my gratitude to God for giving me ideas and strength to make my dreams true and accomplish this thesis.

To achieve success in my work, guidance plays an important role. It makes us put right amount of energy in the right direction and at the right time to obtain the desired result. Express my sincere gratitude to my guide, **MR. NAUSHAD A. ANSARI**, Asst. Professor, Mechanical Engineering Department for giving me valuable guidance during the course of this work, for his ever encouraging and timely moral support. His enormous knowledge always helped me unconditionally to solve various problems.

I am grateful to XXX labs for providing the infrastructure for conducting the experiment required for the proper analysis.

I am greatly thankful to **DR. R.S. MISHRA**, Professor and Head, Mechanical Engineering Department, Delhi Technological University, for his encouragement and inspiration for execution of this work. I express my feelings of thanks to the entire faculty and staff, Department of Mechanical Engineering, Delhi Technological University for their help, inspiration and moral support, which went a long way in the successful completion of my report work.

(LOKESH BEHL)
M.Tech (Thermal Engg.)
2K12/THE/26

ABSTRACT

Enthusiasm for using waste heat to drive refrigeration frameworks for aerating and cooling or refrigeration purposes has developed ceaselessly. Waste heat worked cooling is included numerous alluring components in residential and also mechanical uses and is one way towards a more reasonable vitality framework. The execution of such cooling frameworks is firmly subject to running states of a engine. These cooling frameworks can be effectively worked in areas where the adequate measure of depleted heat from a engine is accessible.

A waste heat driven ejector refrigeration framework has been chosen as a contextual analysis for a further point by point examination. In which the depleted heat from a Hindustan Ambassador engine utilized as a driving operator for the cooling cycle. The low temperature heat source can be utilized to drive the ejector refrigeration cycle, making the framework appropriate for mix with the heat exchanger. Investigation of the waste heat driven ejector framework is started by enduring state examination. Framework execution relies on upon the decision of working liquid (refrigerant), working conditions and ejector geometry. An ejector refrigeration cycle utilizing R-134a as working liquids to creates great execution and lower natural effect, since customary working liquids, CFC's and HFC's are solid atmosphere gasses. Advance on, vitality examination is utilized as an apparatus in distinguishing ideal working conditions and researching misfortunes in the framework. Vitality examination delineates that the dissemination of the irreversibilities in the cycle between parts depends unequivocally on the working temperatures. The most critical piece of the proposition is to investigate the waste heat turning out from a Hindustan Ambassador engine and utilization of this warmth to drive the cooling arrangement of the vehicle to give agreeable conditions in the inside without utilizing any extra mechanical work as utilized as a part of current situation.

Keywords: Waste heat recovery; Waste heat-driven Refrigeration System; Ejector; Ejector Refrigeration Cycle.

List of figures

List of Tables

Table of Content

Chapter 1

Introduction

1.1 Introduction of refrigeration.

Refrigeration is a procedure of keeping up low temperature in contrast with encompassing temperature. “Refrigeration is the process of removing heat from an enclosed space, or from a substance, and rejecting it elsewhere for the primary purpose of lowering the temperature of the enclosed space or substance and then maintaining that lower temperature.”

It is done using a mechanical device e.g. pump with the assistance of a substance called refrigerant which ingests heat from low temperature space and discharges heat to high temperature space. A refrigerant can work in two phase conditions, i.e., liquid and gas, in case of vapour compression refrigeration system and it can also work in single-phase in case of air cycle refrigeration.

1.2 Applications of Refrigeration.

o Refrigeration of food items at domestic level and in mass storage warehouses.
o Air-conditioning of spaces.
o Cool stockpiling of organic products, vegetables, fish and meats securely for long stretches.
o Meats, poultry and fish in atmosphere controlled conditions.
o Refrigeration helps in keeping products of the soil new for more.
o Dairy items likewise require refrigeration.
o Refrigeration is required to condense gasses like oxygen, nitrogen, and so forth.
o Refrigeration is utilized as a part of oil refineries and concoction plants to keep up specific procedures at low temperatures.
o Refrigeration is utilized to temper steel and cutlery.

1.3 Methods or types of Refrigeration System.

1. Vapour Compression Refrigeration System.
2. Vapour Absorption Refrigeration System.
3. Vapour Ejection Refrigeration System.
4. Vortex Tube Refrigeration System.
5. Thermo-electric Refrigeration.
6. Magnetic Refrigeration.
7. Cascade Refrigeration System.

1.3.1. Vapour Compression Refrigeration System.

In vapour-compression heat is removed from the space to be cooled by removing heat using a circulating liquid refrigerant as the medium. Figure 1.1 shows a, single-stage vapour-compression system. There are four components in this system: a compressor, a condenser, a thermal expansion valve (also called a throttle valve), and an evaporator. Refrigerant enters the compressor in the form of saturated vapour [1] and is compressed to a higher pressure, which increases the temperature as well. The superheated vapour formed due to compression can be condensed with either cooling water or cooling air.

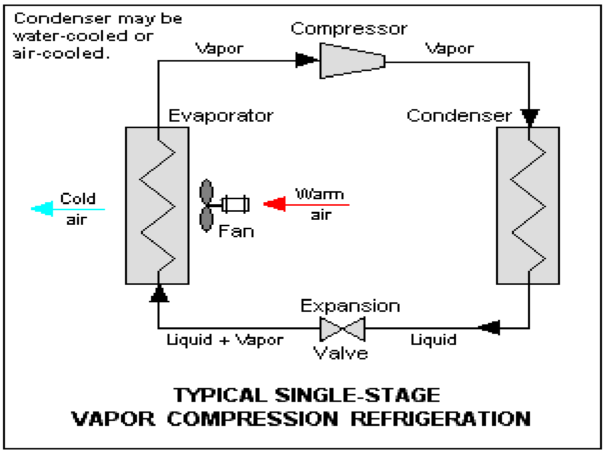


Figure 1.1 : Simple vapour compression system.[1]

That hot vapour is cooled and condensed into a liquid by flowing through condenser with the help of cool water or air flowing across the coils or tubes. Heat rejected by refrigerant is carried away by either the water or the air (whichever may be the case). The saturated liquid formed after condensation undergoes expansion through an expansion valve where it reduces pressure. The adiabatic flash evaporation of a part of the liquid refrigerant takes place because of this pressure reduction which results in lowering the temperature of the liquid and vapour refrigerant mixture which becomes colder than the temperature of the enclosed space to be refrigerated.

The cool blend is then goes through the evaporator. A fan circles the warm air in the encased space over the curl or tubes conveying the icy refrigerant fluid and vapor blend. The warm air coursed through a fan vanishes the fluid piece of the icy refrigerant blend. This circling air gets cooled and brings down the temperature of the encased space to the coveted temperature**.[2]** The refrigeration cycle completes with saturated vapour from the evaporator is routed back into the compressor.

Facts of interest.

- Keeping in mind the end goal to refrigerate various encased spaces or rooms huge business or mechanical refrigeration frameworks may have different extension valves and numerous evaporators. In such frameworks, the consolidated fluid refrigerant might be steered into a weight vessel, called a receiver, from which fluid refrigerant is pulled back and directed through various pipelines to the different extension valves and evaporator.
- To protect the compressors from internal damage filters and dryers are installed before the compressors to catch any moisture or contaminants in the system.
- Multiple compressors in various arrangements are used in multiple stages refrigeration systems.

1.3.2. Vapour Absorption Refrigeration System.

The vapour absorption refrigeration is heat operated system. If we compare vapour absorption & vapour compression in both the systems, there are evaporator and condenser. In both the cases Evaporation and condensation of the refrigerant takes place at two different pressure points to achieve refrigeration. The difference between these refrigeration system is the process employed to create the two pressure levels in the system for evaporation and condensation of the refrigeration. Circulation of refrigerant is also different in both the cases.

A French scientist Ferdinand Carre developed the first vapour absorption refrigeration machine in 1860. Ammonia is commonly used in vapour absorption refrigeration systems as refrigerant. This framework might be utilized as a part of both the local and mechanical refrigerating plants. Keeping in mind the end goal to change the states of the refrigerant required for the operation of the refrigeration cycle warm vitality is utilized as a part of vapor retention cycle rather than mechanical vitality as if there should arise an occurrence of vapor pressure cycle.

Rather than compressor there is a mix of "absorber" and "generator" in vapor assimilation cycle. An absorbent, which has a partiality for the refrigerant utilized, is coursed by a pump between the absorber and the generator. The absorbent in the absorber draws the refrigerant vapor shaped in the evaporator in this manner keeping up a low weight in the evaporator to empower the refrigerant to dissipate at low temperature. In the generator the absorbent is heated.[3] There by discharging the refrigerant vapor (assimilated in the safeguard) as high weight vapor, to be consolidated in the condenser. Along these lines the suction capacity is performed by permeable in the absorber and the generator plays out the capacity of the pressure and release. The permeable arrangement conveys the refrigerant vapor from the low side (evaporator–absorber) to the high side (generator-condenser). The melted refrigerant streams from the condenser to the evaporator because of the weight distinction between the two vessels; in this manner setting up flow of the refrigerant through the framework.

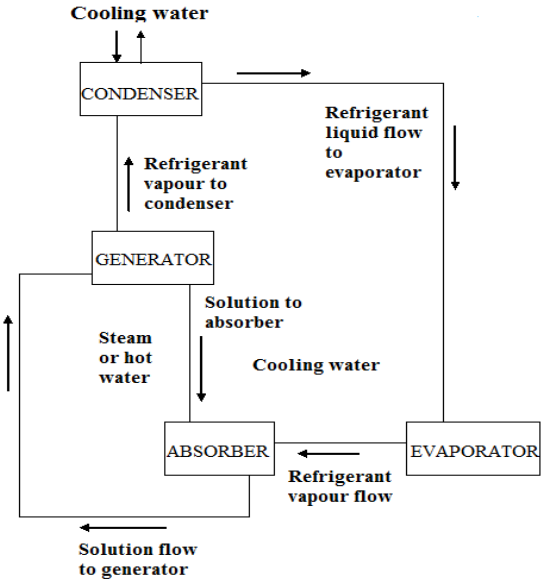


Figure 1.2 : Simple vapour absorption refrigeration system.[3]

Above figure explains the absorption cycle with below mentioned flow paths of refrigerant and absorbent.

Evaporator ⟶ Absorber ⟶ Generator ⟶ Condenser ⟶ Evaporator.

For the absorbent it is,

Absorber ⟶ Generator ⟶ Absorber.

The hot spongy arrangement goes from the generator to the absorber must be cooled, though the cooled permeable arrangement sent to the generator must be warmed in the generator for the recovery of the refrigerant. Between the generator and the absorber there is a shell and tube warm exchanger.

1.3.3. Vapour Ejection Refrigeration System.

A thermally driven technology of Ejector or jet pump refrigeration has been used for many years now for different cooling applications. COP of these frameworks are much lower than vapor pressure frameworks however it offers simplicity as there is no moving parts. It can deliver refrigeration utilizing waste heat or sunlight based vitality as a heat source over 80°C.As shown in Figure1.3, the framework has two circles, the power circle and the refrigeration loop.[4] In the power circle, to vanish high weight fluid refrigerant (p second rate warm, Qb, is utilized as a part of a heater or generator (prepare 1-2). The essential liquid which is the high weight vapor created courses through the ejector and quickens through the spout,. The weight lessening happens instigates vapor from the evaporator, known as the optional liquid, at point 3. Blending of both the liquids happens before entering the diffuser segment where the stream decelerates and weight recoups. The buildup of the blended liquid happens in the condenser where warmth is rejected to nature, Qc. For the finish of the power cycle a part of the fluid leaving the condenser at guide 5 is pumped toward the evaporator. The staying fluid is extended through a development gadget before entering the evaporator of the refrigeration circle at point 6 as a blend of fluid and vapor. Dissipation of the refrigerant in the evaporator produces a refrigeration impact, Qe, and the subsequent vapor is then drawn into the ejector at point 3. The refrigerant (optional liquid) blends with the essential liquid in the ejector and is compacted in the diffuser segment before entering the condenser at point 4. The blended liquid consolidates in the condenser and ways out at point 5 for the reiteration of the refrigeration cycle.

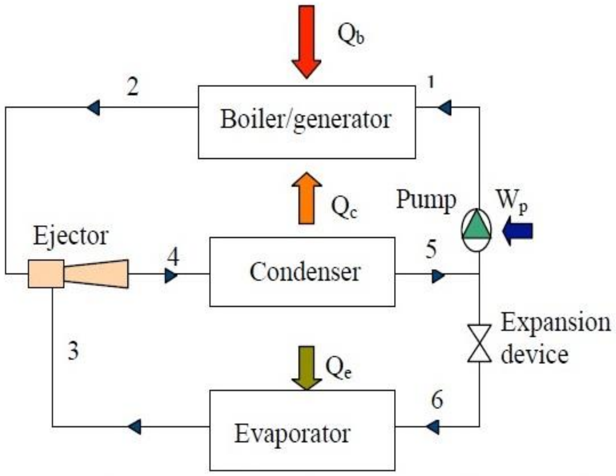


Figure 1.3 : Ejector refrigeration system.[4]

Applications in the food industry

Applications in the food industry where squander warmth is accessible to drive the framework can be found in sustenance preparing plants and can be utilized for item and process cooling and transport refrigeration. Ejector refrigeration framework can likewise be utilized as a part of conjunction with joined warmth and power frameworks to give cooling.

1.3.4. Vortex Tube Refrigeration

The vortex tube is a mechanical gadget otherwise called the Ranque-Hilsch vortex tube, that isolates a compacted gas into hot and cool streams. The "hot" end air can achieve temperature of 200 °C, though the "chilly end" air can reach - 50 °C. It has no moving parts.

There is a whirl chamber in which pressurized gas is infused digressively and quickened to a high rate of rotation.[5] Only the external shell of the compacted gas is permitted to escape at that end because of its conelike spout. The rest of the gas is compelled to return in an inward vortex of diminished width inside the external vortex.

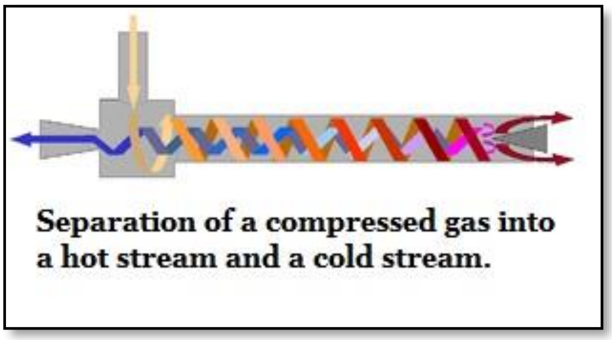


Fig.1.4: Concept of Vortex Tube Refrigeration.[5]

The air encounters "solid body rotation" in the tube, because of which the pivot rate (angular velocity) of the inward gas and external gas is same. This is not the same as general standard vortex conduct — where pivot rate of inward liquid is higher than external liquid.

Pressure is higher on outer air compared to inner air (because of centrifugal force) which results into higher temperature of the outer air compared to inner air.

This is somewhat similar to a Peltier effect device,[6] which uses Potential difference (voltage) to move heat to one side, causing the other side to grow cold of a dissimilar metal junction.

Application. For cooling of cutting tools during machining vortex tubes are used. The vortex tube suits this application as it helps cooling of the tool and removal of chips produced through jet of cold air.

1.3.5. Thermo-electric Refrigeration.

Thermoelectric cooling makes a heat flux utilizing the Peltier impact between the intersection of two distinct sorts of materials. A warmer, cooler, or heat pump which exchanges heat from one side of the gadget to the next, with utilization of electrical vitality, contingent upon the course of the current such an instrument is additionally called a Peltier gadget. They can be utilized either to cool or heating,[7] it can likewise be utilized as a temperature controller that either cools or warms.

This technology is more commonly applied compared to vapour-compression refrigeration. This system has the advantage of no moving parts or circulating liquid, due to which life is more and no risk of potential leaks, also the size of the system is small and flexible. But the disadvantage is its high cost and poor power efficiency.

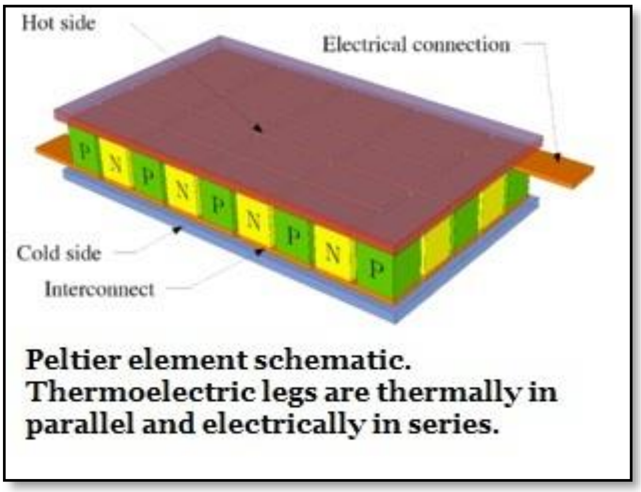


Fig.1.5: Thermo-electric Refrigeration.[7]

Application. The heat pumps can be utilized to remove water from dehumidifiers. Thermoelectric coolers actively cool the modules for microprocessors are used to replace standard heat sinks as they only provide passive cooling. [8] Thermoelectric coolers can be used to keep the temperature of computer components within design limits.

1.3.6 Magnetic Refrigeration.

It's a technology based on the principle of **magneto caloric effect**. The magneto caloric impact is a wonder in which by presenting the material to a changing attractive field there is an adjustment in temperature of that material. Extremely low temperatures can be attained using this technique.

