Performance Evaluation of Waste Heat Driven Absorption Refrigeration System

Sheetal Dudhade, Nagnath Shinde, Rushikesh Vanshette

Abstract— Automobiles lose a lot of heat in exhaust gases which reduces the overall thermal efficiency of the engine and is also a source of pollution. In present work vapour absorption system exhaust heat from engine is used as heating source of vapour absorption system. From the literature, it is clear that heat potential in the exhaust is enough for powering the present air conditioning system. The significance of the work is that it will prolong the working of VARS and enhances engine performance and efficiency without affecting performance of the automobile, essentially the fuel economy. Further the vapour absorption cycle uses non-CFC refrigerant-ammonia, and thereby have no ill effect on environment. The present work is focused towards the mathematical model of a VARS for the automobile using waste heat from exhaust gas. This helps to improve thermal efficiency of an engine. This study aims to investigate the effects of different heat inputs supplied to the generator on the energy performance of Absorption Refrigeration System. To achieve this goal, we have mathematically calculated the effects of changing generator input on COP, heat absorbed by evaporator and rejected by absorber.

Index Terms— VARS, VCRS, PCM, PCT, Waste heat

◆

1 INTRODUCTION

Environmental pollution is a major issue with which the world is dealing right now and it is caused due to many reasons. One of them is direct emission of exhaust gases from engines, industries etc. which contribute in increase in temperature of atmosphere causing problems like Global warming. Standard of living of people increased and with it the consumption of energy sources. Many researches are going on to use renewable sources and to improve the quality of already existing systems. In internal combustion engines, only a small amount of heat is utilized to produce mechanical power and the rest of the heat is exhausted into atmosphere. This low-grade waste heat can be utilized to drive auxiliary systems and improve the engine performance.

Absorption refrigeration system uses ammonia as a refrigerant and water as an absorbent to operate and the advantage of this system is that it also runs on residual heat and heaters thus, saving electricity cost. It uses ammonia as a refrigerant which has ozone depletion potential (ODP) and global warming potential (GWP) as 0 and have low operating cost, making it environment friendly. It can operate on exhaust gases of engines which helps in reutilization of waste heat increasing the thermal efficiency of engine. Many developments have been achieved to bridge the gap between using exhaust heat of an engine to drive ARS. The disadvantage of using this system is that exhaust is not always constant causing fluctuations in temperature of HTF.

One of the ways in which heat is utilized is by using phase change materials to store heat for use when temperature fluctuations occur and for the system to run smoothly. The use of phase change materials for thermal energy storage provides cheap and efficient energy storage. Phase change material is a substance which releases/absorbs sufficient energy at phase transition to provide useful heating/cooling.

In the present work, we calculate the mathematical results and observe the effects of different generator heat inputs on system, using exhaust heat from engine as heat source.

Nomenclature

VARS	Vapour Absorption Refrigeration System
VCRS	Vapour Compression Refrigeration System
ODP	Ozone Depletion Potential
GWP	Global Warming Potential
PCM	Phase Change Material
HTF	Heat Transfer Fluid
Q_e	Heat absorbed by the evaporator
Q_a	Exothermic heat of absorberhea rejected to the surrounding
Q_g	Heat Rate supplied to the generator
Q_c	Condenser Heat Rejection
T_e	Temperature of the evaporator
T_a	Temperature of the absorber
T_g	Temperature of the generator
T_c	Temperature of the condenser
$\dot{m}$	Mass flow rate across the system
$\dot{m}s$	Mass flow rate of the strong solution
$\dot{m}w$	Mass flow rate of the weak solution
ξw	Concentration of weak solution
ξs	Concentration of strong solution
λ	Circulation Ratio
hw	Enthalpy of weak solution
hw	Enthalpy of strong solution
h1, h2, h3, h4	Enthalpy values across the system
COP	Coefficient of Performance

2 LITERATURE REVIEW

A large amount of heat energy generated by engine goes to waste in the form of exhaust gases. Thereby, reducing the efficiency of engine and emission of gases contribute to environmental pollution. The present study is about utilizing this waste heat in order to increase the overall thermal efficiency of engine. To utilize this, we are going to use PCM based system to drive Diffusion Absorption Refrigeration System to deal with the fluctuating exhaust emission.

