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Utilization of Exhaust Heat of Internal Combustion Engines for Cooling Purpose: A Review

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Abstract-Thermal energy is predominantly released through the coolant and exhaust systems of a typical internal combustion engine. About 20% of the energy released during combustion power produced by burning fuel has the potential to be used for work output and remaining 70-80 % as a part of waste heat as friction, exhausts gas and engine cooling system. This paper presents a brief review of studies conducted by the previous researchers on cooling produced in moving vehicles by using vapor absorption system. It provides information about the importance of utilizing this heat energy released through the exhaust system of internal combustion engines to develop a refrigerant system which does not require the electricity as a primary input.

Keywords-Thermal Energy, Internal Combustion Engine, Vapor Absorption, Combustion, Refrigerant System

I. INTRODUCTION

A car's radiator is used to keep the engine cool. During operation, an engine's moving parts create friction, which produce heat. Even with the use of engine oil as a lubricant, the heat from an engine's natural friction can be enough to damage the engine if it is not kept cool by the radiator. Once the engine reaches a certain temperature, the radiator is engaged to keep the engine from overheating, which can cause catastrophic damage. The radiator, which usually sits near the front of the engine bay in a front engine car, is constructed of thin, hollow passageways that run between two header tanks. Liquid coolant is pumped through a series of channels that take it through the engine block, where it is warmed by the engine's friction. . The warmed liquid is then pumped to the radiator, where it makes its way through the narrow passageways. The radiator is constructed to have passageways with a high surface area, so that as the liquid passes through, it is cooled by air rushing over the radiator (usually this air is allowed in through the car's front grille). The coolant loses its heat to the atmosphere and is then pumped back into the engine where it absorbs and removes more of the engine's heat. This continuous cycle is controlled by a thermostat that keeps the engine operating at an optimal temperature near 200 degrees.

[i] Uses the organic rankine cycle for compression ignition engine to recover waste heat for the additional power output. The discussed the research challenges associated with engine ORC-technology. Variable exhaust gas heat source used for the designing of engine-ORC evaporator. It is concluded that maximum thermal efficiency range of engine ORC are 10-25%. Lower temperature difference in ORC are the main reason for low efficiency. It is also found that for the engine ORC application R245fa is the better organic working fluid.

[ii] Integration of heat rejected during scavenging air cooling process and exhaust gas for the power generation cycle operation a novel technique was presented. At off design conditions power output to access the applicability a power analysis was conducted. It is concluded that tis cycle increases efficiency to 5.1% from 2.8% with additional power output of 1210KW.

Waste heat of diesel engine was recover by preheating S-CO_2 cycle. Evaporator is used to utilized the high temperature engine exhaust gas and then it is cooled was engine cooling jacket. System performance increase with deeper utilization of the regeneration heat load with this improved system [iii].

II. METHODOLOGY

In vapour absorption refrigeration system , the compressor is replaced by an absorber, a pump, a generator anda pressure reducing valve. These components in the system perform the same function as that of compressor in VCR system. The vapour refrigerated from evaporator is drawn into the absorber where it is absorbed by the weak solution of refrigerant forming a strong solution. This strong solution is pumped to the generator where it is heated utilizing exhaust heat of vehicle. During the heating process the

vapour refrigerant is driven off by the solution and enters into the condenser where it is liquefied. The liquid refrigerant then flows into the evaporator and the cycle is completed.

Methodology used in current review is to calculate COP of vapor compression system with different input values as given in different articles and replace parts of vapor compression system parts with vapor absorption system to provide more cooling to moving vehicle. Different researchers used different techniques to replace cooling of vapor compression system with vapor absorption system and all are studied and results are written in a brief form which shows the cooling of vehicle can be replaced to efficient COP.

III. Literature Review

To make environment friendly system for passenger in a vehicle, internal combustion engine energy can be used to run absorption refrigeration system [iv]. Energy produced by exhaust gas and cooling load of vehicle has been calculated. EES (Engineering Equation Solver) software was used for analytical study of COP relation with different parameters. Fig. 1 represents the schematic diagram of vapor absorption system.

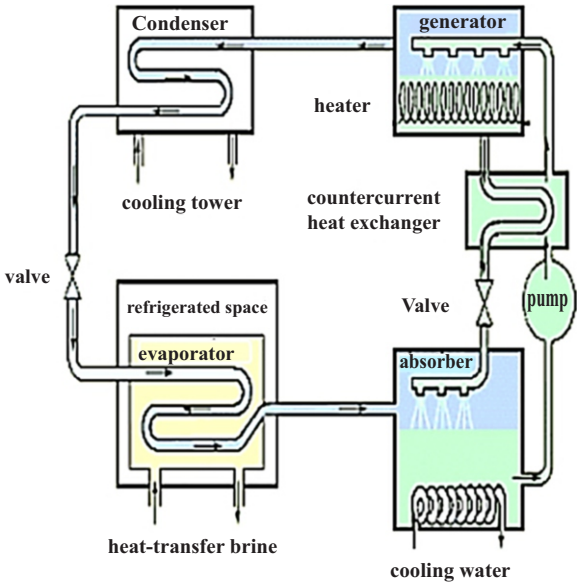

Fig. 1. Vapor-absorption refrigeration system [iv]

According to [v], to design and manufacture lithium Bromide –water absorption refrigerator having 1kW capacity in which heat energy is used in absorption refrigerator for cooling absorption refrigerator machine having no motion of parts. The design of solution heat exchanger has a single pass annulus, by using horizontal tube heat exchanger they designed overall heat transfer coefficient for condenser and generator Fig. 2 represents vapor absorption system.