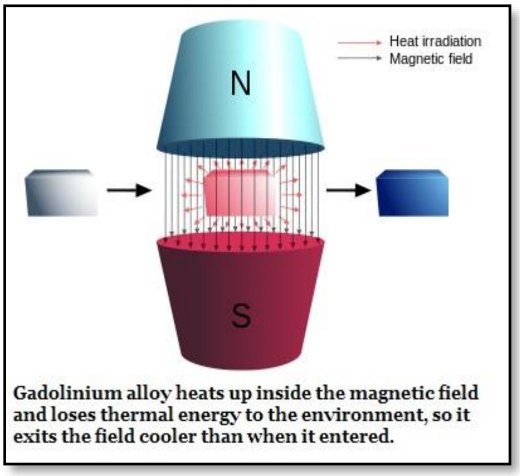
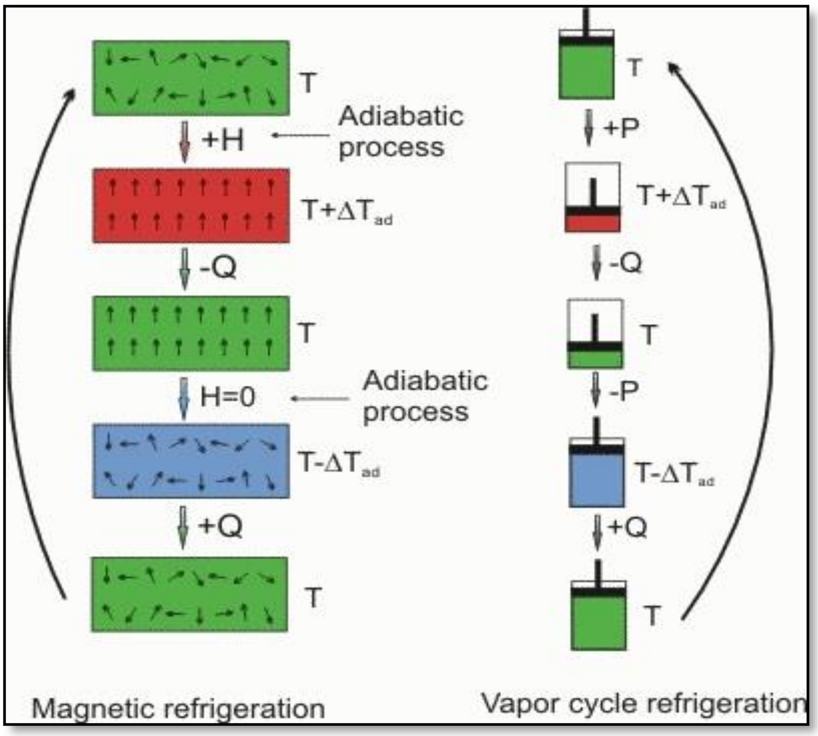


Fig.1.6: Magnetic Heat transfer.[9]

This cycle is performed similar to the Carnot cycle, but with variation in magnetic field strength instead of variation in pressure. [9]



Analogy between magnetic refrigeration and vapour cycle or conventional refrigeration. H = externally applied magnetic field; Q = heat quantity; P = pressure; ΔT_{ad} = adiabatic temperature variation

1. Adiabatic magnetization: A magneto caloric substance is placed in an insulated environment. The increasing external magnetic field (+H) causes the magnetic dipoles of the atoms to align, thereby decreasing the material's magnetic entropy and heat capacity. Since overall energy is not lost (yet) and therefore total entropy is not reduced (according to thermodynamic laws), the net result is that the item heats up ($T + \Delta T_{ad}$).
2. Isomagnetic enthalpic transfer: This added heat can then be removed (-Q) by a fluid or gas — gaseous or liquid helium, for example. The magnetic field is held constant to prevent the dipoles from reabsorbing the heat. Once sufficiently cooled, the magneto caloric substance and the coolant are separated (H=0).
3. Adiabatic demagnetization: The substance is returned to another adiabatic (insulated) condition so the total entropy remains constant. However, this time the magnetic field is decreased, the thermal energy causes the magnetic moments to overcome the field, and thus the sample cools, i.e., an adiabatic temperature change. Energy (and entropy) transfers from thermal entropy to magnetic entropy (disorder of the magnetic dipoles).

4. Isomagnetic entropic transfer: To prevent heating of the material the magnetic field is held constant. The environment being refrigerated with material placed in thermal contact. Heat energy migrates into the working material (+Q) because the working material is cooler than the environment refrigerated.

Once the refrigerant and refrigerated condition are in thermal balance, the cycle starts again.[10]

1.3.7 Cascade Refrigeration System.

Two autonomous vapor-pressure frameworks connected together to shape a course refrigeration framework in a way that the evaporator of the high-temperature framework turns into the condenser of the low-temperature framework. However, the working media of the two frameworks are isolated from each other.

To achieve the desired effect using a single refrigerant bigger operating pressure range is required whereas in case of cascade different refrigerants can be used at different temperature to achieve the same. So, to derive maximum benefit different refrigerants working at different temperature ranges can be used. The working of the cascade refrigeration system is as following:-

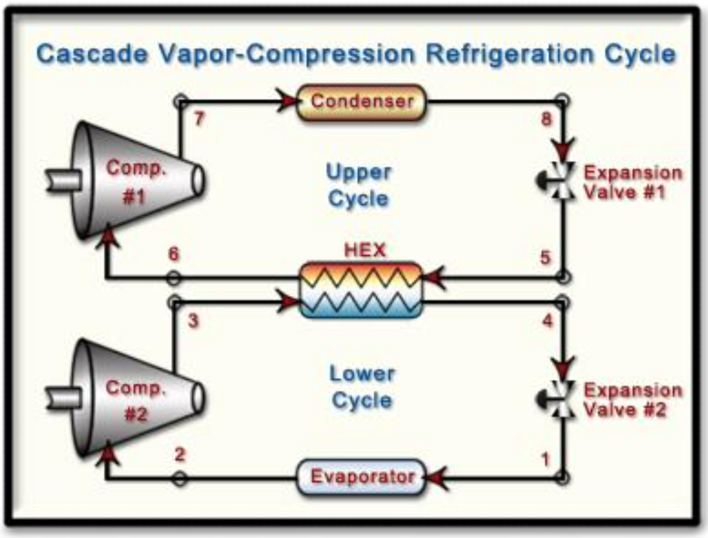


Figure 1.7: Cascade Refrigeration Cycle.[10]

Two refrigeration cycles that utilization two distinct refrigerants are connected by a warmth exchanger.

- The lower cycle is colder and it ingests warm from the refrigerated space.
- The lower cycle rejects warm into the upper spin through the warmth exchanger.
- The upper cycle ingests warm from the lower go through the warmth exchanger.
- The upper cycle is sultrier and can dismiss warmth to an exceptionally hot repository.
- Can utilize a similar refrigerant in both cycles or utilize a refrigerant with a low vapor weight in the upper cycle and one with a generally high vapor weight in the lower cycle.

Chapter 2

Literature Review and future scope

The enthusiasm of specialists in using waste warmth to drive frameworks for ventilating or refrigeration has developed consistently. It could be seen from different reviews and in addition test works that a noteworthy bit of warmth is rejected to the air from a motor as waste warmth. The target of this postulation is to build up a basic reason for further innovative work inside the field of waste warmth recuperation.

An ejector cooling framework running on waste warmth has been chosen for a further point by point examination. A low temperature warm source can be utilized to drive the ejector refrigeration cycle, making the framework reasonable for joining with the warmth exchanger. Framework execution relies on upon the decision of working liquid (refrigerant), working conditions and ejector geometry.

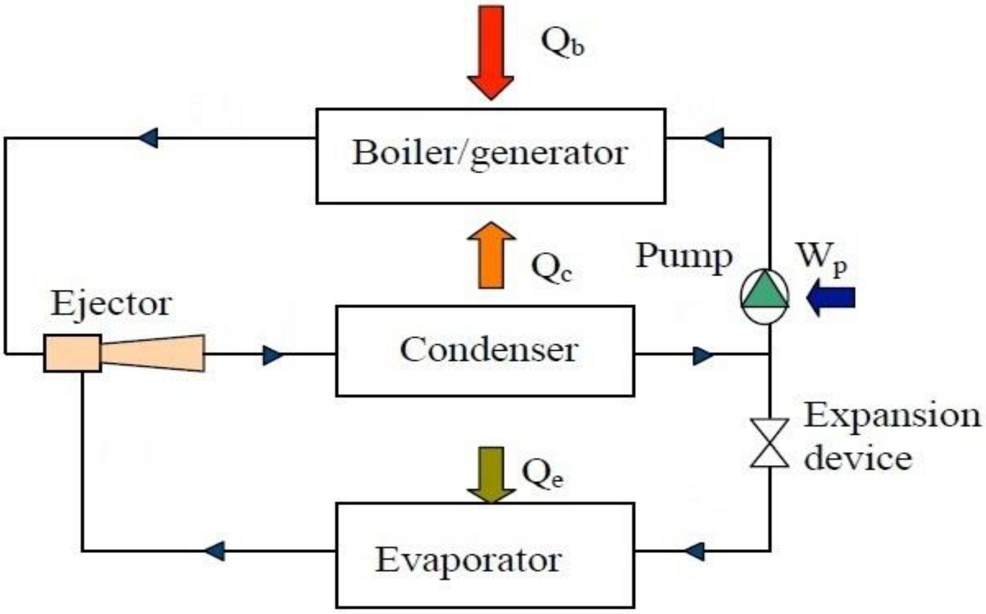


Figure 2.1: General layout of Ejector refrigeration system.[8]

An ejector refrigeration cycle utilizing common working liquids creates great execution and lower natural effect, since customary working liquids, CFC's and HFC's are solid atmosphere gasses. Encourage on, exergy examination is utilized as an apparatus in distinguishing ideal working conditions and exploring misfortunes in the framework. By and by, the cooling load trademark and measure of waste warmth are not steady. Consequently, a dynamic investigation is valuable for deciding the attributes of the framework amid the whole running time frame, and dimensioning the critical segments of the framework segments, for example, warm exchangers. Preparatory computation comes about for one settled ejector considered as a discovery utilizing R11 as the refrigerant is likewise included.

A. Selvaraju, A. Mani [2004][11] displayed the Analysis of an ejector with condition inviting refrigerants with the situation when an ejector is worked at gagging mode and reasoned that it gives a superior execution with higher entrainment proportion. A PC code in light of existing one-dimensional ejector speculation is made to dismember execution out of the ejector. The code fuses effects of granulating at the steady zone mixing chamber and change specifically heat of the working fluid other than inside irreversibility of the ejector. The mimicked execution is contrasted and the accessible exploratory information from the writing for approval. Examination of execution of ejector with condition benevolent refrigerants, R134a, R152a, R290, R600a and R717 is made.

R. Yapıcı , H.K. Ersoy [2005][12] introduced a hypothetical examination of the ejector refrigeration framework in light of the consistent territory ejector stream demonstrate. Streamlined outcomes for R-123 are displayed. It is resolved that the varieties in condenser and evaporator temperature greaterly affect the ideal coefficient of execution (COP) than the variety in generator temperature. At the same working temperatures of the ejector refrigeration framework, the ideal COP and zone proportion decided in this review utilizing the steady region stream demonstrate. For a similar region proportion, the COP for the framework with the steady weight ejector is moderately higher than that with the consistent range ejector. For this situation, be that as it may, the condenser temperature ought to be brought down. What's more, the refrigeration frameworks have practically a similar COP values at lower evaporator or higher condenser temperatures.

T. Sankarlal [2006][13] introduced an Experimental reviews on a smelling salts ejector refrigeration framework which has been outlined and created to work with a mimicked (electric) warm source. He makes a trial think about on an ejector refrigeration framework working with smelling salts is displayed. The impact of the generator, condenser, and evaporator temperatures on the ejector refrigeration framework execution was exhibited. The entrainment proportion and COP of the framework increment with expanding generator and evaporator temperatures and abatement with expanding condenser temperature.

A. Selvaraju [2006][14] displayed an Experimental examination on R134a vapor ejector refrigeration framework. The framework utilizes R134a as working liquid and has an appraised cooling limit of 0.5 kW. The impact of generator, evaporator and condenser temperatures on the framework execution is examined. The working conditions are picked appropriately as, generator temperature between 338 K and 363 K, condenser temperature between 299 K and 310.5 K, and evaporator temperature between 275 K and 285.5 K. Six designs of ejectors of various geometrical measurements are chosen for the parametric review.

K. Pianthong [2007] [15] arranged a review on Investigation and change of ejector refrigeration framework utilizing computational liquid progression procedure where the computational liquid elements (CFD) code, FLUENT, is utilized to foresee the stream marvels and execution of CPM and CMA steam ejectors. The ejector refrigeration framework, utilizing water as the working liquid, is worked at 120–140 °C heater temperature and 5–15 °C evaporator temperature. CFD can foresee ejector execution exceptionally well and uncover the impact of working conditions on a compelling range that is specifically identified with its execution. This examination helps the comprehension of ejector attributes and gives data to outlining the ejector to suit the ideal condition.

Rafet Yapıcı [2008] [16] introduced a novel ejector which was planned in view of a steady region ejector display and made keeping in mind the end goal to explore the execution of an ejector refrigeration framework in a more extensive working reach. The refrigeration framework has been tried utilizing high temp water as driving liquid and R123 as working liquid. The impacts of the working temperatures on the cooling limit and execution coefficient of the framework were explored tentatively when the essential spout position was ideal at the ejector region proportion of 9.97. Thus, an execution coefficient of 0.39 was acquired at the vapor generator temperature 98 °C, the evaporator temperature 10 °C and basic condenser weight 129 kPa.

R. Yapıcı & H.K. Ersoy [2008] [17] exhibit exploratory and systematic aftereffects of the execution of the ejector refrigeration framework utilizing ejectors with tube shaped blending chamber and learned at working conditions with gagging in the blending chamber. The condenser weight is picked so that the optional stream stifling can happen even in the ejector with the littlest zone proportion and R-123 utilized as a working liquid in the framework. The review is performed over a scope of the ejector zone proportion from 6.5 to 11.5 at the pressure proportion 2.47. In the contemplated extend, the test coefficient of execution of the framework ascends from 0.29 to 0.41, as the ideal generator temperature increments from 83 to 103 °C.

G Vicatos [2008] [18] arranged a review on vitality from the fumes gas of an inside ignition motor is utilized to control an ingestion refrigeration framework to cool a standard traveler auto. The hypothetical plan is confirmed by a unit that is tried under both research facility and street test conditions. For the last mentioned, the unit is introduced in a Nissan 1400 truck and the outcomes show an effective model and empowering prospects for future improvement.

Khaled S. AlQdah [2011][19] presents an exploratory investigation of a water smelling salts ingestion framework utilized for vehicle aerating and cooling framework, this framework utilizing the fumes squander warmth of an inner ignition diesel motor as vitality source. The vitality accessibility that can be utilized as a part of the generator and the impact of the framework on motor execution, fumes emanations, auto ventilating execution and efficiency are assessed. The primary reason for this examination to investigate the achievability of utilizing waste vitality to plan the safeguard and era since these segments are the most vital segments of ingestion and they are specifically impact the execution of the entire framework. It has been found that the water - smelling salts focus impact the cooling limit. The evaluated cooling load for the vehicle observed to be inside satisfactory reaches which are around 1.37 ton refrigeration.

Zhengshu Dai & Yijian He [2012] [20] gave the proposal of pump-less innovation to wipe out the mechanical coursing pump of the working liquid from condenser to generator in ejector refrigeration frameworks can meet the negligible upkeep necessity and increment operation lifetime of the framework. He concentrated, a pump-less ejector refrigeration framework driven by sunlight based warm vitality, utilizing R134a as a refrigerant. The model is built and the execution of the ejector which will be utilized as a part of a pump-less framework is researched tentatively. The outline state of the pump-less ejector refrigeration framework is: dissipation temperature of 15 ℃, buildup temperature of 45 ℃, era temperature of 80 ℃, and refrigeration limit of 1.5 kW.

Chaobin Dang [2012] [21] proposed a hybrid ejector-vapor pressure warm pump cycle. The hybrid framework utilizes an ejector cycle on the high temperature side and an ordinary vapor pressure cycle on the low-temperature side to upgrade the cycle execution of a sun oriented controlled aeration and cooling system. A cycle reenactment demonstrated that the proposed hybrid ejector cycle could work amid both the warming and cooling seasons and would give vitality funds. In warming mode, the hybrid cycle could decrease vitality utilization by up to 50%.

Yongfang Zhong [2012][22] learned around a motor waste-warm determined adsorption ventilating framework is to give cooling to vehicles to enhance efficiency. It is basic to diminish the span of the framework keeping in mind the end goal to receive the innovation in the utilizations of traveler autos and light-obligation trucks. Therefore, a secluded plan utilizing the zeolite-water working pair is demonstrated to decide the span of the framework for the cooling prerequisite of 3.5kW amid unfaltering operation. The strategies to lessen the module number and in this way the measure of the framework are examined and the control system to fulfill a high cooling prerequisite amid the start-up of the cooling time frame is likewise talked about.

Satish K. Maurya [2014][23] presents A Cooling System for an Automobile Based on Vapor Absorption Refrigeration Cycle Using Waste Heat of an Engine in which the motor waste warmth is utilized to drive the cooling arrangement of car. Also known thing about VAS that these machines required poor quality vitality for operation. Consequently in such sorts of framework, a physicochemical procedure replaces the mechanical procedure of the Vapor Compression Refrigerant System by utilizing vitality as warmth instead of mechanical work. This warmth got from the fumes of high power inward ignition motors.

Shengqiang Bai [2014][24] talked about an exploratory learn about Ideal warmth exchangers recoup however much warmth as could be expected from a motor fumes at the cost of an adequate weight drop. They give essential warmth to a thermoelectric generator (TEG), and their ability and effectiveness is subject to the material, shape, and kind of the warmth exchanger. Six diverse fumes warm exchangers were planned inside a similar shell, and their computational liquid elements (CFD) models were created to look at warmth exchange and weight drop in average driving cycles for a vehicle with a 1.2 L fuel motor. The outcome demonstrated that the serial plate structure upgraded warm exchange by 7 perplexes and exchanged the most extreme warmth of 1737W. The numerical outcomes for the pipe structure and a void hole were confirmed by investigations. Under the greatest power yield condition, just the slanted plate and discharge cavity structure experiences a weight drop under 80 kPa, and the biggest weight drop surpasses 190 kPa. For this situation, an instrument with a differential weight change is basic to sidestep some portion of the fumes.

Jia Yan [2016][25] proposed a hybrid ejector-vapor pressure cycle to enhance the COP of vapor pressure sub cycle. The sub cooling level of the VCSC was enhanced by utilizing the impact of ejector refrigeration sub cycle. R 134a was utilized as a part of both the cycles. As a result a significant improvement of 19.4% in COP was observed in EVCC cycle as compared of VCSC.

This thesis, presents the concept of an advance air conditioning system operated by waste heat resource using ejector refrigeration cycle i.e heat exhausted by an engine rather than the consumable source of energy also including a discussion of the energy source to the system generator, and ejector cooling cycle along with R-134a as a working fluid to match cooling load. The performance of the cooling systems is strongly dependent on local conditions. Such cooling systems can be efficiently operated in the vehicles having high capacity engines where sufficient amount of heat could be used to operate the cooling system.

Chapter 3

Present Work

3.1 Introduction.

Present air-conditioning systems used in automobiles consumes over 15% of all mechanical energy generated in the internal combustion engines and creates two sources of environmental pollution: 1) the ozone-depletion effect of traditional refrigerants belonging to CFC and HCFC groups, and 2) the excess amount of emission of greenhouse gases (by the combustion of fuel) connected with the generation of extra mechanical power to operate the cooling system. Both sources are contributing fundamentally to the an unnatural weather change impact. Furthermore, with vitality cost rising always, industry is hoping to decrease fuel utilization costs as a methods for bringing down their settled expenses so as to remain focused.