In their paper, Ganesh S. Wahile, Prateek D. Malwe, Ajay V. Kolhe used sodium nitrate as a pcm to recover waste heat from twin-cylinder four-stroke diesel engine exhaust. They concluded that waste heat recovery reduces the emission of greenhouse gases and that the system containing pcm reduces emission from 45.1% to 39.5%. Yiji Lu, Anthony Paul Roskilly, Rui Huang, Xiaoli Yu in their paper integrated organic Rankine cycle, vapour compression cycle and liquid desiccant technology. This hybrid refrigeration system potentially converts industrial waste heat into refrigeration. They concluded that the proposed system generated 50KW sensible cooling and 132KW latent heat cooling effect with COP of 0.8 to 0.96 when n-Butane is working fluid. Chandrmani Yadav, Rashmi Rekha Sahoo in their paper analyzed energy and exergy on three organic PCMs. The TES system was integrated with engine exhaust. They concluded that lauric acid gives high energy and exergy efficiency as compared to paraffin wax and stearic acid. Sorawit Kaewpradub, Prawit Sanguanduean in their paper investigated a single effect absorption refrigeration system using Li-Br solution and varying exhaust. They concluded that the increase of the LiBr-water solution flow rate increases cooling load but decrease COP. Highest COP of 0.275 was found at 1400 rpm.

Ram Thakara, Dr. Santosh Bhosleb, Dr. Subhash Lahane in their paper placed heat exchanger just near the inlet and outlet duct of the engine to preheat the air passed to the engine. They found that at full load 150 deg Celsius temperature at inlet was reached. The proposed system increased the efficiency of diesel engine and also reduced the emission significantly. Wael I. A. Aly, MohammedAbdo, Gamal Bedair, A. E. Hassaneen evaluated experimentally the performance of DAR using diesel engine waste heat. The engine was tested at various torques and they found that at 30 Nm torque a COP of 0.10 was obtained. Maximum of 10% of waste heat recovery was obtained in this study and refrigeration temperature reached 10-14.5℃. Dheeraj Kishor Johar, Dilip Sharma, Shyam Lal Soni, Pradeep K. Gupta, Rahul Goyal in their paper developed a shell and tube type heat exchanger to store thermal energy, in which Erythritol was used as a phase change material and it was integrated with stationary C. I. engine. They found that the maximum charging efficiency, recovery efficiency and percentage energy saved were 69.53%, 38% and 11.33% respectively at a load of 4.4 KW. M. Hatami, D. D. Ganji, M. Gorji-Bandpy in their paper revived about varioustechnologies that are used to recover waste heat from exhaust. They found that one of the most common ways is to use heat exchangers. V. Pandiyarajan, M. Chinna Pandian, E. Malan, R. Velraj, R. V. Seeniraj in their paper, shell and finned tube heat exchanger integrated with an IC engine was setup to extract heat from the exhaust gas and a thermal energy storage tank used to store the excess energy available. They concluded that almost 10-15% of fuel power was stored as heat in the combined system of sensible and latent heat storage systems.

Gawon Lee, Hyung Won Choi, Yong Tae Kang in their paper have proposed a DAR system with a novel working fluid pair, R600a/n-octane. They have compared simulation results with experimental and numerical results. A maximum COP of 0.162 was achieved at a driving temperature of approximately 100 °C and concluded that concluded that, R600a/n-octane has significant potential for DAR application. N. Ben Ezzine, R. Garma, A. Bellagi in their paper developed a thermodynamic model for R124-DMAC diffusion absorption refrigeration cycle, and the system performances are analyzed parametrically by computer simulation. The results show that the driving temperature and the absorber effectiveness have the largest effect on the COP and the minimum evaporation temperature reached.

3 VAPOUR COMPRESSION REFRIGERATION SYSTEM

3.1 VAPOUR COMPRESSION REFRIGERATION SYSTEM

By and large refrigeration means, expelling the warmth from a space so that the space gets to be colder than the encompassing. Naturally the warmth streams from hot locale to chilly district. Be that as it may, in a refrigeration framework the warmth is expelled from frosty area and rejected into a hot district, subsequently the icy locale gets to be colder and hot areas get to be more sizzling.

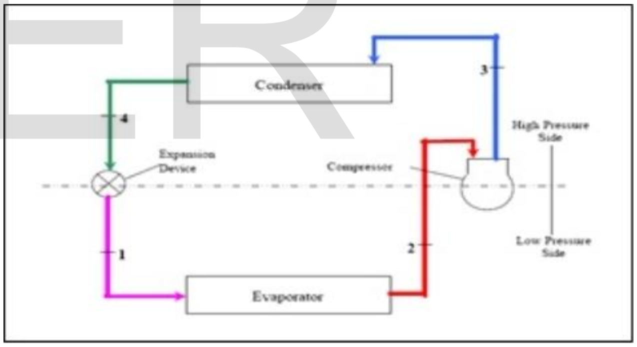

Figure 3.1: Single-stage vapour-compression system[15]