Experiment were conducted and it was observed that for single effect of LiBr-H_2O behavior of COP (coefficient of performance) changes by changing the quantity of lithium bromide mixture [vi]. Other parameters (temperature of generator, absorber, evaporator and capacity of evaporator)as given in Table I, have been taken as a constant and changing condenser COP temperature is to be calculated. Calculated value of COP for condenser temperature is 0.65.

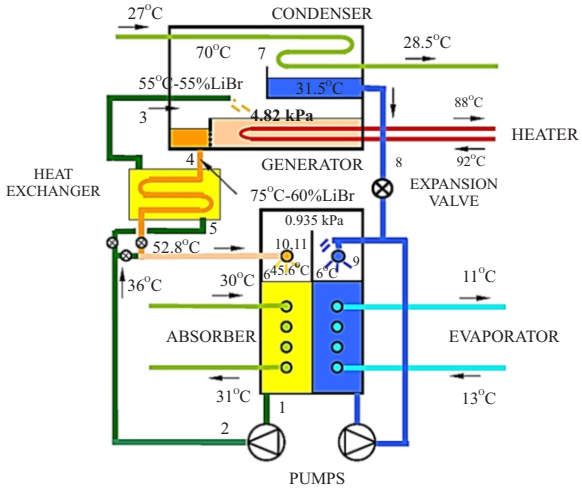

Fig. 2. Vapor-absorption system [v]

TABLE I
WATER LI-BR ABSORPTION REFRIGERATION SYSTEM BASED ON GENERATOR TEMPERATURE OF 75°C AND SOLUTION HEAT EXCHANGER EXITS TEMPERATURE OF 55°C [VI]

Point	H (kJ/kg)	$\dot{m}$ (Kg/s)	P (kPa)	T (°C)	%LiBr (X)	Remarks
1	85.3	0.00517	0.93	36	55	
2	85.3	0.00517	4.82	36	55	
3	124.7	0.00517	4.82	**55**	55	Sub-cooled liquid
4	183.2	0.00474	4.82	**75**	60	
5	140.3	0.00474	4.82	52.8	60	
6	140.3	0.00474	0.93	45.6	60	
7	2624.8	0.000431	4.82	**70**	0	Superheated Steam
8	131.0	0.000431	4.82	31.5	0	Saturated liquid
9	131.0	0.000431	0.93	6	0	
10	2511.8	0.000421	0.93	6	0	Saturated vapour
11	23.45	0.000011	0.93	6	0	Saturated liquid

Description	Symbol	kW
Capacity (evaporator output power)	$\dot{Q}_e$	**1.0**
Absorber heat, rejected to the environment	$\dot{Q}_a$	1.28
Heat input to the generator	$\dot{Q}_g$	1.36
Condenser heat, rejected to the environment	$\dot{Q}_c$	1.08
Coefficient of performance	COP	0.74

Study on the use of lithium bromide [vii] as a working fluid and practical behavior of single effect absorption refrigerator was carried out. Experimental results show that 2kw cooling produced by refrigerator and Performance of system can be made better by (SCR) Solution Circulation Ratio. Result of SCR (Solution Circulation Ratio) was 2-5 times better than theoretical results because of bad efficiency of absorber. By using solution heat exchanger COP increases to 60%.

Model a simple absorption refrigeration system on supposition for two absorber (lithium bromide-water or ammonia-water).Compression system has been changed by absorption. Heat energy from sun or ejection of hot gases from generators has been used thus Examine the behavior of system by changing the vapor absorber, generator and condenser temperature by simulation [viii]. Fig. 3 represents simple vapor refrigeration system.

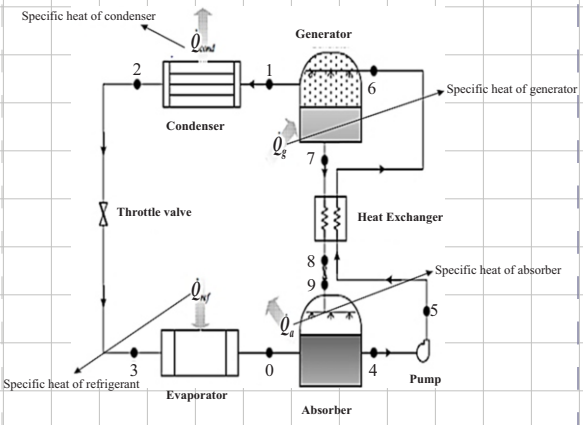

Fig. 3. Simple vapor absorption refrigeration system [v]

Absorption system working on solar power is more compatible in term of cost [ix]. These systems can be used in homes and factories for cooling and heating purpose.