This review introduces the improvement of cooling innovation that totally wipes out the ozone exhaustion impact by utilizing normal refrigerants and furthermore significantly lessens the requirement for electric power or additional mechanical. This is refined by utilizing free or cheap warmth i.e squander warm, as the primary wellspring of vitality rather than power or mechanical vitality. The depicted framework is an alteration of a notable vapor pressure cycle (VCC) and it utilizes our already created ejector gadget for non-mechanical pressure. Rather than pressurizing the refrigerant by a mechanical compressor, a pump packs the condensed refrigerant, then warmth is added to dissipate it lastly the refrigerant is re-compacted in an ejector with no additional mechanical vitality spent. The fundamental distinction between this cycle and the traditional refrigeration cycle (turn around Rankine cycle), other than end of a compressor, is that it requires three warmth sources at various temperatures as opposed to two, This review introduces the improvement of cooling innovation that totally wipes out the ozone exhaustion impact by utilizing normal refrigerants and furthermore significantly lessens the requirement for electric power or additional mechanical. This is refined by utilizing free or cheap warmth i.e squander warm, as the primary wellspring of vitality rather than power or mechanical vitality. The depicted framework is an alteration of a notable vapor pressure cycle (VCC) and it utilizes our already created ejector gadget for non-mechanical pressure. Rather than pressurizing the refrigerant by a mechanical compressor, a pump packs the condensed refrigerant, then warmth is added to dissipate it lastly the refrigerant is re-compacted in an ejector with no additional mechanical vitality spent. The fundamental distinction between this cycle and the traditional refrigeration cycle to be specific at the generator level, which is the temperature of the waste warmth source, at a consolidating level, which is the surrounding temperature (really this is a warmth sink) and the evaporator temperature required for cooling impact.This invention relates to heat transfer apparatus therefore, and more particularly to ejector type refrigeration systems employing heat as a source of power. Heretofore mainly vapour compression refrigeration systems have been provided in most of the automobiles for cooling purpose. The various types are determined by the grade of energy required to power them. For instance, one type, the mechanical compressor refrigeration system requires mechanical or electrical energy to power it, the mechanical or electrical energy being the highest grade of energy and is reversibly convertible, however, in many instances high grade energy is not economical to use for powering refrigeration systems. Thus, another type of refrigeration system currently being used is the absorption type refrigeration system which is powered from heat energy which, however, must be at a fairly high temperature level. Still another type of refrigeration system is the ejector type refrigeration system which is likewise powered from heat energy at a fairly high temperature level. Thus, from the foregoing it can be realized it would be desirable to provide a refrigeration system which could be powered by waste heat energy at a lower temperature level than required by the present absorption type and ejector type refrigeration systems.

3.2 Need.

This invention relates to heat transfer apparatus therefore, and more particularly to ejector type refrigeration systems or heat pump systems employing heat as a source of power. Heretofore many types of refrigeration or heat pump systems have been provided. The various types are determined by the grade of energy required to power them. For instance, one type, the mechanical compressor refrigeration system requires mechanical or electrical energy to power it, the mechanical or electrical energy being the highest grade of energy and is reversibly convertible. However, in many instances high grade energy is not economical to use for powering refrigeration systems. Thus, another type of refrigeration system currently being used is the absorption type refrigeration system which is powered from heat energy which, however, must be at a fairly high temperature level. Still another type of refrigeration system is the ejector type refrigeration system which is likewise powered from heat energy at a fairly high temperature level. Thus, from the foregoing it can be realized it would be desirable to provide a refrigeration system which could be powered by heat energy at a lower temperature level than required by the present absorption type and ejector type refrigeration systems.

Prior art ejector type refrigeration systems, which also are powered from heat energy at a relatively high temperature level, likewise have several disadvantages. One such disadvantage, which has rendered the ejector type refrigeration system noncompetitive with the absorption type refrigeration system, is the very low coefficient of performance of the ejector type refrigeration system. Such prior ejector type refrigeration systems have attempted to improve the coefficient of performance by utilizing two working fluids of different molecular weight. However, even in such attempts the prior art ejector type systems were such that working fluids having usually desirable properties could not be used.

Therefore, object of this thesis is to provide a thermally powered refrigeration system that is capable of operating from a relatively small temperature difference between the heat source and the ejected heat at the condenser.

A further object of this invention is to provide a thermally powered refrigeration system that can satisfactorily operate with working fluids that are noncorrosive, nonflammable and nontoxic such as fluorocarbon compounds.

A further object of this invention is to provide a thermally powered refrigeration system which has incorporated therein at least one ejector and in which the excess energy of the power fluid discharged from the ejector is effectively utilized to increase the efficiency of the system.

A further object of this invention is to provide a waste heat operated cooling system for an automobile interior with the help of a heat exchanger which transfer the waste heat of exhaust gases of an automobile to the generator of the ejector cooling system.

Another object of this invention is to provide a thermally powered ejector type heat pump or refrigeration system which operates with one or two working fluids which do not need to be restricted to immiscible fluids, thus permitting the selection of working fluids with optimum properties.

3.3 Working Principle. Ejector refrigeration systems are basically works on the principle of Organic Rankine Cycle (ORC). The Organic Rankine cycle (ORC) is named for its utilization of a natural, high sub-atomic mass liquid with a fluid vapor stage change, or breaking point, happening at a lower temperature than the water-steam stage change. [25] The liquid permits Rankine cycle warm recuperation from lower temperature sources, for example, biomass ignition, modern waste warmth, geothermal warmth, sunlight based lakes and so on. The low-temperature warmth is changed over into helpful work, that can itself be changed over into power.

The working standard of the natural Rankine cycle is the same as that of the Rankine cycle: the working liquid is pumped to a heater where it is vanished, and afterward gone through a turbine where it is at long last re-consolidated.

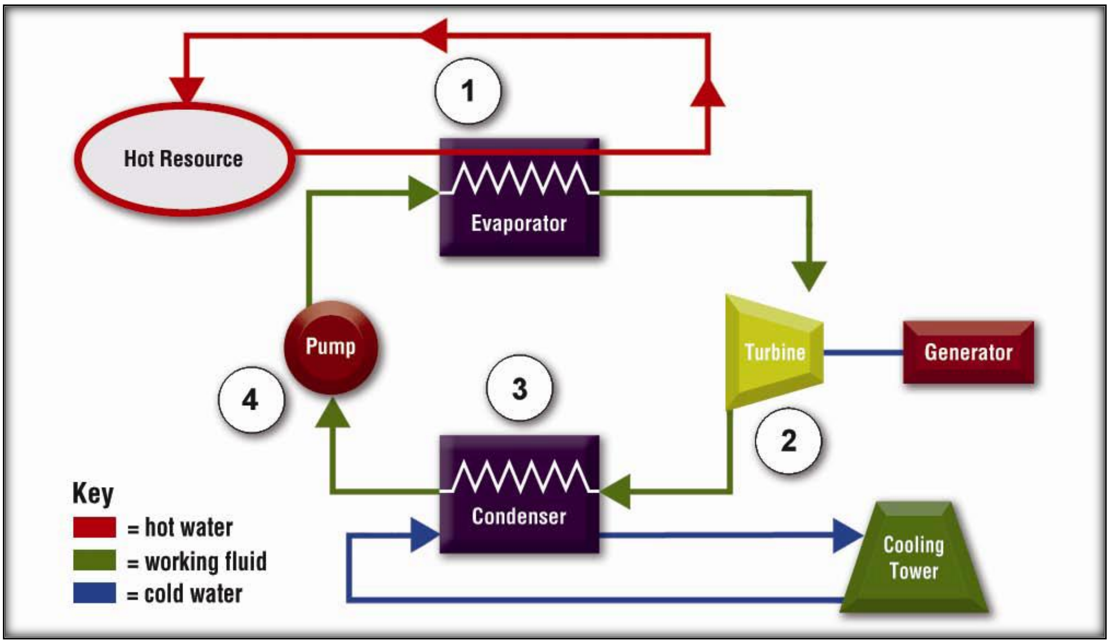


Figure 3.1 : Schematic diagram of ORC.[9]

In the perfect cycle portrayed by the motor's hypothetical model, the development is isentropic and the dissipation and buildup procedures are isobaric.

In any genuine cycle, the nearness of irreversibilities brings down the cycle effectiveness. Those irreversibilities for the most part happen:

- During the development: Only a piece of the vitality recoverable from the weight distinction is changed into helpful work. The other part is changed over into warmth and is lost. The effectiveness of the expander is characterized by examination with an isentropic extension.
- In the warmth exchangers: The working liquid takes a long and twisted way which guarantees great warmth trade yet causes weight drops that lower the measure of force recoverable from the cycle. In like manner, the temperature contrast between the warmth source/sink and the working liquid produces exergy devastation and diminishes the cycle execution. Alternatively the working of Organic Rankine Cycle can be summarized by following the steps discussed below.

- ➢ Thermal vitality in the waste heat stream is exchanged to the ORC's vaporizer by appropriate liquid.
- ➢ Fluid coursing through the Heat Recovery Unit. The ORC working liquid is vaporized by the heat exchange liquid.
- ➢ The coming about natural vapor drives the turbine, which is coupled to the generator, or an extra compressor.
- ➢ The turbine debilitate vapor courses through the recuperator, is condensed and reused by liquid pump.

3.4 Applications for the Organic Rankine Cycle(ORC).

The natural Rankine cycle innovation has numerous conceivable applications, and checks more than 250 recognized power plants around the world. Among them, the most broad and promising fields are **following**

3.4.1Waste heat recovery

Waste heat recuperation is a standout amongst the most essential advancement fields for the natural Rankine cycle (ORC). It can be connected to heat and power plants (for instance a little scale cogeneration plant on a residential water warmer), or to mechanical and cultivating procedures, for example, natural items maturation, hot depletes from broilers or heaters (e.g. lime and concrete furnaces), pipe gas buildup, fumes gasses from vehicles, entomb cooling of a compressor, condenser of a power cycle, and so forth.

3.4.2 Biomass power plant

Biomass is accessible everywhere throughout the world and can be utilized for the generation of power on little to medium size scaled power plants. The issue of high particular venture costs for hardware, for example, steam boilers are overcome because of the low working weights in ORC control plants. Another preferred standpoint is the long operational existence of the machine because of the qualities of the working liquid, that dissimilar to steam is non disintegrating and non eroding for valve seats tubing and turbine sharp edges. The ORC procedure additionally conquers the moderately little measure of information fuel accessible in numerous locales in light of the fact that a productive ORC control plant is feasible for littler estimated plants.

3.4.3 Geothermal plants

Geothermic warmth sources fluctuate in temperature from 50 to 350°C. The ORC is along these lines consummately adjusted for this sort of utilization. In any case, it is vital to remember that for low-temperature geothermal sources (normally under 100°C), the proficiency is low and depends emphatically on warmth sink temperature (characterized by the surrounding temperature).

3.4.4 Solar thermal power

The natural Rankine cycle can be utilized as a part of the sun oriented explanatory trough innovation set up of the standard steam Rankine cycle. The ORC permits control era at lower limits and with a lower authority temperature, and subsequently the likelihood for ease, little scale decentralized CSP units.

3.5 Description of technology and Operational Stages.

3.5 .1 Description of technology

Ejector or fly pump refrigeration is a thermally determined innovation that has been utilized for cooling applications for a long time. In their current situation with advancement they have a much lower COP than vapor pressure frameworks yet offer preferences of effortlessness and no moving parts.[26] Their most prominent preferred standpoint is their capacity to deliver refrigeration utilizing waste warmth as a warmth source at temperatures over 80°C.

Alluding to the fundamental ejector refrigeration cycle in Figure 3.2,the framework comprises of two circles, the power circle and the refrigeration circle. In the power circle, second rate warm, QG, is utilized as a part of a generator to dissipate high weight fluid refrigerant (process 6-1). The high weight vapor produced, known as the essential liquid, moves through the ejector where it quickens through the nozzle.[27-28]

The lessening in weight that happens initiates vapor from the evaporator, known as the auxiliary liquid, at point 2. The two liquids blend in the blending chamber before entering the diffuser area where the stream decelerates and weight recuperation happens. The blended liquid then streams to the condenser where it is dense dismissing warmth to the earth, Qc. A bit of the fluid leaving the condenser at point 4 is then pumped to the heater for the fulfillment of the power cycle. The rest of the fluid is extended through an extension gadget and enters the evaporator of the refrigeration circle at point 5 as a blend of fluid and vapor. The refrigerant vanishes in the evaporator creating a refrigeration impact, QE, and the subsequent vapor is then drawn into the ejector at point 2. The refrigerant (auxiliary liquid) blends with the essential liquid in the ejector and is packed in the diffuser area before entering the condenser at point 3.The blended liquid consolidates in the condenser and ways out at point 4 for the redundancy of the refrigeration cycle.

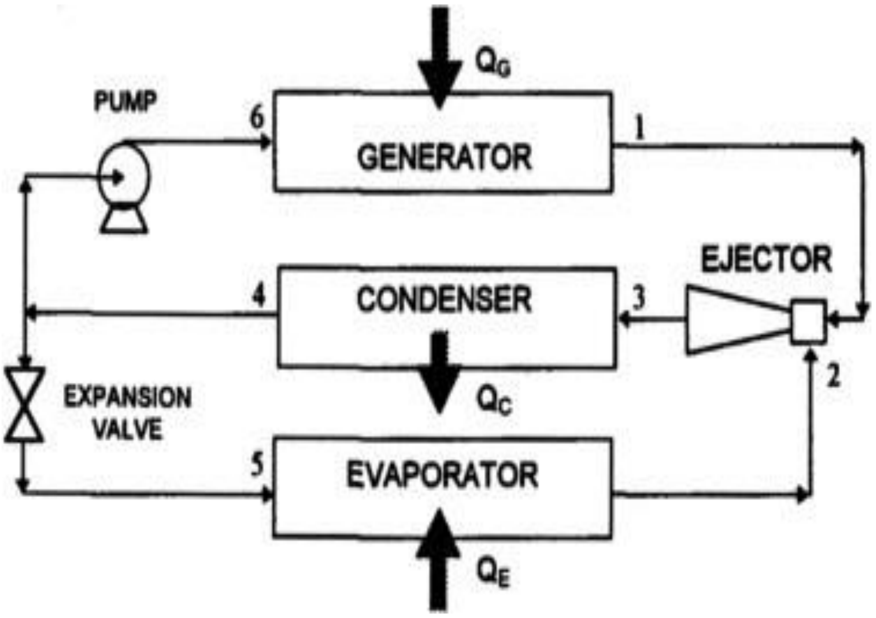


Figure 3.2: Line Diagram of ERC.[27]

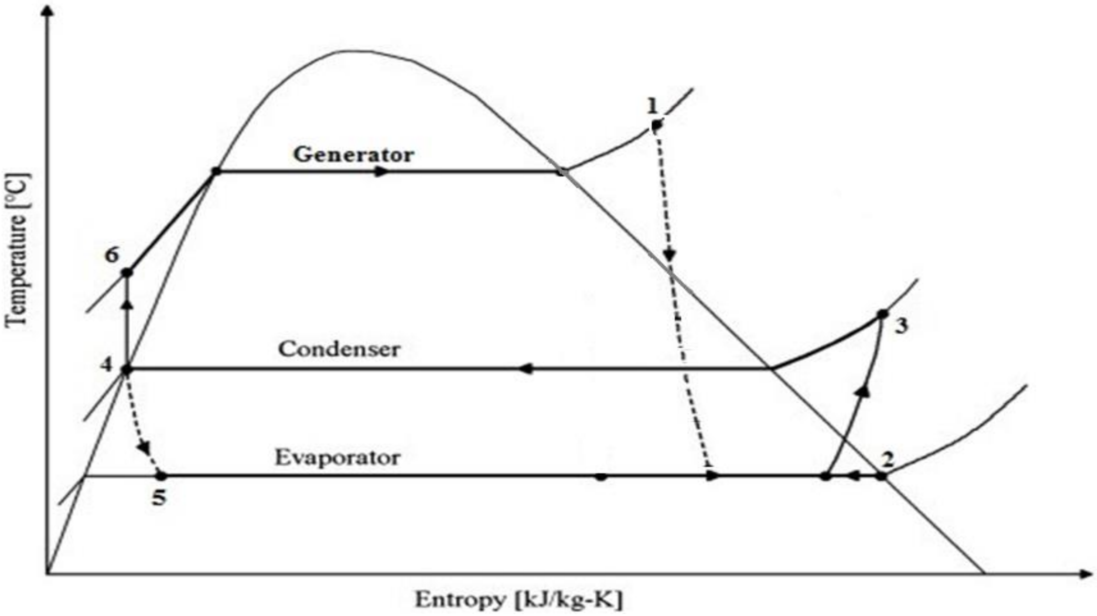


Figure 3.3 : T-s diagram of ERC[28]

3.5.2 Operational Stages:

- The framework comprises of two circles, the power circle and the refrigeration circle.
- In the power circle, low grade heat, QG, is utilized to vanish high pressure fluid refrigerant (process 6-1).
- The high pressure vapor created (essential liquid) courses through the ejector where it quickens through the nozzle.
- The decrease in pressure that happens actuates vapor from the evaporator (optional liquid) at point 2.
- The blended liquid then streams to the condenser where it is consolidated dismissing heat to the environment, Qc.
- A part of the fluid leaving the condenser at point 4 is then pumped to the generator for the finishing of the power cycle.
- The rest of the fluid is extended through a expansion device.
- After that it enters the evaporator of the refrigeration circle at point 5 as a blend of fluid and vapor.
- The refrigerant vanishes in the evaporator delivering a refrigeration impact, QE.
- The resulting vapour obtained from evaporator is then drawn into the ejector at point 2 for the completion of the refrigeration cycle.

3.6 Refrigerant used.

There are several refrigerants are available which could be used in ejector air conditioning system. Many studies were made (mentioned in literature review) regarding ejector system in which are R-134a, R-717, R-718, or R-123 could be used as a working substance for producing refrigerating effect. In current work R-134a is used as a refrigerant. Some physical properties of R-134a are given below due to which it is easy to choose the refrigerant for this purpose. [29]

- It is stable, non-flammable and non-toxic.

- No chlorine content, no ozone depletion potential, ODP = 0.
- The boiling point at atmospheric pressure is -26℃.
- It has a low side pressure of 4.17 bar at 10 ℃.
- The leak may be detected by using a soap solution of by electrode detector.

Following tables are shows a comparison of operating thermal properties of different refrigerants.