The vapor-pressure utilizes a coursing fluid refrigerant as the medium which assimilates and expels heat from the space to be cooled and along these lines rejects that warmth somewhere else. Figure 1 portrays a normal, single-stage vapor-pressure framework. Every single such framework have four segments: a compressor, a condenser, a warm development valve (likewise called a throttle valve), and an evaporator. Circling refrigerant enters the compressor in the thermodynamic state known as an immersed vapor and is compacted to a higher weight, bringing about a higher temperature too. The hot, compacted vapor is then in the thermodynamic state known as a superheated vapor and it is at a temperature and weight at which it can be consolidated with either cooling water or cooling air. That hot vapor is steered through a condenser where it is cooled and dense into a fluid by coursing through a curl or tubes with cool water or cool air streaming over the loop or tubes. This is the place the circling refrigerant rejects heat from the framework and the rejected warmth is diverted by either the water or the air (whichever may be the situation).

The dense fluid refrigerant, in the thermodynamic state known as an immersed fluid, is next steered through an extension valve where it experiences a sudden diminishment in weight. That weight diminishment results in the adiabatic glimmer vanishing of a piece of the fluid refrigerant. The auto-refrigeration impact of the adiabatic glimmer dissipation brings down the temperature of the fluid and vapor refrigerant blend to where it is colder than the temperature of the encased space to be refrigerated.

The vapor-weight uses a coursing liquid refrigerant as the medium which ingests and ousts heat from the space to be cooled and thusly rejects that glow elsewhere. Figure1 portrays a common, single-stage vapor-weight system. Each and every such structure have four sections: a compressor, a condenser, a warm augmentation valve (in like manner called a throttle valve), and an evaporator. Coursing refrigerant enters the compressor in the thermodynamic state known as a drenched vapor and is compacted to a higher weight, achieving a higher temperature as well. The hot, stuffed vapor is then in the thermodynamic state known as a superheated vapor and it is at a temperature and weight at which it can be thick with either cooling water or cooling air. That hot vapor is coordinated through a condenser where it is cooled and thick into a liquid by coursing through a circle or tubes with cool water or cool air gushing over the twist or tubes. This is the spot the streaming refrigerant rejects heat from the system and the rejected warmth is occupied by either the water or the air (whichever may be the circumstance).

The merged liquid refrigerant, in the thermodynamic state known as a splashed liquid, is next guided through an advancement valve where it encounters a startling diminishment in weight. That weight abatement results in the adiabatic burst vanishing of a bit of the liquid refrigerant. The auto-refrigeration effect of the adiabatic gleam vanishing cuts down the temperature of the liquid and vapor refrigerant mix to where it is colder than the temperature of the encased space to be refrigerated.

The chilly blend is then steered through the loop or tubes in the evaporator. A fan flows the warm air in the encased space over the curl or tubes conveying the cool refrigerant fluid and vapor blend. That warm air vanishes the fluid piece of the icy refrigerant blend. In the meantime, the flowing air is cooled and, in this way, brings down the temperature of the encased space to the fancied temperature. The evaporator is the place the flowing refrigerant retains and uproots heat which is consequently dismisses in the condenser and exchanged somewhere else by the water or air utilized as a part of the condenser.

To finish the refrigeration cycle, the refrigerant vapour from the evaporator is again a soaked vapour and is directed once more into the compressor.

3.2 DRAWBACKS OF VCRS

Though this system is the most efficient of all the refrigeration system still it has some disadvantages:

A vapour compression system has more, tear and noise due to moving parts of the compressor.

The amount of work required to compress the gas in the compressor is very high.

It strictly depends on electric power or mechanical power and cannot be used at places where these recourses are not available.

The capacity of vapour compression system drops rapidly with lowered evaporator pressure.

The performance of a vapour compression system at partial loads is poor.