Mostly energy used in the industry is produced by burning of fuel. For sugar plants, steam operating turbines ejects a huge amount of heat energy and this energy can be used to run absorption system so they may gave us comfort. Benefits of single effect li-Br water absorption system by using waste heat were low energy consumption and less cost. Main mission was to design a absorption system operating on waste heat of sugar plant. Absorption system consists of absorber, solution heat exchanger, evaporator, condenser, and generator. Cooling system that has been modeled on basis of calculations and analysis can be used for cooling DC thrust motor in sugar plant. Energy used and saved was also measured. Efficiency of COP and heat transfer coefficient was calculated. Graph shown in Fig. 4 represents energy requirement for various refrigeration system [x].

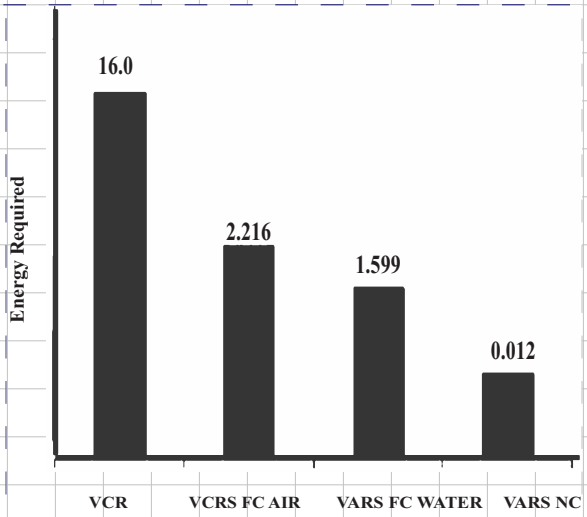

Fig. 4. The reduction of ozone layer caused by the refrigerant which use in vapor compression system but the vapor absorption system offer better environment [x]

Description about absorption system using three fluids is practiced for cooling purpose in automobile having one ton capacity was given by [xi]. Heat was supplied to generator having ammonia solution in it by means of automobile exhaust. Temperature of Heat ejected through exhaust has been measured at various engine speed (opening of throttle valve at quarter and half). Maximum heat that can be achieved is 6 KJ/sec at the exhaust of automobile. Required heat energy for generator of absorption system is 3.02 KJ/sec, so energy at exhaust of car is far more and can be used to operate air conditioning system.

Consumption of fuel can be reduced for vehicles if cooling system were operated by waste heat of engine [xii]. Air conditions in automobile consume 7.1 billion gallons of gasoline in USA per annum which can be lowered by using that raw waste heat of engine. Vehicle engine use 30% heat energy and remaining heat was wasted in environment. Engine having capacity of consuming 115-kW energy, waste heat changes from 20 to 400 kW with common value over FTP cycle of 23kW. Ejected heat temp remain between 200^{o}C at surface temperature and 600^{o}C gas temperature. This huge amount of wasted heat energy can be used for constructive purposes i.e minimizing fuel consumption in automobiles.

Li-Br water absorption system having capacity of 1kW was designed by [xiii]. Absorption system used for cooling environment have static components, all components of absorption system (evaporator, absorber, sol heat exchanger, generator, condenser) were designed on different parameters. Heat transfer coefficient for these components was difficult task to find. Absorber and evaporator were replaced by single-pass vertical-tube exchanger while condenser and generator were modeled on basis of horizontal heat

exchanger, single-pass annulus exchanger lead the designing of solution heat exchanger. Condenser having water in its extreme purity and heat transfer coefficient value that are used for condenser can be found by using equations (Q=AuΔT). Values for U (heat transfer coefficient) for generator resulted experiment. Fig. 5 shows the relation between COP and Δx at three different temperatures for single effect Li-Br system.

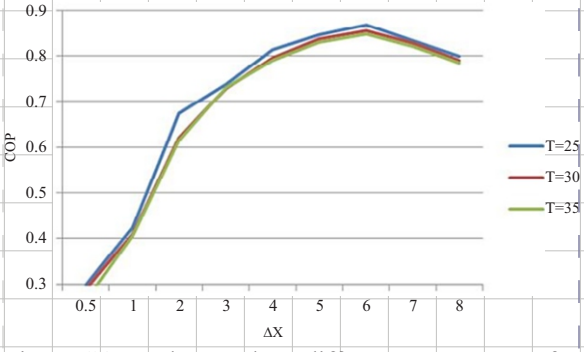

Fig. 5. COP and Δx at three different temperatures for single effect Li-Br system [xiii]

Cooling facility in vehicles seems to be very important and necessary [xiv]. Several refrigeration systems were used to provide cooling effect in vehicle. Waste heat energy or minor valued energy of IC engine can also be used to run such refrigeration systems (LI-Br-H_2O, aqua ammonia, Li-Cl-H_2O refrigeration). Using kirlosker diesel engine to operate one ton absorption system. Refrigeration systems use common type of exchangers. Amount of heat energy ejected by diesel engine determines efficiency of all absorption systems. These absorption systems will lower car's fuel consumption, eco-friendly, less maintenance cost. Fig. 6 indicates the existing cooling system of automobile. Comparison between vapor absorption and vapor compression systems is provided in Table II.