Table 3.1: R152a, Difluoroethane ($C_2H_4F_2$) [29]

Saturation Pressure (Bar)	Saturation Temp. (℃)	Sp. Enthalpy (KJ/Kg)			Sp. Entropy (KJ/Kg-K)		Sp. Volume (m^3/kg)	
		h_f	h_{fg}	h_g	s_f	s_g	v_f	v_g
3.7	10	216.9	297.2	514.1	1.062	2.11	0.0010	0.086
9.02	40	271.8	260.0	513.8	1.250	2.08	0.0011	0.035
11.7	50	291.5	245.1	536.6	1.314	2.07	0.0012	0.027

Table 3.2: R600a, Isobutane ($C_4 H_{10}$) [29]

Saturation Pressure (Bar)	Saturation Temp. (℃)	Sp. Enthalpy (KJ/Kg)			Sp. Entropy (KJ/Kg-K)		Sp. Volume (m^3/kg)	
		h_f	h_{fg}	h_g	s_f	s_g	v_f	v_g
2.2	10	223.4	346.9	570.3	1.082	2.30	0.0017	0.170
5.3	40	298.2	313.9	611.7	1.326	2.32	0.0018	0.072
6.9	50	325.07	300.0	625.3	1.407	2.33	0.0019	0.056

Table 3.3: R717, Ammonia, NH_3 [29]

Saturation Pressure (Bar)	Saturation Temp. (°C)	Sp. Enthalpy (KJ/Kg)			Sp. Entropy (KJ/Kg-K)		Sp. Volume (m^3/kg)	
		h_f	h_{fg}	h_g	s_f	s_g	v_f	v_g
6.16	10	246.5	1225	1471.5	1.166	5.492	0.0016	0.205
15.57	40	390.6	1099.8	1490.4	1.643	5.155	0.0017	0.083
20.331	50	440.1	1051.7	1491.8	1.79	5.051	0.0017	0.063

Table 3.4: R718, Water, H_2O [29]

Saturation Pressure (Bar)	Saturation Temp. (°C)	Sp. Enthalpy (KJ/Kg)			Sp. Entropy (KJ/Kg-K)		Sp. Volume (m^3/kg)	
		h_f	h_{fg}	h_g	s_f	s_g	v_f	v_g
0.012	10	42.0	2477.9	2519.9	0.151	8.9	0.001	106.4
0.073	40	167.5	2406.9	2574.4	0.574	8.2	0.001	19.54
12.35	50	209.31	2382.7	2592.9	0.704	8.076	0.001	12.03

Table 3.5: R134a, Tetrafluoroethane (CH_2FCF_3). [29]

Saturation Pressure (Bar)	Saturation Temp. (°C)	Sp. Enthalpy (KJ/Kg)			Sp. Entropy (KJ/Kg-K)		Sp. Volume (m^3/kg)	
		h_f	h_{fg}	h_g	s_f	s_g	v_f	v_g

10	4.14	213.3	197.4	410.8	1.048	1.746	0.0079	0.049
40	10.16	256.4	169.7	426.1	1.193	1.735	0.0087	0.019
50	13.18	271.9	158.4	430.4	1.241	1.731	0.0090	0.015

Above comparative study shows that for the same operating temperature R-134a requires less heat to evaporates in the generator of the cooling system. As the tables presents that for the temperature of 50 ℃, R-152a requires 245.1kJ/kg; R-600a requires 300.0 kJ/kg; R-717 requires 1051.7 kJ/kg , and R-718 requires 2082.7 kJ/kg to convert it to liquid to saturated vapour form. The amount of heat input for generator operation conditions is comparatively less. On the basis of above properties and comparison R-134a could be choose as a refrigerant for this system.

3.7 Advantages and disadvantages of ejector refrigeration system.

Following are the advantages and disadvantages of the ejector refrigeration system. [30]

Advantages.

1. It is a vibration free system as pumps are the only parts.
2. It is simple in construction and rigidly designed.
3. This system has an ability to adjust quickly to load variations.
4. The running cost of this system is quite low.
5. It has relatively less plant mass (kg/TR). Hence, there are now a number of air conditioning applications ranging up to 300 TR in capacity as well as many industrial applications of even larger size.
6. Low maintenance cost.
7. Low production cost.
8. High reliability.
9. It is also most suitable for places where steam is available such as process industry, steel plants, petroleum plants, thermal power plants etc. Moreover, it is a boon to the places where electricity is not available since a pump operating on steam can be incorporated.

Disadvantages.

1. The maintenance of high vacuum in the evaporator is necessary for proper functioning of the system. This is achieved by direct vaporization to produce refrigeration effect which is usually limited as a large volume of vapour needs to be handle.
2. Since the ejected vapour and motive vapour condenses in the condenser. Thus large size condenser is needed in the former.
3. The installation cost is quite high.
4. Co-efficient of performance is very low of the order of about 0.4 to 0.6.

3.8 Comparison.

1. The ejector refrigeration utilizes heat vitality to change the state of the refrigerant from the evaporator. The vapor pressure framework utilizes mechanical vitality to change the state of the refrigerant from the evaporator.
2. In ejector refrigeration systems the only moving of the entire system is a pump which has a small motor. Thus, the operation of this system is essentially quite and is subjected to little wear whereas in case of vapour compression system of same capacity has more wear, tear and noise due to moving parts of compressor.
3. The load variation does not affect the performance of the vapour absorption refrigeration system. The load variations are met by controlling the quantity of refrigerant circulated and the quantity of heat supplied to the generator. The performance of a vapour compression system at partial load is poor.
4. In the ejector refrigeration system, the liquid refrigerant leaving the evaporator has no bad effect on the system except that of reducing the refrigerating effect. In vapour compression system, it is essential to superheat the vapour refrigerant leaving the evaporator so that no liquid may enter the compressor.
5. The ejector refrigeration systems are usually designed to use steam, either high pressure or low pressure. The exhaust steam from furnace or waste energy from an engine may also be used.

Chapter 4

Internal Combustion Engine

4.1 Introduction. Internal combustion engines are seen each day in autos, trucks, and transports. The name interior ignition alludes additionally to gas turbines with the exception of that the name is typically connected to responding inner burning (I.C.) motors like the ones found in ordinary cars. There are fundamentally two sorts of I.C. start motors, those which require a start plug, and those that depend on pressure of a fluid.[31] Spark start motors take a blend of fuel and air, pack it, and touch off it utilizing a start plug. Figure demonstrates a cylinder and some of its fundamental segments. The name `reciprocating' is given in perspective of the development that the torque framework encounters. The barrel chamber engine is basically a torque slider framework, where the slider is the chamber for this circumstance. The barrel is climbed and around the turning development of the two arms or associations. The crankshaft turns which makes the two associations turn. The barrel is embodied inside a consuming chamber. The drag is the estimation of the chamber. The valves on top address acknowledgment and exhaust valves basic for the affirmation of an air-fuel mix and vapor of chamber residuals. In a start motor a start connection is required to trade an electrical discharge to touch off the mix. In pressure start motors the mix touches off at high temperatures and pressure. The most minimal point where the cylinder scopes is called base right on target. The most elevated point where the cylinder ranges is called best right on target. The proportion of base right on to top perfectly focused is known as the pressure proportion. The pressure proportion is essential in numerous parts of both pressure and start motors, by characterizing the effectiveness of engines.[32,33] Pressure start motors take barometrical air, pack it to high weight and temperature, at which time ignition happens. These motors are high in power and mileage. Motors are likewise separated into four stroke and two stroke motors. In four stroke motors the cylinder achieves four particular strokes for each two upsets of the crankshaft. In a two stroke motor there are two unmistakable strokes in one upheaval. At the point when the cylinder begins at base flawlessly focused (BDC) the admission valve opens.

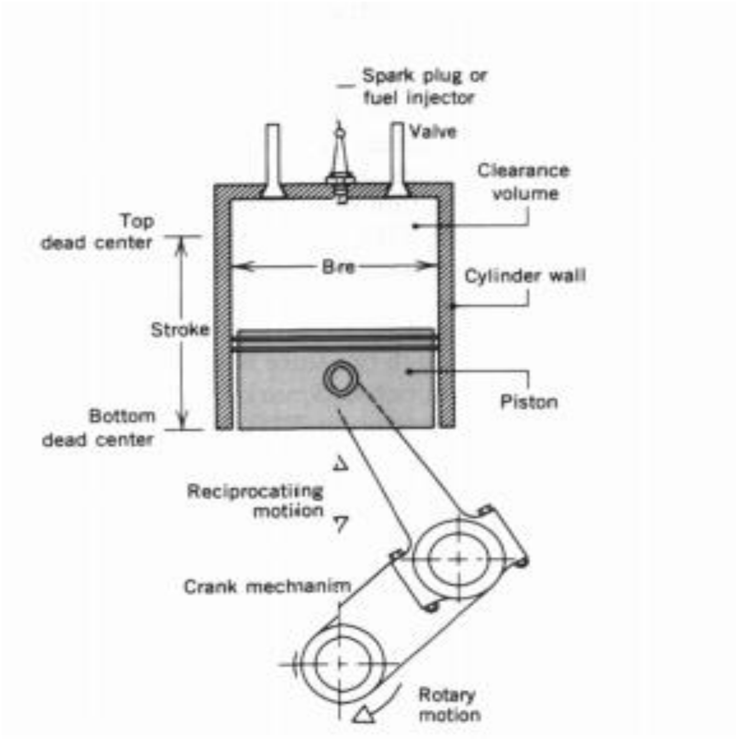
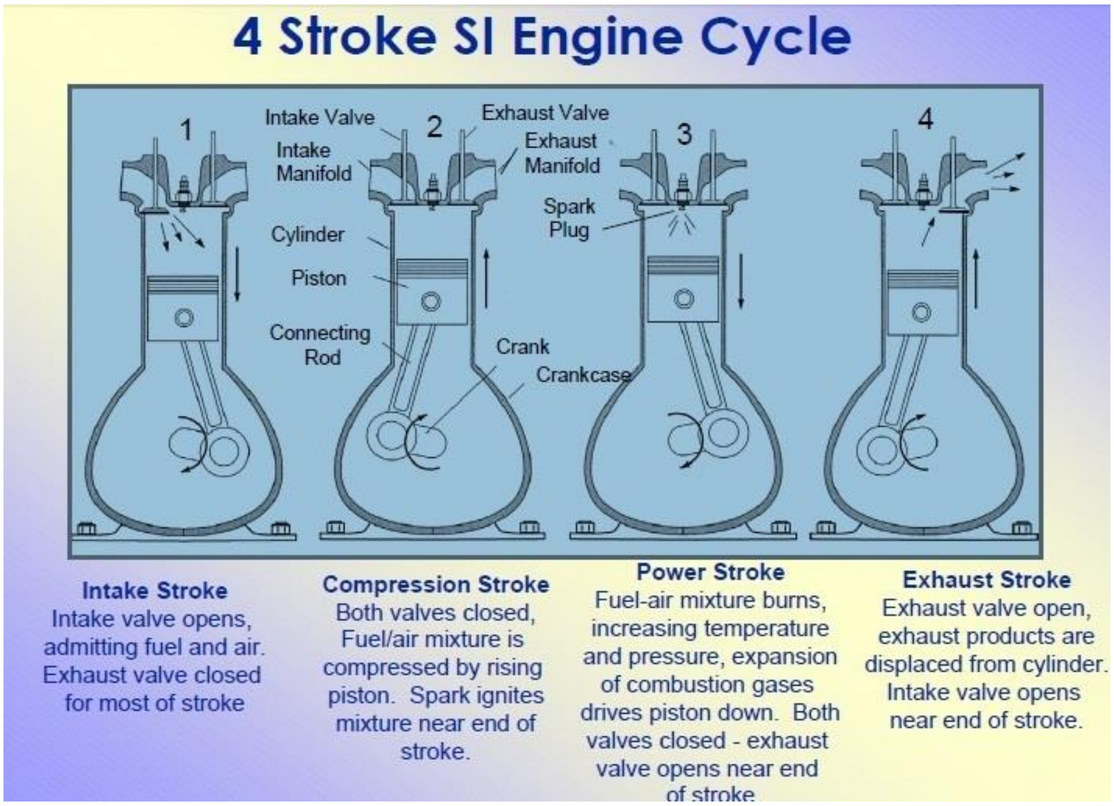


Figure 4.1: Basic components of IC Engine.[31]

A blend of fuel and water then is packed to top flawlessly focused (TDC), where the start attachment is utilized to touch off the blend. This is known as the pressure stroke. In the wake of hitting TDC the air and fuel blend have touched off and ignition happens. The development stroke, or the power stroke, supplies the constrain important to drive the crankshaft. After the power stroke the cylinder then moves to BDC where the fumes valve opens. The fumes stroke is the place the fumes residuals leave the burning chamber.[34] all together for the fumes residuals to leave the ignition chamber the weight should be more noteworthy than environmental. At that point the cylinder continues to TDC where the fumes valve closes. The following stroke is the admission stroke. Amid the admission stroke the admission valve opens which allows the air and fuel blend to enter the ignition chamber and rehash a similar procedure.

4.2 Working Principle. Figure shows the general description of working principle of four stroke SI Engine. In which all the four strokes are discussed shortly. Several features are connected with one another in case of “Otto cycle engine”

- Fuel and air mixture is produced outside the cylinder and the mixture of fuel and air flow into the cylinder, mixture can produced by carburetor or injection system.
- Mixture in the cylinder is ignite by a spark-plug. That’s why these type of engines are called spark ignition (SI) engines.
- Fuel can be petrol or gas, hence these types of engines generally called petrol engine.



Intake Stroke
Intake valve opens, admitting fuel and air. Exhaust valve closed for most of stroke

Compression Stroke
Both valves closed, Fuel/air mixture is compressed by rising piston. Spark ignites mixture near end of stroke.

Power Stroke
Fuel-air mixture burns, increasing temperature and pressure, expansion of combustion gases drives piston down. Both valves closed - exhaust valve opens near end of stroke

Exhaust Stroke
Exhaust valve open, exhaust products are displaced from cylinder. Intake valve opens near end of stroke.

Figure 4.2: General description of working principle of SI engine.[34]

4.3 Possibility of heat recuperation and accessibility from I.C. engine.

Waste heat is heat, which is produced in a procedure by method for fuel burning or synthetic response, and after that "dumped" into the earth despite the fact that it could at present be reused for some helpful and monetary reason. This heat depends to some extent on the temperature of the waste warmth gasses and mass stream rate of fumes gas. Waste heat misfortunes emerge both from hardware wasteful aspects and from thermodynamic confinements on gear and procedures. For instance, consider inner ignition motor roughly 30 to 40% is changed over into helpful mechanical work. The rest of the heat is removed to the earth through fumes gasses and motor cooling frameworks [35]. It implies around 60 to 70% vitality misfortunes as a waste warmth through fumes (30% as motor cooling framework and 30 to 40% as condition through fumes gas). Fumes gasses instantly leaving the motor can have temperatures as high as 842-1112°F [450-600°C]. Therefore, these gasses have high warmth content, diverting as fumes outflow. Endeavors can be made to outline more vitality proficient reverberatory motor with better heat exchange and lower deplete temperatures; notwithstanding, the laws of thermodynamics place a lower restrict on the temperature of fumes gasses [36].

4.4 Waste heat. Nowadays in diesel engines, where the main part of losses occurs, only trends of around 40% of efficiencies at the best engine running conditions are expected. In other words, approximately 60% of available chemical energy in the fuel is wasted in the engine mostly in form of heat from combustion via exhaust gasses and cooling system (figure).

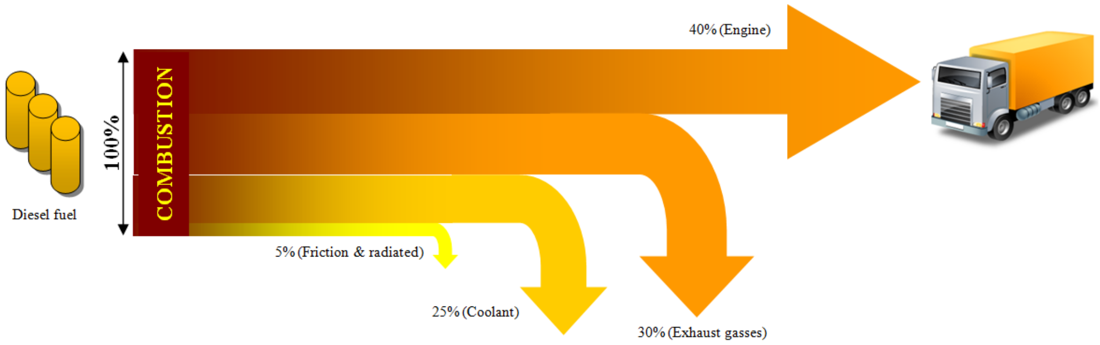


Figure 4.3: Typical energy flow in HDVs. About 40% of the chemical energy in the fuel is delivered to the power train by the engine.[35]

4.5 Possible way of using heat recovery system.

Today's cutting edge life is incredibly relies on upon vehicle motor, i.e. Inward Combustion motors. The greater part of vehicles are still fueled by either start (SI) or pressure start (CI) motors. Little air-cooled diesel motors of up to 35 kW yield are utilized for water system reason, little horticultural tractors and development machines though substantial homesteads utilize tractors of up to 150 kW yield. Water or air-cooled motors are utilized for a scope of 35-150 kW and unless entirely air cooled motor is required, water-cooled motors are favored for higher power ranges. Earth moving apparatus utilizes motors with a yield of up to 520 kW or much higher, up to 740 kW. Marine and train applications for the most part utilize motors with a yield scope of 150 kW or more. Trucks and street motors more often than not utilize rapid diesel motors with 220 kW yield or more. Diesel motors are utilized as a part of little electrical power producing units or as standby units for medium limit control stations [37].

4.6 Case study : Hindustan Ambassador Car.

The basic objective of developing an advanced air conditioning system for Hindustan Ambassador Car is to cool the space inside the car by utilizing waste heat and exhaust gases from engine. The air conditioning system of cars in today’s world uses “Vapour Compression Refrigerant System” (VCRS) which absorbs and removes heat from the inside of the auto which is the space to be cooled and further rejects the warmth to be somewhere else. Presently to expand an effectiveness of auto past a specific breaking point vapor pressure refrigerant framework opposes it as it can't make utilization of the fumes gasses from the motor. In vapor pressure refrigerant framework, the framework uses control from motor shaft as the information energy to drive the compressor of the refrigerant framework, consequently the motor needs to deliver additional work to run the compressor of the refrigeration framework using additional measure of fuel.[38]

This loss of force of the vehicle for refrigeration can be dismissed by using another refrigeration framework i.e. a "Vapor Absorption Refrigerant System" i.e poor quality warmth worked frameworks. It is outstanding that an IC motor has a productivity of around 35-40%, which implies that just a single third of the vitality in the fuel is changed over into valuable work and around 60-65% is squandered to condition. In which 28-30% is lost by cooling water and grease misfortunes, around 30-32% is lost as fumes gasses and leftover portion by radiation, and so forth. In current aerating and cooling framework, a physicochemical procedure replaces the mechanical procedure of the Vapor Compression Refrigerant System by utilizing vitality as warmth as opposed to mechanical work. The warmth required for running the Ejector System can be gotten from that which is squandered into the environment from IC engine.[39] Hence to use the fumes gasses and squander warm from a motor the ejector refrigeration framework can be put into practice which expands the general effectiveness of an auto.