4 VAPOUR ABSORPTION REFRIGERATION SYSTEM

4.1 VAPOUR ABSORPTION REFRIGERATION SYSTEM

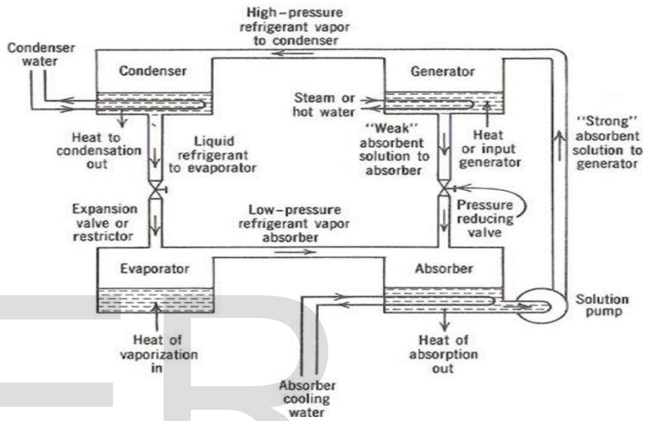

Figure 4.1: Basic Absorption Refrigeration System[16]

The vapor assimilation refrigeration is one of the most seasoned routines for delivering refrigerating impact. The guideline of vapour assimilation was initially found by Michael Faraday in 1824 while performing an arrangement of analyses to melt certain gasses. The principal vapour ingestion refrigeration machine was produced by a French researcher Ferdinand Carre in 1860. This framework may be utilized as a part of both the household and expansive mechanical refrigerating plants. The refrigerant, ordinarily utilized as a part of a vapour retention framework is smelling salts. The vapor retention framework uses heat vitality, rather than mechanical vitality as in vapor pressure frameworks, keeping in mind the end goal to change the states of the refrigerant required for the operation of the refrigeration cycle. The capacity of a compressor, in a vapor pressure framework, is to pull back the vapor refrigerant from the evaporator. It then raises its temperature and weight higher than the cooling specialists in the condenser so that the higher weight vapors can reject heat in the condenser. The fluid refrigerant leaving the condenser is currently prepared to extend to the evaporator conditions. This refrigeration framework comprises of a condenser, an extension valve and an evaporator like a Vapor Compression Refrigeration System. Be that as it may, the compressor of the Vapor Compression Refrigeration System is supplanted by a generator, a safeguard and a little pump. A Vapor Absorption Refrigeration System uses two or more than two liquids which has high liking towards one another, in which one is the refrigerant and the other is the retentive.

The procedure of working of this refrigeration framework is that a blend of refrigerant and a safeguard (i.e., solid arrangement) is pumped from the safeguard utilizing a little pump to the generator. The generator is the fundamental unit of the entire refrigeration framework. This is the spot where warmth is supplied to the solid arrangement. Because of the supplied warmth to the blend in the generator the refrigerant is isolated from the solid arrangement and structures vapor. The staying powerless arrangement streams back through a restrictor into the safeguard. The refrigerant is then permitted to go through a condenser where the warmth of the vapor is removed and the refrigerant temperature is conveyed to the room temperature. This cooled refrigerant is then gone through a development gadget where amid extension the temperature of the refrigerant falls beneath the climatic temperature. This chilly refrigerant is then gone through an evaporator from where the refrigerant assimilates warmth and produces refrigerating impact. The refrigerant originating from the evaporator is hot and it is gone to the safeguard. The powerless arrangement originating from the generator blends with the refrigerant originating from the evaporator in the safeguard because of high fondness towards one another for the two liquids, thus shaping an in-number arrangement. The framed solid arrangement is again pumped into the generator and the cycle rehashes itself.

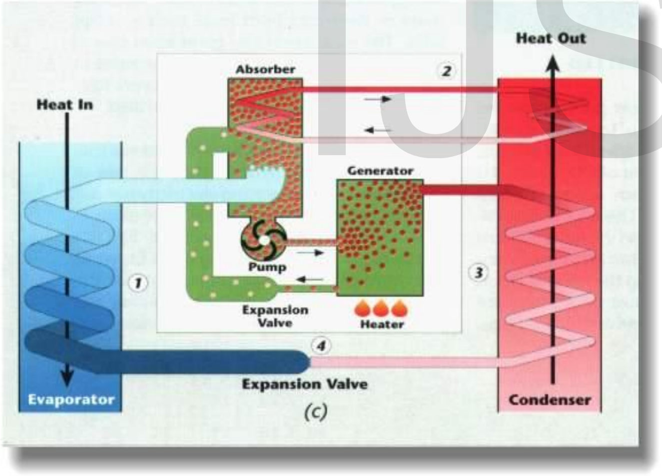

Fig. 4.2: VARS Cycle[15]