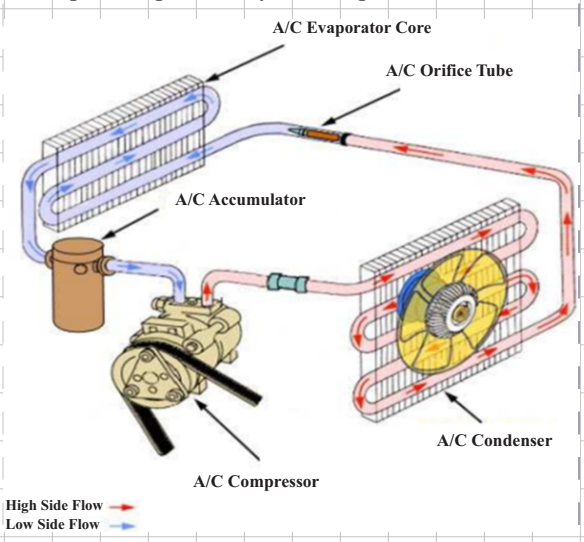

Fig. 6. Existing cooling system of automobile[xiv]

TABLE II
COMPARISON BETWEEN VAPOR ABSORPTION AND VAPOR COMPRESSION SYSTEM

Sr. No	Vapour Absorption System	Vapour Compression System
1.	Uses low grade energy like heat, therefore may be worked on exhaust system from I.C engines etc	Using high-grade energy like mechanical work
2.	Moving parts are only in the pump which is small element of the system. Hence operation is smooth.	Moving parts are in the compressor. Therefore more wear, tear and noise
3.	The system can work on lower evaportor pressures also without affecting the COP.	The COP decreases in evaporator pressure considerbly with decrea
4.	No effect of reducing the load on performance	Performance is adversely affected at partial loads.
5.	Liquid traces of refrigerant present in piping at the exit of evaporator	Liquids traces in suction line may damage the compressor.
6.	Automatic operation for controlling the capacity is easy.	It is difficult

Heavy vehicles have huge engines and some places in India having high temperature result hard and tough condition in passenger cabin/compartment [xv] and made impossible for them to sit in it. So air condition for these vehicles was very necessary and some efforts must be done in this field. Waste heat of engine to run cooling absorption system was strong option because available energy is enough to run cooling system, fuel consumption reduces, engine efficiency and power was enhanced. Refrigerant applied in absorption system is CFC (chlorofluorocarbons) having small effect on surrounding. To develop and fabricate air conditioning vapor absorption system using waste heat is main concern now a days.

According to [xvi], there are mainly two kinds of energy named high grade and low grade energy. High grade energy is used extensively in many applications and are limited .Instead of high grade energy need is to find unlimited, non-traditional. Or use energy from wastes (heat, biogas etc.) Waste heat is used to operate absorption cycle.

Researchers [xvii] investigated Li-Br-H2O solution utilized in absorption chiller, application is followed to yield result for absorption chiller. Data given as input was operating temp of chiller parts (absorber, condenser etc.) By applying such application for set of input data heat transfer properties at all points and cycle efficiency can be analyzed. By controlling the parameters (input data) result may vary. Fig. 7 shows that the increase in mass flow rate

increases the absorber temperature for given evaporator at varying temperature.

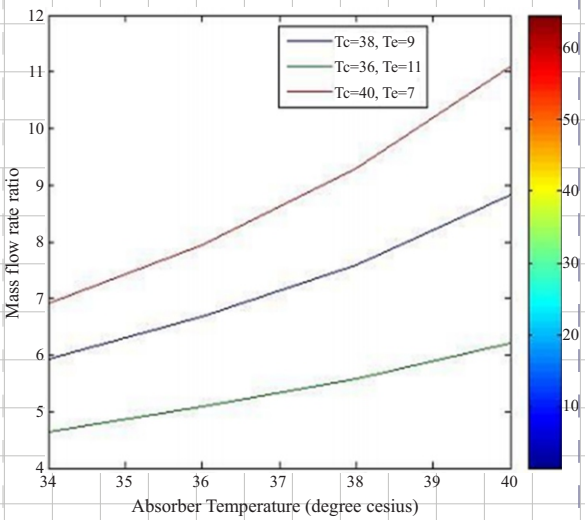

Fig. 7. Variation in mass flow rate with absorber temperature for given evaporator at various temperature [xvii].

Result of [xviii]shows that efficiency of Absorption system having capacity of 3.5 ton operated on heat energy using manual calculations from different papers. Design and made mathematical model of vapor absorption system.

Done analysis on absorption system. Minimum and extreme limits for COP of absorption cooling process can be calculated by using laws of thermodynamics. These limits changes with change in temperature of parts of process and also changes with thermodynamic properties of solution and absorption system parts. Main effort is to make Li-Br-H_2O absorption system sizing 5.25kW. Modeled parts of absorption system such as (absorber, evaporator etc.) to measure COP [xix].