4.6.1 Vehicle description. The Ambassador was first car to be produced in India, has been administering the Indian streets as far back as its beginning in 1948. Initially it depended on Morris Oxford (United Kingdom, 1948), the Ambassador has been experiencing a progression of changes, adjusting to client desires. The Ambassador, which the main car to be Indian streets for over five decades now, has cut an uncommon specialty for itself in the traveler auto section. Its steadfastness, openness and solace figure makes it the most favored auto for some eras of Indians. The Ambassador's opportunity tried, extreme, obliging and pragmatic attributes make it a really mind made to deal with the Indian streets.

4.6.2 Different views of Hindustan Ambassador car.

Figure 4.4: Views of car interior.

Following data is taken from a morse test kit of four-stroke, four cylinder engine of Hindustan Ambassador. The technical details required for the analysis are given below:

4.6.3 Technical specifications:

1. Engine type : 4- stroke petrol engine.
2. No. of cylinder : 4
3. Engine capacity : 1489 cc
4. Revolution per min (rpm) : 4200
5. Volumetric efficiency : 70%
6. Air/ fuel ratio : (13:1)
7. Max. air speed : 90 m/s
8. Atmospheric pressure : 1.013 bar
9. Atmospheric temperature : 20 ℃ = 293 K
10. Exhaust gas temperature : 240 ℃ = 513 K
11. Specific heat of exhaust gas : 1.05 kJ/kg-K.

Figure shows the testing kit of the engine having the technical specifications discussed above,

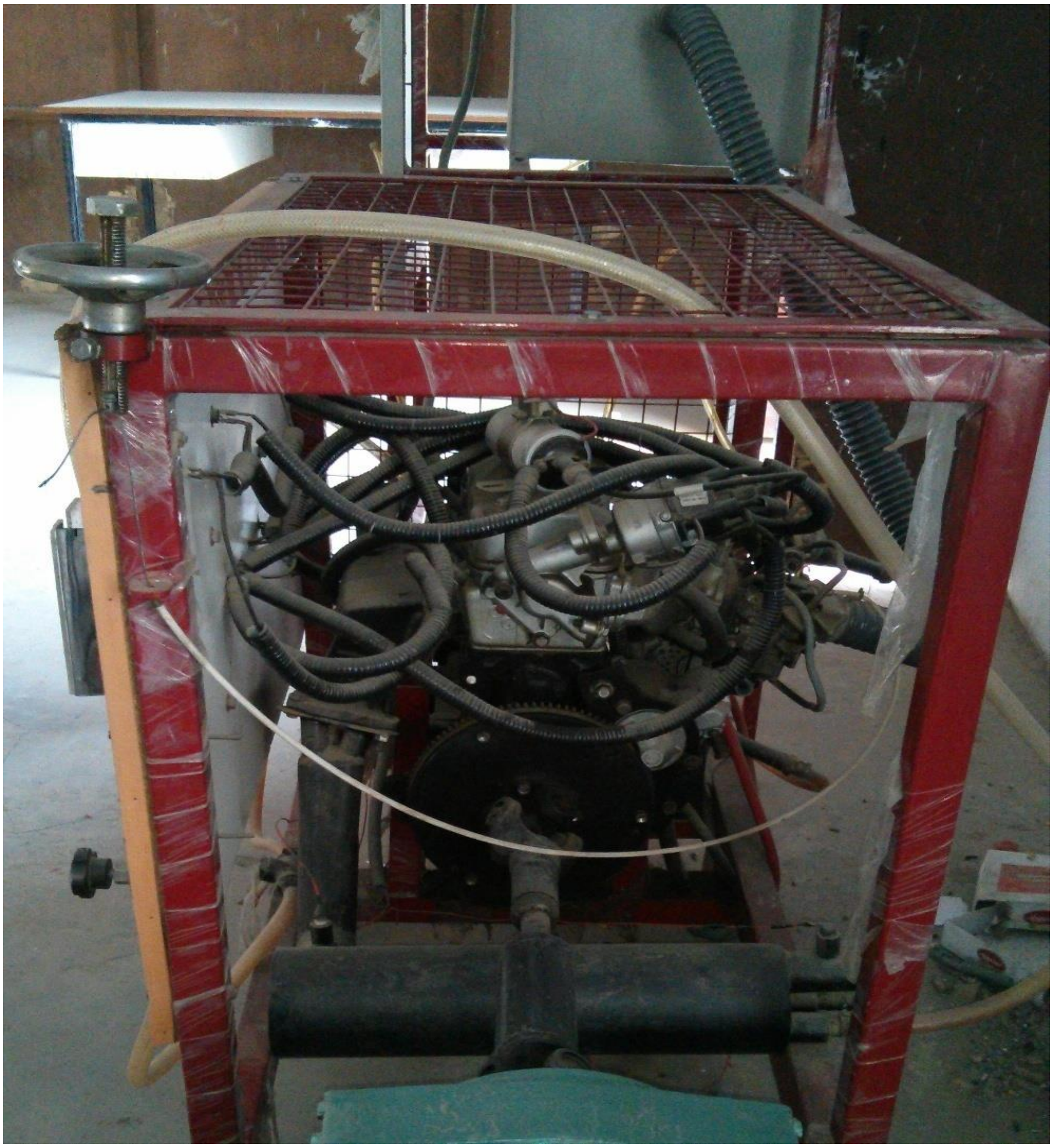


Figure 4.5: Testing kit of Hindustan Ambassador engine.

4.7 Mass flow rate analysis :

Swept volume = 1489 cc = 0.001489 m^3

Volume of air induced = $\eta_v \times v_s$

$$= \frac{0.7*0.001489*4200}{2*60}$$

$$= 0.03648\ m^3/s$$

$$\dot{m} = \frac{pv}{RT} = \frac{1.013*10^5*0.03648}{0.287*10^3*293} = \mathbf{0.04395\ kg/s}$$

For compressible flow, velocity at throat

$$V_T = \sqrt{\left[2\ T_a C_p \left\{1 - \left(\frac{p_T}{p_a}\right)^{(\gamma-1)/\gamma}\right\}\right]}$$

$$90 = \sqrt{\left[2 * 293 * 10^3 * 1.005 \left\{1 - \left(\frac{p_T}{p_a}\right)^{0.286}\right\}\right]}$$

$$90 = 767.4 \sqrt{\left\{1 - \left(\frac{p_T}{p_a}\right)^{0.286}\right\}}$$

$$\frac{p_T}{p_a} = 0.9527$$

p_T= 0.9527 * 1.013 = 0.9651 bar

Volume flow of air at choke

$$v_T = 0.0365 * \left(\frac{p_a}{p_T}\right)^{1/\gamma}$$

$v_T = 0.0365 * (1.0496)^{1/1.4}$ = 0.03776 m^3/s

Therefore,

$$A_T = \frac{v_T}{C_T * 0.85} = \frac{0.03776}{90 * 0.85}$$

A_T = 0.0004936 m^2 = 493.6 mm^2

Now,

$$\frac{\pi}{4}(D^2 - d^2) = 493.6$$

Given $d = \frac{D}{2.5}$

$$\therefore \quad \frac{\pi}{4}(D^2 - d^2) = 493.6$$

$$D = \sqrt{\frac{4 * 493.6}{\pi * 0.84}} = 27.35\ mm$$

Mass flow rate of fuel,

$$\boldsymbol{\dot{m}_f = \frac{\dot{m}}{13} = \frac{0.04395}{13} = 0.00338\ kg/s}$$

As we know that, according to law of conservation of mass, mass can neither be created nor be destroyed hence the mass flow rate of exhaust gases must be equal to the mass of air and mass of fuel entering per second. Mathematically, mass flow rate of exhaust gases = (mass of air + mass of fuel) entering per second in the engine cylinder.

$$= (\dot{m} + \dot{m}_f) \text{ kg/s}$$

$$= (0.04395 + 0.00338) \text{ kg/s}$$

$$\mathbf{= 0.04733 \text{ kg/s}}$$

4.8 Exhaust heat analysis:

Out of the aggregate warmth provided to the motor as fuel, roughly, 30 to 40% is changed over into helpful mechanical work; the rest of the warmth is ousted to the earth through fumes gasses and motor cooling frameworks, bringing about to entropy rise and genuine ecological contamination, so it is required to used waste warmth into valuable work.As mention above the temperature of exhaust gases (measured) coming out from the engine is approximate 240℃ where as the surrounding atmosphere temperature is taken as 20 ℃. Mass flow rate of these exhausted gases is 0.04733 kg/s and specific heat of these flue gases is taken 1.05 kJ/kg-K. Given figure shows the arrangement of temperature measurement of exhaust gas from the engine.

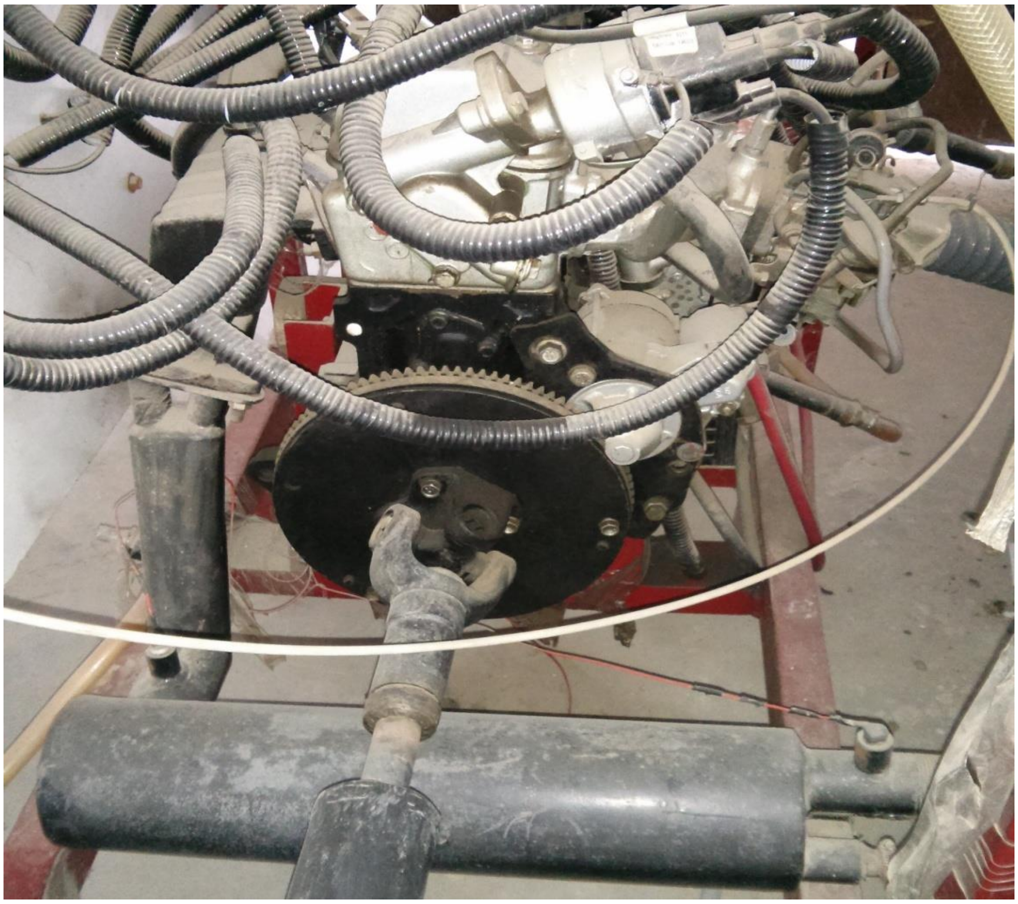


Figure 4.6: Exhaust gas system of Hindustan Ambassador engine.

Hence the amount of heat exhausted through silencer can be calculated with the help of expression given below,

Heat exhausted = $m_g\, c_p\, \Delta T$

Where,

m_g = mass flow rate of exhaust gas (kg/s)

c_{pg} = specific heat of exhaust gas (kJ/kg-K)

ΔT = temperature difference between exhaust and atmosphere (K)

Hence,

Heat exhausted = 0.04733 * 1.05 * (513 - 293) kJ/s

= **10.933 kJ/s**

The recuperation and usage of waste warmth preserves fuel (fossil fuel) as well as diminishes the measure of waste warmth and nursery gasses damped to condition. The review demonstrates the accessibility and probability of waste warmth from inner burning motor, likewise portray loss of fumes gas vitality of an inside ignition motor. Conceivable techniques to recuperate the waste warmth from inside burning motor and execution and emanations of the inner ignition motor. Squander warm recuperation framework is the most ideal approach to recoup squander warmth and sparing the fuel.

Chapter 5

Construction Details

The arrangement of various refrigeration components along with the T-s diagram representation are shown in figure given below:

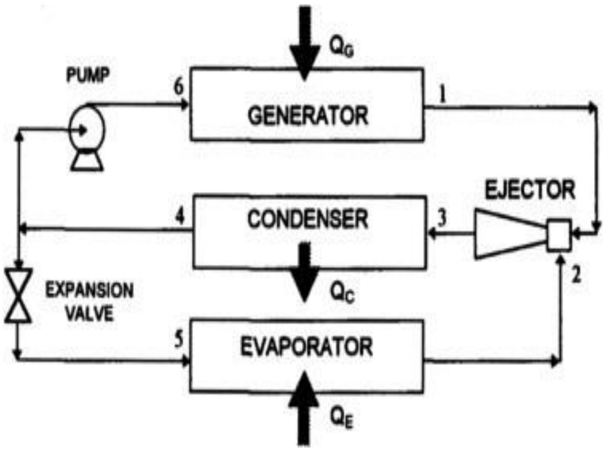


Figure : Line Diagram of ERC.

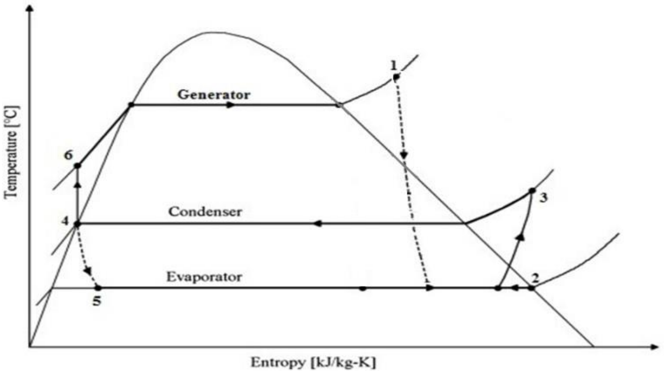


Figure : T-s diagram of ERC.

5.1 List of Components. The components and their details involved in the whole system are discuss as:

1. Generator
2. Condenser
3. Evaporator
4. Expansion device
5. Pump
6. Ejector
7. Receiver-Drier.
8. Heat exchanger.

5.2 Component Details.

5.2.1.Generator. Generator is a closed vessel helical coil heat exchanger including heating coil (by means of waste heat or exhaust heat of engine) in it. Generator having helical loop setup are much successful as contrast with other straight designed heat exchangers because of their small size. Their qualities of heat exchange are vastly improved than that of straight exchangers with wonderful increment in heat exchange coefficient. The stream geometry of a helical warmth exchanger is to such an extent that a temperature cross is overseen inside a solitary unit. Advantages of use of helical coiled generator.

- Cleaning the casing-side flow area is easily managed.
- The casing can be unbolted and the entire bundle assembly removed for inspection or replacement.
- The coil's compactness also provides advantages, because the exchanger requires minimum floor space.
- The heat exchanger's spring-like loop disposes of thermal stun issues that frequently happen amid startup or amid cryogenic or high-temperature benefit.

- Lower upkeep cost and less potential outcomes of harm.

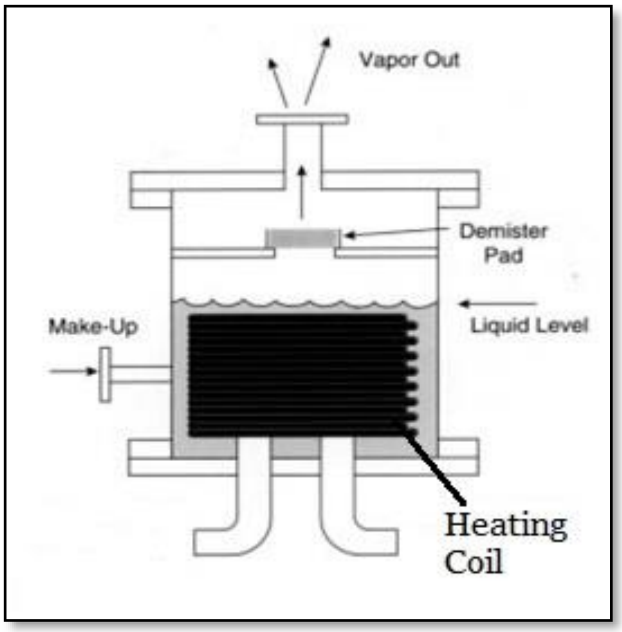


Figure 5.1: Generator of ERC.

Heat required for generator. If 'm' is the mass flow rate of refrigerant in across the generator and working condition with the assumption that the vapour refrigerant becomes in dry saturated state at the exit of generator. After pressurizing the liquid refrigerant entering to a closed chamber, called generator, at point 6. In the generator the refrigerant get heated by means of solar heater and converted into vapour form. The vapour refrigerant is exit at point 1 as shown in figures. The amount of heat required for evaporate the liquid refrigerant can be calculated by the expression:
(let the vapour exit from the generator is dry saturated).

$$Q_G = m(h_1 - h_6) \quad \text{kJ/min} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.1)$$

Where,

m is the mass flow rate of refrigerant (in kg/min) .

h_6 = The inlet enthalpy of refrigerant (kJ/kg).

h_1 = The inlet enthalpy of refrigerant (kJ/kg).

5.2.2.Condenser. Condensers are fundamentally warm exchangers in which the refrigerant experiences a stage change. It is a critical part of any refrigeration framework. In a common refrigerant condenser, the refrigerant enters the condenser in a superheated state. It is first de-superheated and after that dense by dismissing warmth to an outside medium. The refrigerant may leave the condenser as an immersed or a sub-cooled fluid, contingent on the temperature of the outer medium and plan of the condenser. Figure demonstrates the variety of refrigeration cycle on T-s outline. In the figure, the warmth dismissal process is spoken to by 3-4. It can be seen that procedure 3-3' is a de-superheating process, amid which the refrigerant is cooled sensibly from a temperature T3 to the immersion temperature relating gathering weight, T3'. Handle 3'- 4 is the buildup procedure, amid which the temperature of the refrigerant stays consistent as it experiences a stage change prepare. In any case, at present for effortlessness, it is expected that the refrigerant utilized is an unadulterated refrigerant (not an azeotropic blend) and the condenser weight stays steady amid the buildup procedure.