4.2 VARS CYCLE

The vapour assimilation refrigeration framework includes every one of the procedures in the vapour pressure refrigeration framework like pressure, buildup, extension and vanishing. In the vapour retention framework, the refrigerant utilized is smelling salts, water. The refrigerant gets consolidated in the condenser and it gets dissipated in the evaporator. The refrigerant produces cooling impact in the evaporator and discharges the warmth to the climate by means of the condenser. The significant distinction between the two frameworks is the system for the suction and pressure of the refrigerant in the refrigeration cycle. In the vapour pressure framework, the compressor sucks the refrigerant from evaporator and packs it to the high weight. The compressor additionally empowers the stream of the refrigerant through the entire refrigeration cycle. In the vapour assimilation cycle, the procedure of suction and pressure are completed by two unique gadgets called as the safeguard and the generator. Consequently, the safeguard and the generator supplant the compressor in the vapour ingestion cycle. The retentive empowers the stream of the refrigerant from the safeguard to the generator by retaining it. Another significant distinction between the vapour pressure and vapour assimilation cycle is the strategy in which the vitality data is given to the framework. In the vapour pressure framework, the vitality data is given as the mechanical work from the electric engine keep running by the power. In the vapour assimilation framework, the vitality data is given as the warmth. This warmth can be from the abundance steam from the procedure or the high temp water. The warmth can likewise be made by different sources like characteristic gas, lamp fuel, and radiator and so forth however these sources are utilized just as a part of the little frameworks.

4.3 AMMONIA-WATER ABSORPTION CYCLE

An Absorption Cycle can be viewed as a mechanical vapour-compression cycle, with the compressor replaced by a generator, absorber and liquid pump. Absorption cycles produce cooling and/or heating with thermal input and minimal electric input, by using heat and mass exchangers, pumps and valves. The absorption cycle is based on the principle that absorbing ammonia in water causes the vapour pressure to decrease. The basic operation of an ammonia-water absorption cycle is as follows. Heat is applied to the generator, which contains a solution of ammonia water, rich in ammonia. The heat causes high pressure ammonia vapour separate from the solution. Heat can either be from combustion of a fuel such as clean-burning natural gas, or waste heat from engine exhaust, other industrial processes, solar heat, or any other heat source. The high-pressure ammonia vapour flows to a condenser, typically cooled by outdoor air. The ammonia vapour condenses into a high-pressure liquid, releasing heat which can be used for product heat, such as space heating. The high-pressure ammonia liquid goes through a restriction, to the low-pressure side of the, cycle. This liquid, at low pressures, boils or evaporates in the evaporator. This provides the cooling or refrigeration product. The low-pressure vapour flows to the absorber, which contains a water-rich solution obtained from the generator. This solution absorbs the ammonia while releasing the heat of absorption. This heat can be used as product heat or for internal heat recovery in other parts of the cycle, thus unloading the burner and increasing cycle efficiency. The solution in the absorber, now once again rich in ammonia, is pumped to the generator, where it is ready to repeat the cycle.

4.4 DESCRIPTION OF VAPOUR ABSORPTION REFRIGERANT SYSTEM

An absorption refrigerator is a refrigerator that uses a heat source (e.g., solar, kerosene-fueled flame, waste heat from factories or district heating systems) to provide the energy needed to drive the cooling system. In the early years of the twentieth century, the vapour absorption cycle using water-ammonia systems was popular and widely used. Ammonia-water combination possesses most of the desirable qualities which are listed below:

1m^3 of water absorbs 800m^3 of ammonia (NH_3).
Latent heat of ammonia at -15^{O}C = 1314 kJ/kg.
Critical temperature of NH_3 = 132.6^{O}C.

The NH_3-H2O system requires generator temperatures in the range of 125°C to 170°C with air cooled absorber and condenser and 80°C to 120°C when water-cooling is used. These temperatures cannot be obtained with flat-plate collectors. The coefficient of performance (COP), which is defined as the ratio of the cooling effect to the heat input, which vary between 0.6 to 0.7. Ammonia is highly soluble in water.

5 PHASE CHANGE MATERIAL

5.1 PHASE CHANGE MATERIAL

A phase change material (PCM) is a substance which releases/absorbs sufficient energy at phase transition to provide useful heat/cooling. Generally, the transition will be from one of the first two fundamental states of matter - solid and liquid - to the other. The phase transition may also be between non-classical states of matter, such as the conformity of crystals, where the material goes from conforming to one crystalline structure to conforming to another, which may be a higher or lower energy state.

The energy released/absorbed by phase transition from solid to liquid, or vice versa, the heat of fusion is generally much higher than the sensible heat. Ice, for example, requires 333.55 J/g to melt, but then water will rise one degree further with the addition of just 4.18 J/g. Water/ice is therefore a very useful phase change material and has been used to store winter cold to cool buildings in summer since at least the time of the Achaemenid Empire.

By melting and solidifying at the phase change temperature (PCT), a PCM is capable of storing and releasing large amounts of energy compared to sensible heat storage. Heat is absorbed or released when the material changes from solid to liquid and vice versa or when the internal structure of the material changes; PCMs are accordingly referred to as latent heat storage (LHS) materials.