Researchers[xx] mention the advantages of plate type heat exchanger used in Li-Br absorption chiller system. Using inter relation equations, the heat transfer coefficient for components of a system can be estimated. These parameters give external source of heating to system. At different temp ranges, a reason for COP varying for cooling load has been discussed there.

Experimental conclusion of [XXI] shows that diesel engine were considered less efficient by their consumption, emission of gases that effect ozone and large waste heat ejection. Further concluded that effective systems can be made, operating on waste heat. They presented different techniques and method of recovery of waste heat and their utilization for some services in automobile. Table iii shows output of various engines and also amount of heat dissipated by them.

TABLE III
VARIOUS ENGINES AND THEIR OUTPUT [XXI]

Engine Type	Power Output (kW)	Waste Heat
Small air cooled diesel engine	35	30-40 % of energy waste loss from IC engines
Water air cooled engine	35-150	
Earth moving machineries	520-720	
Marine applications	150-220	
Trucks and road engines	220	

Investigation of [xxii] shows that absorption system can use heat energy or low grade energy to provide cooling effect. Laws of thermodynamics determine analysis for Li-Br absorption system. COP and efficiency for such refrigeration system can be calculated by using laws of thermodynamics.

Analysis of [xxiii] pointed out that Local heat power to run absorption system having capacity to work at low temperature capability. Law of single effect refrigeration system, guides working of absorption system has cooling capability of 50kW at low available temperature. Calculations yield a result that rigid surface gave working attitude with COP 0.8.

Experimental results of [xxiv] show that efficiency of a single stage lithium bromide –water absorption system. Hot water from electrical boiler cooled by water absorption system. The behavior of water at different temperatures and flow rates externally can be calculated.

Investigation of [xxv] shows that due to surrounding pollution people used to try solar energy or other sources to make it better. Vapor absorption refrigeration system (VARS) has been simulated at steady state. Some equation was used for thermal simulation.

Behavior of ammonia water absorption refrigeration system has been simulated by [xxvi] using waste heat of diesel engine. Uniform energy of diesel engine informs that energy should be sufficient. Max efficiency at $361k^{o}$ for uni-effect absorption system and then decreases till $371k^{o}$.

Experimental investigation [xxvii] shows that fresh water and refrigeration has been formed and the best method to forming both by using minimum heat has been simulated. By joining refrigeration and water a system ARPHA-MEE (absorption refrigeration heat pump and multi effect evaporation desalted) has been made also known as LiBr-H_2O refrigeration system, Mathematical Model made by using LiBr-H_2O heat pump and minimum temperature multi effect evaporated desalination. Efficiency of LiBr-H2O system has been simulated by using that model.

Analysis of [xxviii] shows that the behavior of an absorption heat pump for increasing temperature of

minimum heat level by using computer model of uni stage lithium bromide water system. Waste heat temperature, temperature of cooling water, and rate of flow has been noticed. Temperature and efficiency of pump increased by increasing waste heat temperature or by decreasing cooling water temperature. Coefficient of performance (COP) also varies by changing these parameters.

According to [xxix] that uni-stage solar absorption refrigeration system of (Li-Br-H_2O) has been analyzed by using second law. Thermodynamic analysis and result of work has been simulated by MATLAB. COP of system, entropy of elements and total entropy of each element has been calculated. Behavior of COP and Stott by altering heat exchanger effectiveness, evaporator, generator, absorber and temperature of evaporator has been analyzed. Thus concluded COP directly related with temperature of generator and inversely related with total entropy of system. COP distressed by small change in, evaporator, generator and other parameters rather than total entropy influence by all parameters.

Uni-effect lithium bromide water absorption refrigeration system has been tested thermo-dynamically by [xxx] using 1st and 2nd law. Behavior of system has been examined by varying inlet hot water temperature of generator, evaporator and absorber and condenser inlet cooling water temperature. COP (coefficient of performance, energy efficiency (second law efficiency) and total cost of function has been calculated by using algorithm technique. Final and initial values have been compared. Performance of system upgrade COP (about 75%), energy efficiency (47%) and total cost (12%)

Study of [xxxi] pointed out that industries used energy from waste heat as a remedy to avoid high price of fuel and high quantity of fuel. Sugar industry used outlet thermal energy of steam turbine for vapor absorption system. Thermal and budgetary benefits of uni effect lithium bromide water absorption are described by using waste heat. Li-Br H_2O absorption refrigeration system has been analyzed by means of waste heat of steam turbine in sugar factories. Solution heat exchanger, evaporator, condenser, absorber and generator were used in vapor absorption system. Theoretical model made to produced cooling for DC thyrsit motor. They calculated the overall heat transfer coefficient, effectiveness and COP of heat exchanger

Researchers [xxxii] investigated for the absorbed heat. A sample based on static and dynamic parameters has been made and analyzed suitable for domestic solar thermal collectors. Victoriously demonstrate the charging phenomena and analyze the absorption through discharging. Required heat has been affected due to some factors of heat exchanger. Fig. 8 showing existing cooling system of automobile.