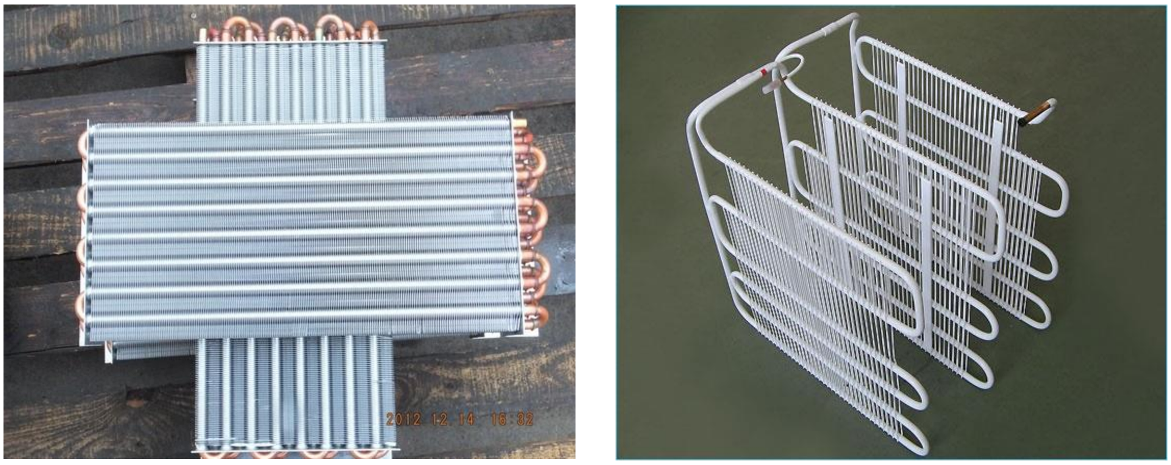


Figure 5.2: Different views of Condenser.

The vapor is dense to a fluid as a result of the high weight that is driving in it, and this produces a lot of heat. The heat is then expelled from the condenser via air moving through the condenser all things considered. It is installed in the high pressure side of the cycle whose function is to remove the heat of the hot vapour refrigerant discharged, which consists of heat absorbed by the evaporator . The heat from the hot vapor refrigerant in a condenser is expelled first by exchanging it to the mass of condenser tubes and after that from the tubes to the consolidating or cooling medium which may water, air or mix of both.

Heat Rejected. As shown in block diagram and temperature- entropy diagram the total mass of refrigerant vapour is entering in the condenser at point 3. In condenser the refrigerant release its latent heat to the atmosphere and converted in liquid form. After that the condensed refrigerant is exit from the condenser at point 4. From Figure, the total heat rejected in the condenser, Q_C is given by the expression:

$$Q_C = m\,(h_3 - h_4) \quad \text{kJ/min} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.2)$$

Where,

m is the mass flow rate of refrigerant (in kg/min) .

h_3 = The inlet enthalpy of refrigerant (kJ/kg).

h_4 = The inlet enthalpy of refrigerant (kJ/kg).

5.2.3.Evaporator. Evaporator is a device used to turn (or allow to turn) the liquid form of a refrigerant into its gaseous form. In the evaporator, the fluid refrigerant is by and large bolstered by a development valve. The extension valve controls the rate of stream of refrigerant to the evaporator in a manner that all the fluid is vaporized and the vapor is likewise superheated to a constrained degree when it achieves the outlet end. At the channel of the evaporator, the refrigerant is dominatingly in the fluid shape with a little measure of vapor framed subsequently of blazing at the extension valve. As the refrigerant goes through the evaporator, more fluid is vaporized by the heap. The refrigerant, when it achieves the finish of the evaporator, is simply in the vapor state and that excessively superheated. Therefore the evaporator in its length is loaded with a shifting extent of fluid and vapor. The measure of fluid in the evaporator will change with the heap on the evaporator. Within the evaporator is a long way from "dry" yet wetted with fluid. All the same, this sort is known as the 'dry-extension' framework to recognize it from the "overwhelmed" framework and furthermore presumably in light of the fact that when the refrigerant reaches the evaporator outlet it is not any more wet (no fluid) however dry (superheated) vapor. An evaporator is utilized as a part of an aerating and cooling framework to permit the packed cooling refrigerant (R-11) to vanish from fluid to gas while engrossing heat all the while. It is introduced in the low weight side of cycle.

Figure 5.3 Evaporator.

How it works?

Ventilating evaporator works by retain warm from the range (medium) that should be cooled. It does that by keeping up the evaporator curl at low temperature and weight than the encompassing air. As the fluid refrigerant enters the evaporator at low weight and moves through it persistently and ingests warm through the loop dividers, from the medium being cooled amid this the refrigerant keeps on bubbling and dissipate.

Why evaporators remain cold?

The evaporator remains cold because of the following two major reasons:

- The temperature of the evaporator loop is low because of the low temperature of the refrigerant inside the coil.
- The low temperature of the refrigerant stays unaltered in light of the fact that any heat it retains is changed over to dormant heat as bubbling continues.

Heat Absorbed. The liquid refrigerant enters to the evaporator at point 5 and after absorbing the latent heat from the surroundings; the liquid refrigerant get evapourates and converted into vapour. Along with the assumption that the refrigerant get dry saturated after absorbing its latent heat in evaporator. So, From Figure, the total heat absorbed in the evaporator, Q_E is given by:

$$Q_E = m\,(h_2 - h_5) \quad \text{kJ/min} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.3)$$

Where,

m is the mass flow rate of refrigerant (in kg/min) .

h_5 , is the inlet enthalpy of refrigerant (kJ/kg).

h_2 , is the inlet enthalpy of refrigerant (kJ/kg).

5.2.4.Expansion Device. The expansion device (otherwise called metering gadget or throttling gadget) is an imperative gadget that partitions the high weight side and low weight side of refrigerating framework. The fundamental elements of an expansion device utilized as a part of refrigeration frameworks are to:

1. Diminish weight from condenser weight to evaporator weight, and
2. Control the refrigerant spill out of the high-weight fluid line into the evaporator at a rate equivalent to the vanishing rate in the evaporator

Under perfect conditions, the mass stream rate of refrigerant in the framework ought to be corresponding to the cooling load. Once more, a perfect refrigeration framework ought to have the office to control it in a manner that the vitality prerequisite is least and the required basis of temperature and cooling burden are fulfilled. The development gadgets utilized as a part of refrigeration frameworks can be partitioned into settled opening sort or variable opening sort. As the name infers, in settled opening sort the stream territory stays settled, while in variable opening sort the stream range changes with changing mass stream rates.In current work the Capillary Tube is used as an expansion device.

Capillary Tube. A capillary tube is a long, contract compartment of reliable separation over. "Fine" is a misnomer since surface pressure is not basic in refrigeration use of thin tubes. Typical tube removes crosswise over of refrigerant hairlike tubes stretch out from 0.5 mm to 3 mm and the length ranges from 1.0 m to 6 m.

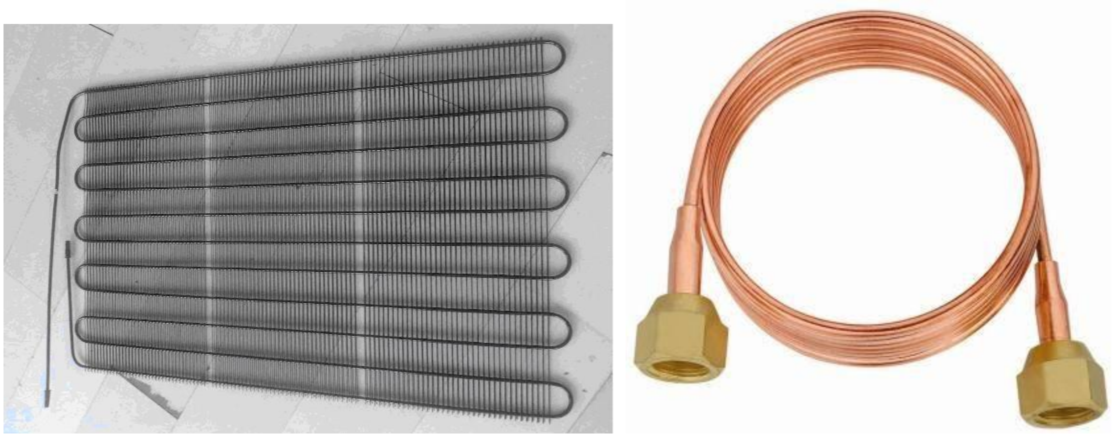


Figure 5.4: operational view of capillary tube.

The pressure diminishment in a hairlike tube happens in view of the going with two components:

1.The refrigerant needs to beat the frictional resistance offered by tube dividers. This prompts to some pressure drop, and

2.The liquid refrigerant flashes (disperses) into mix of liquid and vapor as its pressure decreases. The thickness of vapor is not as much as that of the liquid. Thus, the typical thickness of refrigerant decreases as it streams in the tube. The extension in speed or expanding velocity of the refrigerant moreover requires pressure drop.

A couple mixes of length and bore are open for a comparative mass stream rate and pressure drop. Regardless, once a thin holder of some separation crosswise over and length has been presented in a refrigeration system, the mass stream rate through it will change in such a path, to the point that the total weight drop through it matches with the pressure differentiate among condenser and the evaporator. Its mass stream rate is totally dependent upon the pressure refinement across over it; it can't adjust itself to assortment of load enough. Under the improvement technique it is acknowledged that no glow is acclimatized or rejected by the structure.

5.2.5. Pump.

- A pump is a gadget used to move liquids, for example, fluid refrigerants.
- A pump uproots a volume by physical or mechanical activity.
- Pumps fall into three noteworthy gatherings: coordinate lift, relocation, and gravity pumps. Their names portray the technique for moving a liquid.

Pump changes over the mechanical imperativeness from a motor to essentialness of a moving fluid; a bit of the essentialness goes into engine essentialness of smooth development, and some into potential essentialness, addressed by a fluid weight or by lifting the fluid against gravity to a bigger sum.

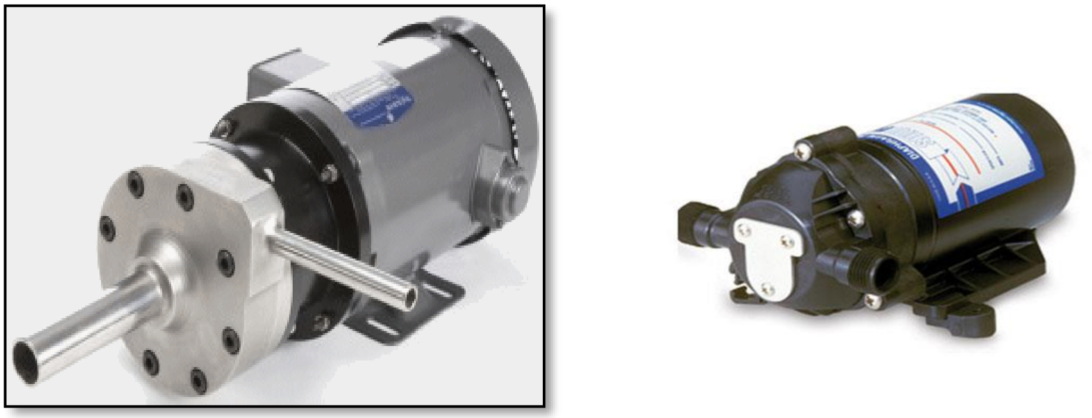


Fig 5.5: Schematic Diagram of Pump.

A centrifugal pump is a rotodynamic pump that uses a turning impeller to grow the pressure and stream rate of a fluid. Radiating pumps are the most surely understood kind of pump used to move liquids through a channeling structure. The fluid enters the pump impeller along or near the rotating center and is enlivened by the impeller, gushing radially outward or significantly into a diffuser or volute chamber, from where it exits into the downstream piping system. Disparate pumps are routinely used for generous discharge through smaller heads.

The liquid refrigerant release at point 4 and divided into two parts one is in refrigeration loop and another is in power loop. In power loop this liquid refrigerant gets compressed in refrigeration pump (shown in figure). The liquid refrigerant get pressurized from point 4 to point 6. The work required to obtained such pressure of refrigerant can be calculated with the help of given expression:

$$\textbf{Pump work } (W_P) = v_f\,(p_6 - p_4) \times 10^5 \times m \quad \text{J/min}$$

OR

$$W_P = m(h_6 - h_4) \quad \text{kJ/min}$$

Where,

V_f = Specific volume of liquid refrigerant (in m^3/ kg)

P_6 = pressure of liquid refrigerant at exit of pump (in bars)

P_4 = pressure of liquid refrigerant at inlet of pump (in bars)

m = mass flow rate of refrigerant (in kg/min)

h_4 = The inlet enthalpy of refrigerant (kJ/kg).

h_2 = The inlet enthalpy of refrigerant (kJ/kg).

5.2.6. Ejector : In this ejector, the process fluid to be evacuated is drawn upward through the vertical pipe by suction. It mixes with a motive fluid ; then, mixture exits through the diffuser. Ejectors are probably the most widely used vacuum- producing devices. The easiest and likely most generally utilized vacuum maker is the ejector (Figure 1). Now and again called a stream pump, an ejector works by changing over pressure vitality of a rationale liquid (which might be the same as or not the same as the procedure liquid) into speed vitality (dynamic vitality) as it courses through a moderately little merging wandering spout.

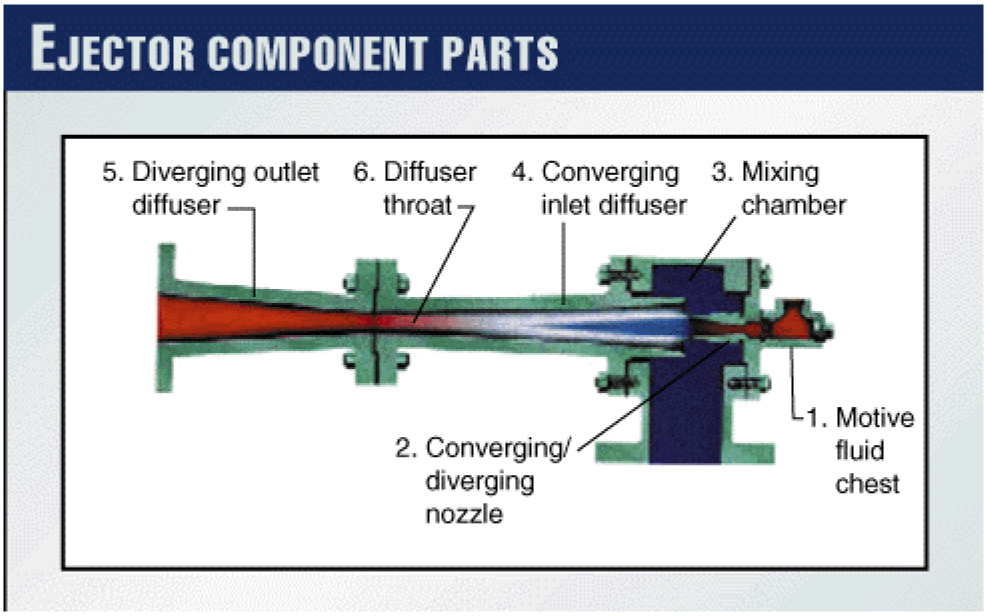


Figure 5.6 : Ejector Geometry

This brought down weight of the intention liquid makes suction in a blending chamber, into which the procedure liquid is drawn from the vessel being cleared. The procedure liquid blends with and gets to be entrained in the intention liquid stream. This blended liquid then goes on through a focalizing wandering diffuser, where the speed is changed over back to pressure vitality. The resultant weight is higher than the suction weight of the ejector. From design point view the ejector geometry and corresponding performance parameters are not taken in consideration. **For simplicity the Ejector is considered as a black box.**

5.2.7. Receiver-Drier. A collector tank is utilized to give stockpiling to the consolidated fluid refrigerant so that a consistent supply of refrigerant is accessible to the cycle according to necessity. Some essential points are listed below regarding the receiver drier. Assuming, there is no role of the receiver drier in the thermal analysis of the system.

- The collector drier is utilized on the high side of frameworks that utilization a heat development valve.
- This kind of metering valve requires fluid refrigerant. To guarantee that the valve gets fluid refrigerant, a beneficiary is utilized.
- The essential capacity of the collector drier is to separate gas and fluid.
- The auxiliary design is to evacuate dampness and sift through soil.

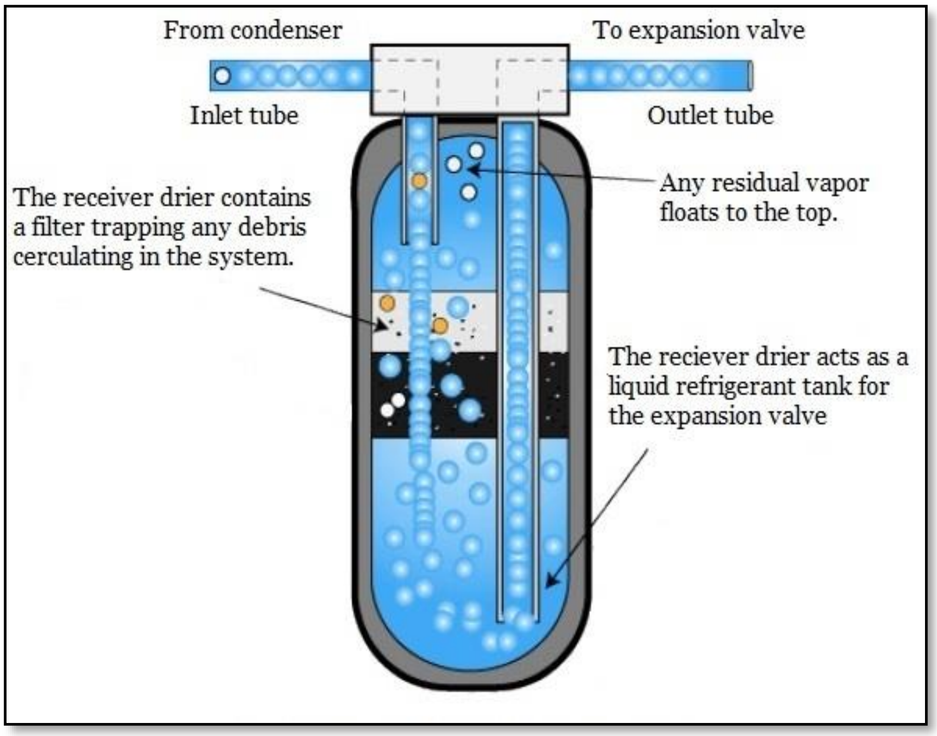


Figure 5.7: Schematic Diagram of receiver-Drier.

- The beneficiary drier normally has a sight glass in the top. This sight glass is frequently used to charge the framework. Under typical working conditions, vapor air pockets ought not be unmistakable in the sight glass.
- This is a little supply vessel for the fluid refrigerant, and expels any dampness that may have spilled into the refrigerant.
- Moisture in the framework causes ruin, with ice gems bringing on blockages and mechanical harm.