There are two principal classes of phase change material: organic (carbon-containing) materials derived either from petroleum, from plants or from animals; and salt hydrates, which generally either use natural salts from the sea or from mineral deposits or are by-products of other processes. A third class is solid to solid phase change.

PCMs are used in many different commercial applications where energy storage and/or stable temperatures are required, including, and among others, heating pads, cooling for telephone switching boxes, and clothing.

By far the biggest potential market is for building heating and cooling. PCMs are currently attracting a lot of attention for this application due to the progressive reduction in the cost of renewable electricity, coupled with limited hours of availability, resulting in a misfit between peak demand and availability of supply. In North America, China, Japan, Australia, Southern Europe and other developed countries with hot summers peak supply is at midday while peak demand is from around 17:00 to 20:00. This creates a lot of demand for storage media.

Solid-liquid phase change materials are usually encapsulated for installation in the end application, to contain in the liquid state. In some applications, especially when incorporation to textiles is required, phase change materials are micro-encapsulated. Micro-encapsulation allows the material to remain solid, in the form of small bubbles, when the PCM core has melted.

Phase Change Materials (PCMs) store thermal energy by the phase change from solid to liquid since the latent heat from melting or freezing is at least 1-2 orders of magnitude higher than the energy stored by the specific heat.

The PCM heat exchanger/cold plate design also plays a large role in ensuring a low-weight heat exchanger is built. PCMs, such as paraffin waxes, that are commonly used in these heat exchangers have poor thermal conductivities, often < 1 W/m-K. This causes a need for additional features, such as extended surfaces and fins to effectively melt the entire PCM with minimal thermal resistance. Accurate predictions of the effective thermal conductivity of the PCM heat exchanger help develop a lean solution.

5.2 PCM APPLICATIONS IN ELECTRONICS THERMAL MANAGEMENT INCLUDE:

1. Smoothing out the thermal energy during pulsed operation, allowing the heat removal system to be designed for the average heat load rather than the peak load.
2. Short-Term Thermal Storage, where a suitable heat sink is not available.
3. Protection from Failure During Coolant Interruptions, when the cooling system is temporarily unavailable.
4. Thermal Storage to increase cooling capacity during hot days, using the colder air at night to recharge the thermal storage.
5. Thermal Storage for Supplemental Power Plant Cooling, using cold air at night to recharge the thermal energy storage reservoir.

6 MATHEMATICAL MODELLING

Applying Mass and Energy Balance for each component of the System

For Evaporator

$\dot{m}1 = \dot{m}4 = \dot{m}$

$Q_e + \dot{m}4h4 = \dot{m}1h1$ kJ/s

$Q_e = \dot{m}(h1-h4)$ kJ/s

For Condenser

$\dot{m}2 = \dot{m}3 = \dot{m}$

$Q_c + \dot{m}3h3 = \dot{m}2h2$ kJ/s

$Q_c = \dot{m}(h2-h3)$ kJ/s

For Expansion Valve

$\dot{m}3 = \dot{m}4 = \dot{m}$

h3 = h4 (isenthalpic process) kJ / kg

For Generator

$\dot{m}w = \dot{m}2 + \dot{m}s$

$Q_g + \dot{m}shs = \dot{m}2h2 + \dot{m}whw$

$Q_g = \dot{m}2h2 - \dot{m}shs + \dot{m}whw$ kJ/s

For Absorber

By Total Mass Balance

$\dot{m}1 + \dot{m}s = \dot{m}w$

$Q_a + \dot{m}shs = \dot{m}whw + \dot{m}1h1$

$Q_a = \dot{m}whw + \dot{m}1h1 - \dot{m}shs$ kJ/s

Theoretical Coefficient of performance(COP):

The Theoretical Coefficient of performance is given by,

$(COP)_{th} = Qe/Qg$

= heat rejected in evaporator / heat supplied to generator

Kirloskar diesel engine specifications:

Table 6.1: Engine Specification[13]

Type	Single Cylinder 4-Stroke Vertical, Water Cooled
Power	3.75Kw
Speed	1500 rpm
Bore	80 mm
Stroke	110 mm

The exhaust temperature was found to be varying from 138°C - 223°C. These temperatures were taken into consideration and further calculations are done.