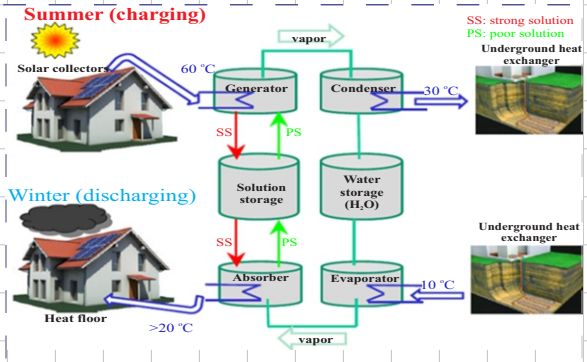

Fig. 8. Existing cooling system of automobile [xxxiii]

Automobile industry has been improved by advancing in field of solar, electrical and battery driven vehicles in order to reduce fuel consumption [xxxiii]. However they gave less importance to cooling system in vehicles using significant amount of fuel. Methods of implementation, obstacles in implementation, and cost of implementation of the absorption system (silica gel-H_2O) are mentioned. Control planed integration with engine command authority of car made air conditioning system of vehicle to run effectively as guided by analysis and limitation in our design.

An idea was proposed [xxxiv] where HTV/big locomotive machinery was cooled by Zeolite-water absorption cooling system operated by using waste heat. To improve efficiency of heavy vehicles, during off state of engine raw heat can be taken by absorption system where fuel is ignited. This causes engine heat up decreases and vehicle work effectively. Absorption system using zeolite and water has been constructed and practiced at various working cycles to check system working. COP and life of cycle were directly related but cooling reduced at the same time. This result enables us how system can be controlled and use less energy.

Concluded that absorption cooling system operated by waste exhaust gases (or heat) of engine. Air conditioning absorption system works in coordination with two generators that were designed with max cooling capability of 2kW [xxxv]. Waste heat source was provided by IC engine. Engine working speed and force causing rotation to engine determines efficiency of two generators integrated with engine and absorption system. 1.4 liter Internal combustion engine gain waste heat between 3-16kw from no load to full load conditions. Experiment evidences that cooling produced by air condition at no load and full load were 0.5 and 2.8kw. Back pressure during cooling reduces fuel consumption and absorption system gave COP of 0.17. In addition exchangers improve efficiency of air condition.

Concluded global warming makes air conditioning necessary for locomotives. Increment in fuel charges, parts and services related to vehicles makes difficult for customers to run automobiles. In

order to avoid all these factors Raw/waste heat from engine was used to run cooling system [xxxvi].

Investigated that gave contrast between various systems using waste heat as their input power. Research is divided into two parts [xxxvii]. First part composed of difference between various systems using raw exhaust heat and gave graphical result. Analytical designs were made and scaled according to actual data given, shows to which amount fuel usage decrease during each cycle. On basis of analytical consequences two solutions were yielded, Rankin cycle and turbo compound. Press drop at outlet is not shown in analysis where car's fuel consumption can't be estimated was restriction of turbo compound. Operating cycle and raw exhaust heat technique determines fuel reduction. Normally 6% could be gained by this technique.

Fig. 9 shows Carbon Dioxide emissions regulations of different governments in the world.

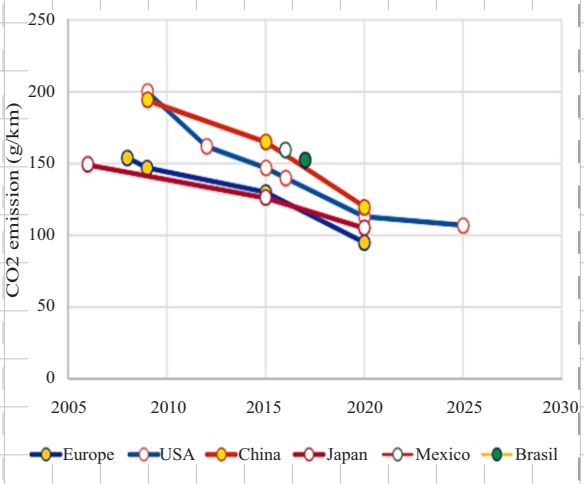

Fig. 9. Carbon Dioxide emissions regulations of different governments across the world [xxxviii]

Air conditioning system was manufactured in a calculated way using raw exhaust heat of engine of car without causing contamination to surroundings [xxxviii]. IC engines were equipped with heat exchangers being design/model and manufactured for using waste heat at exhaust air change per hour is 40 times. Fluid used in system for cooling system had special properties (i.e. heat transfer advancement). These properties were also analyzed

Engine driven vapor compression absorption systems can be used in vehicles for cooling passenger compartment but this system requires extra power from engine so results more fuel consumption [xxxix]. If vapor absorption system was used, it would reduce fuel cost and may use any other form of energy (waste heat from engine) for working. IC engine provides heat energy at their outlet (exhaust).

Researchers [x] concluded the laws and limitations to which absorption cooling system works which provide a detail discussion that how working of systems can be enhanced. Presented various methods, and information to attain maximum efficiency from devices.

Concluded that in IC engine 30-40% heat was used and excess was expelled to environment. This matter is of great concern because it causes global warming, environmental hazards and cause extra fuel usage. To save environment and store energy sources this waste heat can be used for constructive work (cooling). Further concluded that how waste heat is taken from IC engine and used for other purpose to improve efficiency of car (i.e. reduce fuel cost and minimum environmental effects) [xli].