5.2.8 Heat Exchanger. Heat exchangers are the fundamental building frameworks with wide assortment of utilizations including many power divisions, atomic reactors, refrigeration and aerating and cooling frameworks, heat recuperation frameworks, concoction and nourishment businesses. Some configurations of helical tube heat exchangers are discussed below:

 Multiple pass design heat exchanger, which increases tube side velocity, thereby improve the heat transfer rate. With this configuration, there is an implementation in tube side pressure drop.

 Vaporizer or generator design for liquid vaporization and droplet disengagement.

 Condenser design, which comes in some typical configurations. Each condenser depends on the process and vessel's discharge conditions.

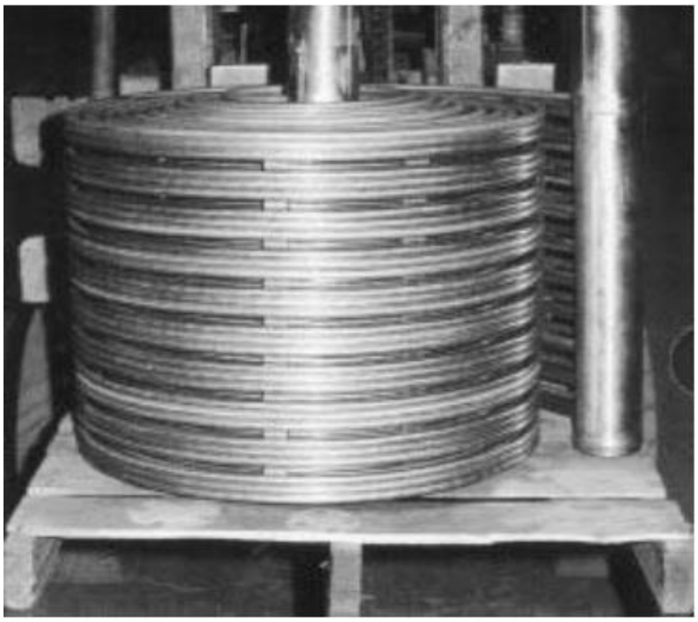


Figure 5.8 : Layout of heat exchanger.

In present work helical coiled heat exchanger is coupled with generator of the cooling system so that the waste heat of the engine could be transferred to the generator of the cooling system. In such system the waste heat of exhaust gases is passes through the helical coils and these helical coils are surrounded by the liquid refrigerant contains in the generator. This heat is used to vaporize the liquid refrigerant, which is the requirement of the system.

Chapter 6

Calculation

6.1 Assumptions.

To simplify this analysis, the following assumptions are made in this study:

(1) The fluid at the exit of condenser is at saturated liquid state.

(2) The fluid at the exit of evaporator is at saturated vapour state.

(3) The fluid at the exit of generator is at superheated vapour state.

(4) The expansion through the expansion value is a throttling process.

(5) The primary stream expands isentropically in the nozzle. The mixture of primary stream and secondary stream is isentropically compressible in diffuser.

(6) Heat loss in the cycle is negligible.

6.2 Working conditions.

Evaporator pressure (p_E) = 4.15 bar
Evaporator temperature (T_E) = 10 ℃
Condenser pressure (p_C) = 10.17 bar
Condenser temperature (T_C) = 40 ℃
Generator pressure (p_G) = 13.18 bar
Generator temperature (T_G) = 50 ℃

6.3 Refrigerant data Used.

Table. 6.1 : Trichloromonofluoromethane (CCl_3F), R-11.

Saturation Pressure (Bar)	Saturation Temp. (℃)	Sp. Enthalpy (KJ/Kg)			Sp. Entropy (KJ/Kg-K)		Sp. Volume (m^3/kg)	
		h_f	h_{fg}	h_g	s_f	s_g	v_f	v_g
4.15	10	213.39	197.46	410.85	1.04	1.74	0.00079	0.000049
10.17	40	256.43	169.74	426.74	1.19	1.73	0.000871	0.000019
13.18	50	271.97	158.43	430.40	1.24	1.73	0.000906	0.000015

6.4 **Calculations.** To simplify the calculation of the system, the schematic diagram and T-s diagram are shown in given figure.

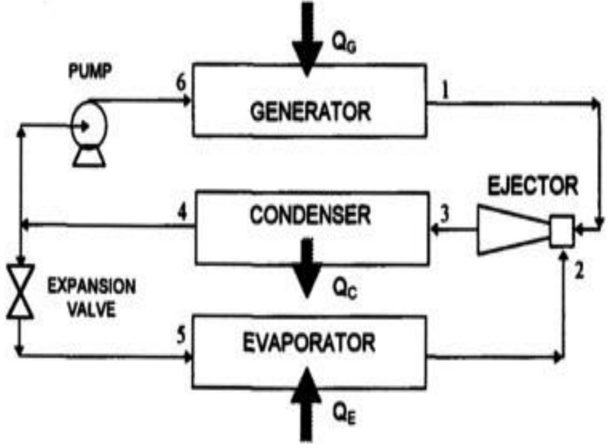


Figure : Line Diagram of ERC.

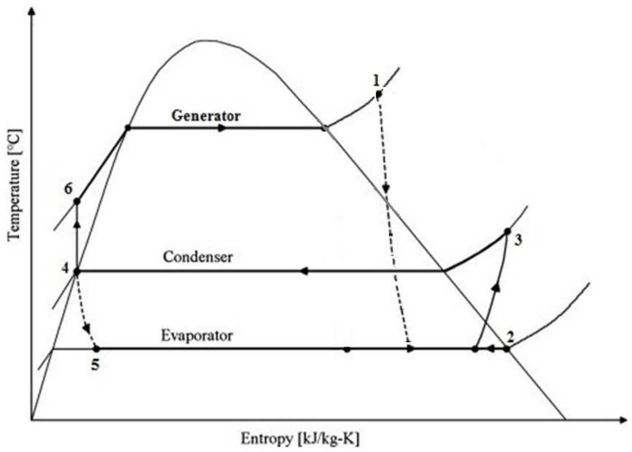


Figure : T-s diagram of ERC

Ejector cycle: The operational cycle contains two loops one is refrigeration loop and another is power loop. The refrigeration loop also known as low pressure loop while power loop is known is high pressure loop. In this system ejector is considered as a black box. Following consideration are taken for simplicity of system performance analysis.

Let,

P_G = Generator pressure (in bars)

P_C = Condenser pressure (in bars)

P_E = Evaporator pressure (in bars)

Similarly, T_G, T_C, T_E are the corresponding temperatures of generator, condenser and evaporator respectively.

h_1 = The enthalpy of vapour refrigerant at exit of generator. (kJ/kg).

h_2 = The enthalpy of vapour refrigerant at exit of evaporator. (kJ/kg).

h_3 = The enthalpy of vapour refrigerant at exit of ejector or inlet of condenser. (kJ/kg).

h_4 = The enthalpy of liquid refrigerant at exit of condenser or inlet of pump. (kJ/kg).

h_5 = The enthalpy of liquid refrigerant at inlet of evaporator. (kJ/kg).

h_6 = The enthalpy of liquid refrigerant at inlet of generator or exit of pump. (kJ/kg).

Q_G = Amount of heat required to run the system (kJ/min)

Q_C = Amount of heat rejected to the atmosphere (kJ/min)

Q_E = Amount of heat absorbed from the space to be cooled. (kJ/min)

W_P = Pump work required to maintain required pressure difference.

m_1 = mass flow rate of refrigerant in loop 1 of the cycle. (kg/min)

m_2 = mass flow rate of refrigerant in loop 2 of the cycle. (kg/min)
m = total mass flow rate i.e $m_1 + m_2$. (kg/min)

As we know that the domestic vapour absorption refrigeration systems works between 0.5 to 1.0 kg/min of refrigerant flow rate (from design point of view) .Hence, taking mass flow rate of refrigerant in power loop is 0.65 kg/min. (justification of mass flow rate is discussed in next article.)

Loop 1 (Power loop)

[a]. Pump work (W_P). The liquid refrigerant release from condenser at point 4 and divided into two parts one is in refrigeration loop and another is in power loop. In power loop this liquid refrigerant gets compressed in refrigeration pump (shown in figure). The liquid refrigerant get pressurized from point 4 to point 6. The work required to obtained such pressure of refrigerant can be calculated with the help of given expression:

Pump work (W_P) = $v_f (p_6 - p_4) \times$ mass flow rate.

$= 0.000871(13.18 - 10.16) \times 10^5 \times 0.65$

= 170.97 J/min..(1)

Also, $W_P = m_1(h_6 - h_4)$..(2)

From (1) and (2),

$0.65(h_6 - 256.43) = 0.17097$

$\mathbf{h_6 = 256.26}$ **kJ/kg**

[b]. Heat required for generator. After pressurizing the liquid refrigerant entering to a closed chamber, called generator, at point 6. In the generator the refrigerant get heated by means of exhaust heat and converted into vapour form. The vapour refrigerant is exit at point 1 as shown in figures.(superheated by 20℃). The value of C_p for the refrigerant is 0.578 kJ/kg K. Hence the amount of heat required for evaporate the liquid refrigerant can be calculated by the expression:
(let the vapour exit from the generator is superheated by 20℃)

$Q_G = m_1(h_1 - h_4)$

$h_1 = h_g + m_1 C_p \Delta T$

$= 430.40 + \{0.65 \times 0.578\ (20)\} =$ **437.5 kJ/kg.**

Now,

$Q_G = m_1(h_1 – h_4)$

$= 0.65(437.5- 256.26)$ kJ/min

= 117.8 kJ/min OR 1.96 kW

Assuming that the effectiveness of heat exchanger (generator) is 90%.

Hence, actual heat required in the generator will be 1.1 times of ideal or calculated value of $Q_{G.}$ the actual Q_G can be calculated as :

$(Q_G)_{act.} = 1.1 \times 117.8$ kJ/min

$(Q_G)_{act}$ = 129.58kJ/min OR 2.16 kW................(3)

Loop 2 (Refrigeration loop).

(Considering non-isentropic expansion and mass flow rate in the loop is 0.75 kg/min.)

[a]. Heat absorbed in evaporator. The liquid refrigerant enters to the evaporator at point 5 and after absorbing the latent heat from the surroundings; the liquid refrigerant get evaporates and converted into vapour. Along with the assumption that the refrigerant get dry saturated after absorbing its latent heat in evaporator. So, From Figure, the total heat absorbed in the evaporator, Q_E is given by:

$Q_E = m_2 (h_2 – h_5)$ kJ/min

Hence, $h_5 = h_{f4} = 256.43$ kJ/kg

Along with the assumption that the refrigerant 95% dry after absorbing heat in evaporator. So,

$h_2 = h_{f2} + xh_{fg}$

$h_2 = 213.39 + (0.95 \times 197.46)$

$h_2 = 400.9$ kJ/kg

$Q_E = m_2 (h_2 – h_5)$ kJ/min

$= 0.75(400.9 – 256.43)$

Q_E = 108.41 kJ/min

Assuming that the effectiveness of heat exchanger (evaporator) is 90%.

Hence, actual heat absorbed in the evaporator will be 0.95 times of ideal or calculated value of $Q_{E.}$ The actual Q_E can be calculated as :

$(Q_E)_{act.} = 0.95 \times 108.41$ kJ/min

$(Q_E)_{act}$ = 102.98 kJ/min......................................(4)

[b]. Heat rejected in condenser. Assuming that the vapour refrigerant get superheated by 10 ℃ in mixing chamber. Hence in condenser the refrigerant release its sensible heat and becomes dry saturated vapour after that its latent heat to the atmosphere and converted in liquid form. After that the condensed refrigerant is exit from the condenser at point 4.

Since the mass flow rate in loop1is 0.65 kg/min whereas in loop2 it is 0.75 kg/min. But the condenser is the intermediate part for the both loops. Hence condenser should have the capacity to handle the mass flow rate of 1.4 kg/min and convert it into liquid state. The amount of heat rejected by the refrigerant in the condenser is calculated as:

$$Q_C = m\,(h_3 - h_4)\ \text{kJ/min}$$

$$h_3 = \frac{m_1 h_2 + m_2 h_1}{m_1 + m_2}$$

$$= \frac{0.65 * 400.9 + 0.75 * 437.5}{0.65 + 0.75}$$

$$h_3 = 417.40\ \text{kJ/kg.}$$

$$Q_C = m\,(h_3 - h_4)\ \text{kJ/min}$$

$$= (0.65 + 0.75)(417.4 - 256.43)$$

$$\mathbf{Q_C = 225.37\ kJ/min}$$

Assuming that the effectiveness of heat exchanger (condenser) is 90%.

Hence, actual heat rejected in the condenser will be 0.9 times of ideal or calculated value of Q_C. The actual Q_C can be calculated as :

$$(Q_C)_{act.} = 0.9 \times 225.37\ \text{kJ/min}$$

$$\mathbf{(Q_C)_{act} = 202.8\ kJ/min} \text{.....................................(5)}$$

Heat Supplied.

Exhaust heat analysis:

As mention in chapter 4, the temperature of exhaust gases coming out from the engine is approximate 240℃ where as the surrounding atmosphere temperature is taken as 20 ℃. Mass flow rate of these exhausted gases is 0.04733 kg/s and specific heat of these flue gases is taken 1.05 kJ/kg-K. Hence the amount of heat exhausted through silencer can be calculated with the help of expression given below,

Heat exhausted = $m_g\, c_p\, \Delta T$

Where,

m_g = mass flow rate of exhaust gas (kg/s)

c_{pg} = specific heat of exhaust gas (kJ/kg-K)

ΔT = temperature difference between exhaust and atmosphere (K)

Hence,

Heat exhausted = 0.04733 * 1.05 * (513 - 293) kJ/s

= 10.93 kJ/s OR 655.8 kJ/min……………………………………..(6)

Co-Efficient of performance.

The coefficient of performance of the system can be calculated as:

$$(\text{COP})_{\text{Actual}} = \frac{Q_E}{Q_G + W_P}$$

$$= \frac{102.98}{129.58 + 0.17097}$$

$$= \mathbf{0.79}$$

Cooling capacity:

Refrigerating effect produced by the system = 102.98 kJ/min

Hence, cooling capacity in terms of tones of refrigeration can be calculated as,

Cooling capacity of the system (in terms of TR) $= \frac{\mathbf{102.98}}{\mathbf{210}}$ **= 0.49 TR**

Another calculation can be make along with lower and upper range of mass flow rate of refrigerant i.e 0.5 kg/min and 1.0 kg/min.

Lower value of mass flow rate i.e m = 0.5 kg/min.

Loop 1 (Power loop).

[a]. Pump work (W_P). Under such condition, the work required to obtained such pressure of refrigerant can be calculated with the help of given expression:

Pump work (W_P) = v_f ($p_6 - p_4$) × mass flow rate.

= 0.000871(13.18 – 10.16) × 10^5 × 0.5**= 131.5 J/min**............................(7)

Also, $W_P = m(h_6 - h_4)$..(8)

From (7) and (8),

$0.5(h_6 - 256.43) = 0.1315$

$\mathbf{h_6 = 256.6\ kJ/kg}$

[b]. Heat required for generator. Under such condition, the amount of heat required for evaporate the liquid refrigerant can be calculated by the expression:

(let the vapour exit from the generator is superheated by 20℃)

$$Q_G = m(h_1 - h_4)$$

$$h_1 = h_g + m\ C_p\ \Delta T$$

$$= 430.40 + \{0.50 \times 0.578\ (20)\} = \mathbf{436.1\ kJ/kg.}$$

Now,

$$Q_G = m(h_1 - h_4)$$

$$= 0.50(436.1 - 256.26)\ kJ/min$$

$$\mathbf{= 90.0\ kJ/min}$$

Assuming that the effectiveness of heat exchanger (generator) is 90%.

Hence, actual heat required in the generator will be 1.1 times of ideal or calculated value of $Q_{G.}$ the actual Q_G can be calculated as :

$$(Q_G)_{act.} = 1.1 \times 90.0\ kJ/min$$

$$\mathbf{(Q_G)_{act} = 98.95 kJ/min} \text{ ....(9)}$$

Loop 2 (Refrigeration loop).

(Considering non-isentropic expansion)

[a]. Heat absorbed in evaporator. Under such condition, the total heat absorbed in the evaporator, Q_E is given by:

$$\mathbf{Q_E = m\ (h_2 - h_5)\ kJ/min}$$

Hence, $h_5 = h_{f4} = 256.43$ kJ/kg

Along with the assumption that the refrigerant 95% dry after absorbing heat in evaporator. So,

$$h_2 = h_{f2} + xh_{fg}$$

$$h_2 = 213.39 + (0.95 \times 197.48)$$

$$h_2 = 400.9\ kJ/kg$$

$$Q_E = m\ (h_2 - h_5)\ kJ/min$$

$$= 0.5(400.9 - 256.43)$$

$$\mathbf{Q_E = 72.23\ kJ/min}$$

Assuming that the effectiveness of heat exchanger (evaporator) is 95%.

Hence, actual heat absorbed in the evaporator will be 0.95 times of ideal or calculated value of Q_E. The actual Q_E can be calculated as :

$$(Q_E)_{act.} = 0.95 \times 72.23 \text{ kJ/min}$$

$$\mathbf{(Q_E)_{act} = 68.62\ kJ/min} \text{......................................}(10)$$

[b]. Heat rejected in condenser. Under such condition, the amount of heat rejected by the refrigerant in the condenser is calculated as: (here $m_1 + m_2 = m = 0.5$)

$$Q_C = (m + m)(h_3 - h_4) \text{ kJ/min}$$

$$h_3 = \frac{m_1 h_2 + m_2 h_1}{m_1 + m_2}$$

$$= \frac{0.50(400.9+437.5)}{0.50+0.50}$$

$$h_3 = 419.20 \text{ kJ/kg.}$$

$$Q_C = m(h_3 - h_4) \text{ kJ/min}$$

$$= (0.5 + 0.5)(419.2 - 256.43)$$

$$\mathbf{Q_C = 167.7\ kJ/min}$$

Assuming that the effectiveness of heat exchanger (condenser) is 90%.

Hence, actual heat rejected in the condenser will be 0.9 times of ideal or calculated value of Q_C. The actual Q_C can be calculated as :

$$(Q_C)_{act.} = 0.9 \times 167.7 \text{ kJ/min}$$

$$\mathbf{(Q_C)_{act} = 150.9\ kJ/min} \text{.....................................}(11)$$

Co-Efficient of performance.

The coefficient of performance of the system can be calculated as:

$$(COP)_{Actual} = \frac{Q_E}{Q_G + W_P}$$

$$= \frac{68.62}{98.95+0.1315} = \mathbf{0.692}$$

Cooling capacity:

Refrigerating effect produced by the system = 68.62 kJ/min

Hence, cooling capacity in terms of tones of refrigeration can be calculated as,

Cooling capacity of the system (in terms of TR) $= \frac{\mathbf{68.62}}{\mathbf{210}} = \mathbf{0.32\ TR}$

Upper value of mass flow rate i.e m = 1.0 kg/min.

Loop 1 (Power loop).