6.2 CALCULATION

Assumptions:

- The system is at a thermodynamic equilibrium state (i.e steady state and steady flow at inlet and outlet of the system)
- The refrigerant solutions which leave the adiabatic absorber and the generator are saturated liquid.
- The ammonia solution condensed in the condenser is at saturated state.
- The ammonia leaving the evaporator is saturated vapour.
- The adiabatic absorber pressure equals the pressure of the evaporator, and the pressure of the generator is equal to the pressure of the condenser.
- The refrigerant entering the generator is at the generator pressure.
- There is no drop in pressure due to friction.
- The refrigerant which boils in the generator is at purest form.

Operating Conditions :

Cooling Capacity=5.275kW (1.5TR)

Generator Temperature=100°C-180°C

Condenser Temperature= 40°C

Absorber Temperature=35°C

Circulation Ratio,

$\lambda = \dot{m}s/ \dot{m}$

$\dot{m} + \dot{m}s = \dot{m}w$

$mw = (1+\lambda)\dot{m}$

Refrigeration Capacity = 1.5TR

Q_e=5.275 kW

T_e=14°C

T_g=120°C

T_c=40°C

T_a=35°C

At 14°C

h_1 =1475.56

At 40°C

h3 = h4 = 390.64

h2 = 1489.

To find the mass flow rate ($\dot{m}$):

$Q_e = \dot{m}$ (h1-h4)

$\dot{m} = Q_e$ / (h1-h4)

$\dot{m}$ = 0.004862109 kg/s

At 40°C

P4 = 1.5MPa

ξw = 0.32

hw = 710 kJ/kg

At 14°C

P1=704.63kPa

ξs=0.62

hs=832 kJ/kg

To find the mass flow rate of strong solution and weak solution:

Circulation Ratio (λ) is to be calculated

$\lambda = \xi w / (\xi s - \xi w)\ \lambda$

$= 0.32/(0.62-0.32)\ \lambda$

$= 1.06\ \dot{m}s$

$= \lambda * \dot{m}$

$\dot{m}s$ = 0.0051 kg/s

$\dot{m}w = (1+\lambda) * \dot{m}$

$\dot{m}w$ = 0.0100 kg/s

To find the heat supplied to the generator:

$Q_g = \dot{m}2h2 - \dot{m}shs + \dot{m}whw$

Q_g = 10.063 kW

To find the heat rejected from the condenser:

$Q_c = \dot{m}$ (h2-h3) kJ/s

Q_c = 5.344kW

To find the heat rejected from the absorber:

$Q_a = \dot{m}whw + \dot{m}1h1 - \dot{m}shs$

Q_a = 9.993 kW

To find the COP of the system

COP = Q1/Q3 (Neglecting pump work)

COP= 0.524

7 RESULTS

7.1 RESULT TABLE:

Capacity of the system= 1.5 TR (5.275 KW)

T_g(°C)	Q_g(KW)	Q_c(KW)	Q_a(KW)	COP
180	8.933	5.344	8.863	0.590
160	8.967	5.344	8.897	0.588
140	9.691	5.344	9.621	0.544
120	10.063	5.344	9.993	0.524
100	10.083	5.344	10.013	0.523

Table 7.1

7.2 GRAPHS

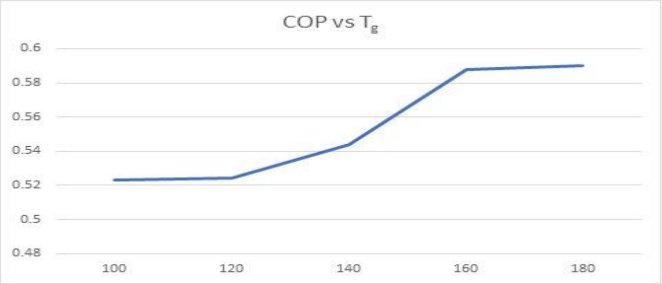

Fig 7.1: Cop vs Tg

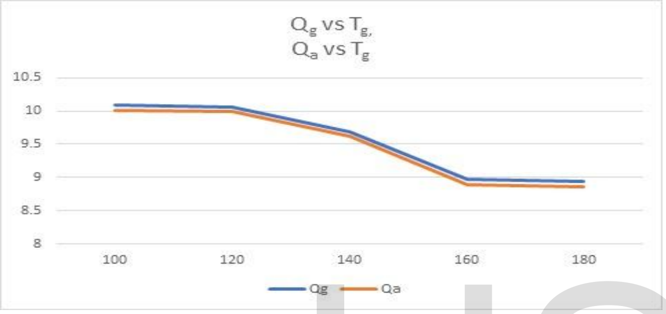

Fig 7.2: Qg vs Tg

7.3 RESULTS

1. The reduction in exhaust temperature can be obtained and contain lower energy resulting in subsequent decrease in greenhouse gas emission.
2. The system is significantly sensitive to generator temperatures.
3. The coefficient of performance (COP) values directly proportional with increasing generator.
4. The COP of the refrigeration system was found to be 0.5538.