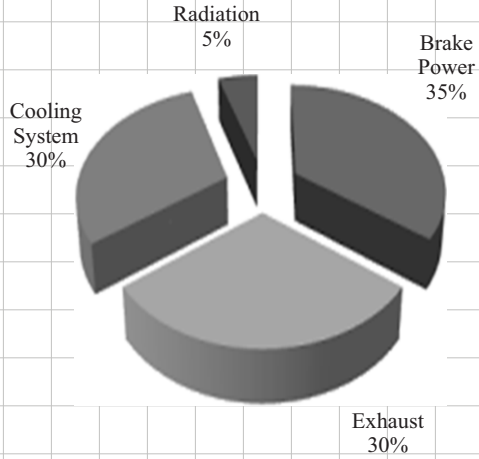

Fig. 10. Pi-chart showing total fuel energy content in IC engine [xli]

Radiator (heat exchanger) was main component used to cool engine by means of fluid or gases [xlii]. Radiator consists of fins and other tiny components to transfer heat in form of conduction and radiation from engine block to radiator. This heat is forward to surroundings by mean of fan installed in front of exchanger. 25 % of heat was used by engine to run vehicle. Out of remaining 75 %, 30 % is dissipated by air condition and 45 % is expelled to environment. If such heat was not released from engine it will seize the engine or damage parts and accessories of engine. Importance of cooling for case of radiator was main discussion.

Mechanical component in combination with IC engine has been used to recover waste heat of engine [xliii]. Result is improved in efficiency of engine, fuel consumption, and environmental conditions. Sterling engine was used to recover the waste heat and utilize it to some valuable work. Stirling engine works efficiently at temp 200^{o}C. So IC engine realease enough heat to operate Stirling engine. Power generated by stirling engine can be estimates.

Analysis of [xliv] shows that the absorption system (Li-Br water absorption system). Numerical equations and properties of fluid. The analysis from

each equation yield heat transfer rate, amount of fluid required, COP and pressure requirement.

Investigation resulted that when cooling system of automobile was running on engine shaft will share power of engine, hence performance of engine was reduced to somewhat half and more fuel is used [xlv]. Cooling system such as thermoelectric generators (TEG) was used in combination with engine to provide cooling. TEG can take power from any low grade sources of energy causing the performance of engine to increase.

Described major improvement and advancement in technology dealing with compensation of released gases from automobile engine [xlvi]. These technologies use heat energy and improve performance. Old system use fossils fuels and result ejection of CO_2 gas having hazardous effects. Using such systems operated on waste heat reduce environmental pollution and global warming. Fig. 11 shows rating of different exchangers.

	Rating: 5 very positive, 2 - no effect, 0 - very negative				
Criteria	Rankine Cycle	TEG	Coolant Heat Exchanger	Oil Heat Exchanger	Oil Heat Exchanger with Bypass
Fuel Economy / CO_2	••	•••	••	••••	•••••
Real World Fuel Economy	••••	••••	•••	••••	•••••
Cost	zero	zero	•	•	•
Safety	zero	•	••	zero	•
Reliability	•	••	••	•	••
Performance	••	•••	••	•••	••••
Regulated Emissions	••	••	••	•••••	•••••
NVH	•	••	••	••	••
Package	zero	•	•	•	•
Cabin Warm-Up	••	•••	•••••	•••	••••
Maintenance	•	••	••	•••••	•••••
Weight	zero	•	•	•	•
Total	16		25	30	36
Ranking	5		3	2	1
Status	Prototype	Prototype	Mass Production	Prototype	Prototype

Fig. 11. Rating of different exchangers [xliv]

Concluded various types of absorption system using waste heat energy [xlvii]. Their difference and specifications were briefly discussed and contrasted with theory. Effective cooling system results less CO_2 emission and less fuel usage etc.

Investigate that 30-32 % energy in diesel engine was wasted to outside environment [xlviii]. So it's important to recover that heat. 15% share of electricity was consumed in air conditions and cooling system. Modern development in technology emphasize on devices that consume waste sources and in response gave some valuable useful comfort (cooling). That makes us enable to fulfill demand of customers and use less amount of fuel. Waste heat can be used for cooling by using Electrolux refrigeration system. Fig. 12 shows Electrolux refrigeration system diagram.