[a]. Pump work (W_P). Under such condition, the work required to obtained such pressure of refrigerant can be calculated with the help of given expression:

Pump work (W_P) = v_f ($p_6 - p_4$) × mass flow rate.

= 0.000871(13.18 – 10.16) × 10^5 × 1.0

= 263.0 J/min..........................(12)

Also, $W_P = m(h_6 - h_4)$..(13)

From (12) and (13),

$1.0(h_6 - 256.43) = 0.263$

h_6 = 256.6 kJ/kg

[b]. Heat required for generator. Under such condition, the amount of heat required for evaporate the liquid refrigerant can be calculated by the expression:

(let the vapour exit from the generator is superheated by 20℃)

$Q_G = m(h_1 - h_4)$

$h_1 = h_g + m\ C_p\ \Delta T$

= 430.40 + {1.0 × 0.578 (20)}= **441.9 kJ/kg.**

Now,

$Q_G = m(h_1 - h_4)$

= 1.0(441.9- 256.26) kJ/min

= 185.7 kJ/min.

Assuming that the effectiveness of heat exchanger (generator) is 90%.

Hence, actual heat required in the generator will be 1.1 times of ideal or calculated value of $Q_{G.}$ the actual Q_G can be calculated as :

$(Q_G)_{act.}$ = 1.1 × 185.7 kJ/min

$(Q_G)_{act}$ = 204.27kJ/min ....(14)

Loop 2 (Refrigeration loop).

(Considering non-isentropic expansion)

[a]. Heat absorbed in evaporator. Under such condition, the total heat absorbed in the evaporator, Q_E is given by:

$$\mathbf{Q_E = m\,(h_2 - h_5)\ kJ/min}$$

Hence, $h_5 = h_{f4} = 256.43$ kJ/kg

Along with the assumption that the refrigerant 95% dry after absorbing heat in evaporator. So,

$$h_2 = h_{f2} + xh_{fg}$$

$$h_2 = 213.39 + (0.95 \times 197.48)$$

$$h_2 = 400.9 \text{ kJ/kg}$$

$$Q_E = m\,(h_2 - h_5) \text{ kJ/min}$$

$$= 1.0(400.9 - 256.43)$$

$$\mathbf{Q_E = 144.46\ kJ/min}$$

Assuming that the effectiveness of heat exchanger (evaporator) is 95%.

Hence, actual heat absorbed in the evaporator will be 0.95 times of ideal or calculated value of Q_E. The actual Q_E can be calculated as :

$$(Q_E)_{act.} = 0.95 \times 144.46 \text{ kJ/min}$$

$$\mathbf{(Q_E)_{act} = 137.23\ kJ/min} \text{....................................(15)}$$

[b]. Heat rejected in condenser. Under such condition, the amount of heat rejected by the refrigerant in the condenser is calculated as: (here $m_1 + m_2 = m = 1.0$)

$$Q_C = (m + m)\,(h_3 - h_4) \text{ kJ/min}$$

$$h_3 = \frac{m_1 h_2 + m_2 h_1}{m_1 + m_2}$$

$$= \frac{1.0(400.9+437.5)}{1.0+1.0}$$

$$h_3 = 419.20 \text{ kJ/kg.}$$

$$Q_C = m\,(h_3 - h_4) \text{ kJ/min}$$

$$= (1.0 + 1.0)(419.2 - 256.43)$$

$$\mathbf{Q_C = 335.5\ kJ/min}$$

Assuming that the effectiveness of heat exchanger (condenser) is 90%.

Hence, actual heat rejected in the condenser will be 0.9 times of ideal or calculated value of Q_C. The actual Q_C can be calculated as :

$$(Q_C)_{act.} = 0.9 \times 335.5 \text{ kJ/min}$$

$$\mathbf{(Q_C)_{act} = 301.9\ kJ/min} \text{.....................................(16)}$$

Co-Efficient of performance.

The coefficient of performance of the system can be calculated as:

$$(COP)_{Actual} = \frac{Q_E}{Q_G+W_P}$$

$$= \frac{137.23}{204.27+0.1315}$$

$$= \mathbf{0.671}$$

Cooling capacity:

Refrigerating effect produced by the system = 137.23 kJ/min

Hence, cooling capacity in terms of tones of refrigeration can be calculated as,

Cooling capacity of the system (in terms of TR) $= \frac{\mathbf{137.23}}{\mathbf{210}} = \mathbf{0.65\ TR}$

Summary:

Mass flow rate of refrigerant(kg/min)	**W_P (kJ/min)**	**Q_G (kJ/min)**	**Q_E (kJ/min)**	**Q_C (kJ/min)**	**COP**	**TR**
$m_1 = m_2 = 0.5$	0.1315	90.0	72.23	167.7	0.69	0.32
$m_1 = 0.65, m_2 = 0.75$	**0.1315**	**117.8**	**108.4**	**225.3**	**0.79**	**0.49**
$m_1 = m_2 = 1.0$	0.1315	185.7	144.4	335.5	0.67	0.65

Table 6.2 : Summarized values of different parameters at various mass flow rate.

Justification of mass flow rate of refrigerant. According to first low of thermodynamics,

$$\mathbf{Q_C = Q_G + Q_E + W_P}$$

Hence, for $m_1 = m_2 = 0.5$kg/min (applying above equation)

167.7 = 90.0 + 72.23 + 0.1315 = 162.3 **(Not acceptable)**

For **$m_1 = 0.65, m_2 = 0.75$** kg/min,

225.3 = 117.8 + 108.4 + 0.1315 = 226.3 **(Acceptable)**

For $m_1 = m_2 = 1.0$ kg/min,

335.5 = 185.7 + 144.4 +0.1315 = 330.2 **(Not acceptable)**

Note: The amount of heat rejected through the condenser is always less than the total heat of the system, so that the possibility of flow of heat remains continuous. Hence m_1= 0.65, m_2 = 0.75 kg/min is a suitable value for the system.

Chapter 7

Result & Discussion

Following observations were made during the system performance analysis :

Working conditions;

T_G (°C)	50	**P_G (Bars)**	13.18
T_C (°C)	40	**P_C (Bars)**	10.17
T_E (°C)	10	**P_E (Bars)**	4.15

Table. 7.1: working conditions of the system.

Analytical result summary:

On the basis of above working conditions, following results are concluded;

Case I : When $m_1 = m_2 = 0.5$ kg/min (lower limit).

Q_G (kJ/min)	**Q_C (kJ/min)**	**Q_E (kJ/min)**	**W_P (kJ/min)**	**Q_S (kJ/min)**	**COP**	**Capacity (TR)**
90.0	**167.7**	**72.23**	**0.1315**	**655.8**	**0.69**	**0.32**

Table.7.2 : Result summary under $m_1 = m_2 = 0.5$kg/min conditions.

Case II : When $m_1 = 0.65, m_2 = 0.75$ kg/min.

Q_G (kJ/min)	**Q_C (kJ/min)**	**Q_E (kJ/min)**	**W_P (kJ/min)**	**Q_S (kJ/min)**	**COP**	**Capacity (TR)**
117.8	**225.3**	**108.4**	**0.1315**	**655.8**	**0.79**	**0.49**

Table.7.3 : Result summary under $m_1 = 0.65, m_2 = 0.75$ kg/min conditions.

Case III : When $m_1 = m_2 = 1.0$ kg/min (upper limit).

Q_G (kJ/min)	**Q_C (kJ/min)**	**Q_E (kJ/min)**	**W_P (kJ/min)**	**Q_S (kJ/min)**	**COP**	**Capacity (TR)**
185.7	**335.5**	**144.4**	**0.1315**	**655.8**	**0.67**	**0.65**

Table.7.4 : Result summary under $m_1 = m_2 = 1.0$ kg/min conditions.

As we can see above that exhaust heat powered ejector air conditioning system is based on the principle, similar to vapour absorption refrigeration system. The calculated COP in actual condition (with losses) is **0.79** along with the cooling capacities of 0.49

TR. The source for running the system is **655.8 kJ/min** exhaust heat along with heat exchanger. Another analysis shows the justification for mass flow rate of refrigerant. In the last part of analysis the mass flow rate is checked with upper and lower limit of mass flow rate in the domestic system.

Note 1. Could be used satisfactorily in smoothly running of the car without installation of battery for backup.

Note 2. Battery having suitable load carrying capacity may also be installed for backup in case of lower exhausted heat.

Chapter 8

Conclusion and Scope for Future work

Conclusion. Considering the impact of Ozone Depletion Potential(ODP) & Global Warming Potential (GWP) waste heat driven vapour absorption system shows a very prospective alternative in refrigeration system. From the Environmental point of view this system is Eco-friendly as it involves the use of R-134a as a refrigerant which is not a chloro-fluoro refrigerant and not responsible for OZONE layer Depletion. Along these lines we can finished up, in fact, that Out of the aggregate heat provided to the engine as fuel, around, 30 to 40% is changed over into valuable mechanical work; the rest of the heat is removed to nature through fumes gasses and engine cooling frameworks, bringing about to entropy rise and genuine ecological contamination, so it is required to used waste heat into helpful work. The recuperation and usage of waste heat moderates fuel (fossil fuel) as well as decreases the measure of waste heat and greenhouse gasses damped to condition. The review demonstrates the accessibility and plausibility of waste heat from inner burning engine, likewise depict loss of fumes gas vitality of an inside ignition engine. Conceivable techniques to recuperate the waste heat from interior ignition engine and execution and discharges of the inward burning engine. Waste heat recuperation framework is the most ideal approach to recoup Waste heat and sparing the fuel.

Future work. To expand the allure and utilization of ejector refrigeration frameworks innovative work is required to:

- Use other refrigerants rather than R-134 a for such systems for getting better co-efficient of performance.
- Analysis of performance of the system with the variation in ejector geometry parameters.
- Increase the proficiency of consistent stream ejectors especially at operation far from the plan point.
- Develop elective ejector sorts, for example, rotodynamic ejectors that offer potential for higher efficiencies.
- Research into the advancement of cycles and the coordination of ejectors with routine vapor pressure and ingestion frameworks.

References

[1]. Nguyen Q. MINH, “Improved vapour compression refrigeration cycles: Literature review and their application to heat pumps” International Refrigeration and Air Conditioning Conference at Purdue, July 17-20, 2006.

[2]. Akhilesh Arora ,S.C. Kaushik “Theoretical analysis of a vapour compression refrigeration system with R502, R404A and R507A” International Journal of Refrigeration Volume 31, Issue 6, September 2008, Pages 998–1005

[3]. P. Srikhirin, “A review of absorption refrigeration technologies” Renewable and Sustainable Energy Reviews, Volume5, Issue 4, December 2001,pages 343-372.

[4]. Satish K. Maurya, “An Automobile Air-Conditioning System Based on an Ejector Refrigeration Cycle Using Heat from Exhaust Gas of an Internal Combustion Engine” VSRD INTERNATIONAL JOURNAL OF MECHANICAL, CIVIL, AUTOMOBILE AND PRODUCTION ENGINEERING, Volume IV Issue V.

[5]. Taylor, R.A., Solbrekken, G., Comprehensive system-level optimization of thermoelectric devices for electronic cooling applications, Components and Packaging Technologies, IEEE Transactions on (Volume:31 , Issue: 1)

[6]. Richard, M. -A. (2004). "Magnetic refrigeration: Single and multimaterial active magnetic regenerator experiments". Journal of Applied Physics **95** (4): 2146.doi:10.1063/1.1643200.

[7]. SB Riffat, SA Omer, X Ma, “A novel thermoelectric refrigeration system employing heat pipes and a phase change material: an experimental investigation” Renewable Energy Volume 23, Issue 2, June 2001, Pages 313–323

[8]. SB Riffat, SA Omer, X Ma, “A novel thermoelectric refrigeration system employing heat pipes and a phase change material: an experimental investigation” Renewable Energy Volume 23, Issue 2, June 2001, Pages 313–323

[9]. Vitalij K. Pecharsky, Karl A. Gschneidner Jr, “Magnetocaloric effect and magnetic refrigeration” Journal of Magnetism and Magnetic Materials**,** Volume 200, Issues 1–3, October 1999, Pages 44–56

[10]. M.E. Wood, W.H. Potter, “General analysis of magnetic refrigeration and its optimization using a new concept: maximization of refrigerant capacity” Cryogenics**,** Volume 25, Issue 12, December 1985, Pages 667–683

[11]. A. Selvaraju, A. Mani “Analysis of an ejector with environment friendly refrigerants” Applied Thermal Engineering Volume 24, Issues 5–6, April 2004, Pages 827–838

[12]. R. Yapıcı, H.K. Ersoy “Performance characteristics of the ejector refrigeration system based on the constant area ejector flow model” Energy Conversion and Management Volume 46, Issues 18–19, November 2005, Pages 3117–3135

[13]. T. Sankarlal, A. Mani “Experimental studies on an ammonia ejector refrigeration system” International Communications in Heat and Mass Transfer Volume 33, Issue 2, February 2006, Pages 224–230

[14]. A. Selvaraju, “Experimental investigation on R134a vapour ejector refrigeration system” International Journal of Refrigeration Volume 29, Issue 7, November 2006, Pages 1160–1166

[15]. K. Pianthong, W. Seehanam, M. Behnia, T. Sriveerakul, S. Aphornratana “Investigation and improvement of ejector refrigeration system using computational fluid dynamics technique” Energy Conversion and Management Volume 48, Issue 9, September 2007, Pages 2556–2564

[16]. R. Yapıcı, “Experimental investigation of performance of vapour ejector refrigeration system using refrigerant R123” Energy Conversion and Management Volume 49, Issue 5, May 2008, Pages 953–961

[17]. R. Yapıcı, H.K. Ersoy “Experimental determination of the optimum performance of ejector refrigeration system depending on ejector area ratio” International Journal of Refrigeration Volume 31, Issue 7, November 2008, Pages 1183–1189

[18]. G Vicatos, “A car air-conditioning system based on an absorption refrigeration cycle using energy from exhaust gas of an internal combustion engine” Journal of Energy in Southern Africa • Vol 19 No 4 • November 2008.

[19]. Khaled S. AlQdah, “Performance and Evaluation of Aqua Ammonia Auto Air Conditioner System Using ExhaustWaste Energy.” Energy Procedia 6 (2011) 467–476.

[20] Zhengshu Dai & Yijian He “Performance of Pump less Ejector Refrigeration System driven by Solar Thermal Energy” International Refrigeration and Air Conditioning Conference at Purdue, July 16-19, 2012.

[21]. Chaobin Dang, “Study on Ejector - Vapor Compression Hybrid Air Conditioning System Using Solar Energy” International Refrigeration and Air Conditioning Conference at Purdue, July 16-19, 2012.

[22]. Yongfang Zhong, “Size Reduction of an Engine Waste-Heat Driven Air-Conditioner for Passenger Cars and Light-Duty Trucks” International Conference on Advances in Energy Engineering (ICAEE2011), Energy Procedia 14 (2012) 351-357.

[23]. Satish K. Maurya, “ A Cooling System for an Automobile Based on Vapour Absorption Refrigeration Cycle Using Waste Heat of an Engine.” *Int. Journal of Engineering Research and Applications, ISSN : 2248-9622, Vol. 4, Issue 3(Version 1), March 2014, pp.441-444.*

[24]. Shengqiang Bai, “Numerical and experimental analysis for exhaust heat exchangers in automobile thermoelectric generators” Case StudiesinThermalEngineering4(2014)99–112, journal homepage: www.elsevier.com/locate/csite.

[25]. Lucien Y. Bronicki, “ORGANIC RANKINE CYCLE POWER PLANT FOR WASTE HEAT RECOVERY” ORMAT International Inc.

[26]. S. A. Sherif, D. Y. Goswami, G. D. Mathur, S. V. Iyer, B. S. Davanagere, S. Natarajan, F. Colacino, (1998) A Feasibility study of steam-jet refrigeration, Int. j. energy res., 22, 1323-1336.

[27]. G. K. Alexis, (2005) Exergy analysis of ejector-refrigeration cycle using water as working fluid, Int. J. Energy Res.; 29:95–105.

[28].Denso Ejector cycle, http://www.globaldenso.com/en/environment/story/no1/2par.html

[29]. http://books.google.co.in/books?id=7M84lvsnlKAC&printsec=frontcover&dq=refrige

ration+and+air+conditioning+by+rs+khurmi&hl=en&sa=X&ei=YJumU9m3Js6MuATMnoKQBA&sqi=2&ved=0CB4QuwUwAA

[30]. http://books.google.co.in/books?id=6z0wRsbPxI4C&pg=PA156&dq=refrigeration+and+air+conditioning+by+rajput&hl=en&sa=X&ei=dpumU6sWl6O6BKv9gtgJ&ved=0CB0QuwUwAA.

[31]. J. S. Jadhao, D. G. Thombare, "Review on Exhaust Gas Heat Recovery for I.C. Engine" International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, Issue 12, June 2013.

[32]. Mukesh Rathore, "Design and development of low cost I.C. Engine based waste heat recovery system"International Journal of Emerging Technology and Advanced Engineering (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013).

[33]. R. Saidur, "Technologies to recover exhaust heat from internal combustion engines" Renewable and Sustainable Energy Reviews 16 (2012) 5649–5659.

[34]. C. Ramesh Kumar, " EXPERIMENTAL STUDY ON WASTE HEAT RECOVERY FROM AN INTERNAL COMBUSTION ENGINE USING THERMOELECTRIC TECHNOLOGY" INTERNATIONAL JOURNAL OF THERMAL SCIENCE, Year 2011, Vol. 15, No. 4, pp. 1011-1022.

[35]. P. Sathiamurthi, "Design and Development of Waste Heat Recovery System for air Conditioning," Unit European Journal of Scientific Research, Vol.54 No.1 (2011), pp.102-110, 2011.

[36]. S. Karellasa, A.-D. Leontaritisa, G. Panousisa , E. Bellos A, E. Kakaras, "Energetic And Exergetic Analysis Of Waste Heat Recovery Systems In The Cement Industry," Proceedings of ECOS 2012 - The 25th International Conference On Efficiency, Cost, Optimization, Simulation And Environmental Impact Of Energy Systems June 26-29, 2012, Perugia, Italy.

[37]. T. Endo, S. Kawajiri, Y. Kojima, K. Takahashi, T. Baba, S. Ibaraki, T. Takahashi, "Study on Maximizing Exergy in Automotive Engines," SAE Int. Publication 2007-01-0257, 2007.

[38]. *M. Hosoz* , *M. Direk*, Department of Mechanical Education, Kocaeli University, Umuttepe, 41100 Kocaeli, Turkey, Performance evaluation of an integrated

automotive air conditioning and heat pump system “Received 5 November 2004; accepted 18 May 2005 Available online 14 July 2005.” Energy Conversion and Management 47 (2006) 545–559.

[39]. T. Endo, S. Kawajiri, Y. Kojima, K. Takahashi, T. Baba, S. Ibaraki, T. Takahashi, “Study on Maximizing Exergy in Automotive Engines,” SAE Int. Publication 2007-01-0257, 2007.