8 CONCLUSION

5. PCM TES has greater potential to store the energy as an option for waste heat recovery system from the engine for green technology.
6. The coefficient of performance (COP) values directly proportional with increasing generator and evaporator temperatures but decrease with increasing condenser and absorber temperatures.
7. While the present work does not include experimental work but from the literature review it can be concluded that exhaust heat recovery is an effective way to increase the efficiency of the engine and that phase change material like Paraffin can be used for energy storage.

ACKNOWLEDGEMENT

We gratefully acknowledge the guidance provided by Prof. A.P. Ogale and a special thanks to all the researchers for the information.

REFERENCES

8. Ganesh S. Wahile, Prateek D. Malwe, Ajay V. Kolhe, Waste heat recovery from exhaust gas of an engine by using a phase change material, Materials Today: Proceedings,2020
9. Yiji Lu, Anthony Paul Roskilly, Rui Huang, Xiaoli Yu, Study of a novel hybrid refrigeration system for industrial waste heat recovery, Elsevier: Energy Procedia, 2019
10. Chandrmani Yadav, Rashmi Rekha Sahoo, Exergy and energy comparison of organic phase change materials based thermal energy storage system integrated with engine exhaust, Elsevier: Journal of Energy Storage, 2019
11. Sorawit Kaewpradub,Prawit Sanguanduean, Absorption refrigeration system using engine exhaust gas as an energy source, Elsevier, 2018
12. Ram Thakara, Dr. Santosh Bhosleb, Dr. Subhash Lahane, Design of heat exchanger for waste heat recovery from exhaust gas of Diesel Engine, Elsevier, 2018
13. Wael I. A. Aly, MohammedAbdo, Gamal Bedair, A. E. Hassaneen, Thermal performance of a diffusion absorption refrigeration system driven by waste heat from diesel engine exhaust gases, Elsevier: Applied Thermal Engineering, 2017
14. Dheeraj Kishor Johar, Dilip Sharma, Shyam Lal Soni, Pradeep K. Gupta, Rahul Goyal, Experimental investigation on latent heat thermal energy storage system for stationary C.I. engine exhaust, Elsevier: Applied Thermal Engineering, 2016
15. M. Hatami, D. D. Ganji, M. Gorji-Bandpy, A review of different heat exchangers designs for increasing the diesel exhaust waste heat recovery, Elsevier: Renewable and Sustainable Energy Reviews, 2014
16. V. Pandiyarajan, M. Chinna Pandian, E. Malan, R. Velraj, R. V. Seeniraj, Experimental investigation on heat recovery from diesel engine exhaust using finned shell and tube heat exchanger and thermal storage system, Elsevier: Applied Energy, 2011
17. Gawon Lee, Hyung Won Choi, Yong Tae Kang, Cycle performance analysis and experimental validation of a novel diffusion absorption refrigeration system using R600a/n-octane, Elsevier: Energy, 2020

18. N. Ben Ezzine, R. Garma, A. Bellagi, A numerical investigation of a diffusion-absorption refrigeration cycle based on R124-DMAC mixture for solar cooling, Elsevier: Energy, 2010
19. Alam S, 2006, A Proposed model for “Utilizing Exhaust Heat to run Automobile Air-conditioner”, the 2nd Joint International Conference on Sustainable Energy and Environment 21-23 November 2006, Bangkok, Thailand.
20. P. Sathiamurthi, “Design and Development of Waste Heat Recovery System for air Conditioning”, Unit European Journal of Scienti_c Research, Vol.54 No.1 (2011), pp.102-110, 2011.
21. 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 Effciency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems June 26-29, 2012, Perugia, Italy.
22. A Textbook of Refrigeration and Air Conditioning by R. S. Khurmi & J. K. Gupta, Chapter-07, Page no.273-291, 2014.
23. A Textbook of Fluid mechanics And Hydraulic Machines by R. K. Bansal, Chapter-11, Page no.461-553, 2005.
24. A Textbook of Engineering Heat and Mass Transfer by M. M. Rathore, Chapter- 05, Page no.263-357, 2012.
25. P. Praveen, S. Santhosh, R. Raaghul, A. S. Pramoth Kumar, Performance Analysis of Vapour Absorption Refrigeration System using Waste Heat from IC Engine, International Journal of Advanced Science and Technology, 2020