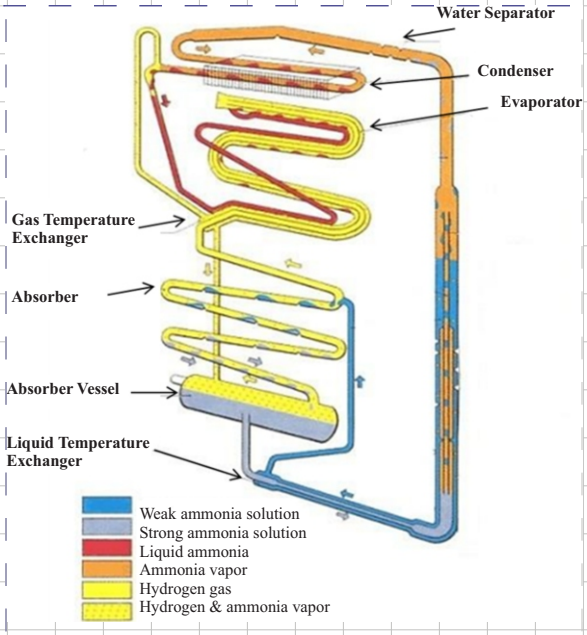

Fig. 12. Electrolux refrigeration system diagram [xlviii]

Normally vehicles consist of vapor compression absorption system whose compressor was driven by engine to forward cooling. Small cooling system have belt to drive compressor [xlix]. Main concern here is to develop such refrigeration system that uses waste heat of IC engine to give cooling effect.[xl]Experimental result and testing of following system verified that they can be used. Vapor absorption system is of less weight because there is no compressor and capital can be saved and maintenance is easy. Basic concern is to study and find effect on IC engine due to vapor absorption system at certain conditions such as slow moving traffic, parking etc.

Described a model and construction of vapor absorption system for cooling passenger compartment of vehicles [li]. Vapor absorption system has specialty that it uses waste heat instead of electricity or any chemical-mechanical power. 10% power of engine is consumed by vapor compression cycle so fuel cost increases and large amount of heat was wasted in environment. COP of this system is 0.5 for capability of cooling was 1kW. This system can be implemented and practiced in vehicles.

Concluded that IC engine release heat by combustion of fuel used to derive appliances/systems. 30-40% heat is consumed for favorable objective while some heat is lost in friction, cooling the system, and remaining 30-40% was exhausted to environment [lii]. Thus results that energy consumption increases causes energy sources to decrease. So the demand of situation is that waste sources were used or less energy consuming system were invented have no hazardous effect to environment. Techniques and advantages of using these systems were discussed briefly. Fig. 13

shows ammonia vapor absorption system.

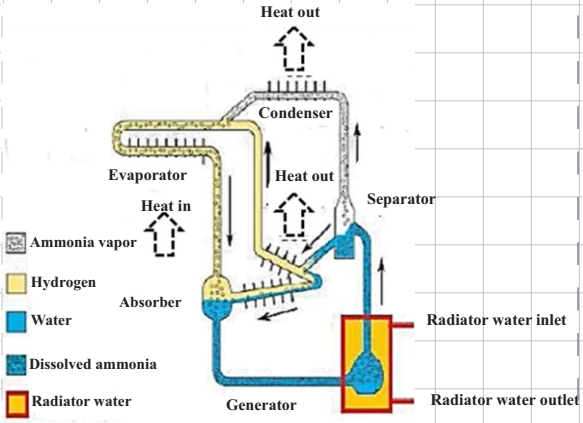

Fig. 13. Ammonia water absorption system [liii]

Researchers [LIII] investigated that during fuel combustion in IC engine, energy is converted from chemical to mechanical and finally into heat energy. 75% of energy in form of heat was wasted. Waste thermal recovery (WTR) system working on Rankine cycle can use that energy.

IV. Results and Discussion

In vapour absorption refrigeration system, a physiochemical process replaces the mechanical process of the vapour compression system by using energy in the form of heat rather than mechanical work. The main advantage of this system lies in possibility of utilizing energy from exhaust a sof vehicle and also using an eco-friendly refrigerant such as water. The vapour absorption system has many favorable characteristics; typically a much smaller electrical input is required to drive the solution pump as compared to the power requirement of the compressor in the vapour compression system. Also, fewer moving parts mean lower noise level, higher reliability and improved durability in vapour absorption system.

This review describes the all possibilities used for vapor absorption system in a vehicle. Cop and its effects with heat variation are also described in present study. It is concluded from this literature that vapor absorption system can be efficiently used in moving vehicle with some modification to vapor compression system.

V. Conclusions

This paper presents a comprehensive review of the research work reported by the previous researchers on the heat recovery from the internal combustion engines and can be used for cooling purpose as heat source in vapor absorption system. Following conclusions can be drawn from the current review:

1. It has been concluded that vapor absorption system can be used in moving vehicles at low cost.
2. Separate electricity are not need for cooling and heating source in moving vehicles
3. Heat transfer of system increases with different refrigerants

References

[i] M. T. Mito, (2018). "Utilizing the scavenge air cooling in improving the performance of marine diesel engine waste heat recovery systems." Energy 142: 264-276.

[ii] V. Chintala, (2018). "A technical review on waste heat recovery from compression ignition engines using organic Rankine cycle." Renewable and Sustainable Energy Reviews 81: 493-509.

[iii] J. Song, (2018). "Performance improvement of a preheating super critical CO 2 (S-CO 2) cycle based system for engine waste heat recovery." Energy Conversion and Management 161: 225-233.

[iv] S. S. Mathapati, M. Gupta, and S. Dalimkar. "A Study on Automobile Air-Conditioning Based on Absorption Refrigeration System Using Exhaust Heat of a Vehicle." International Journal of Engineering Re-search and General Science 2.4 (2014): 80-86.

[v] S. Kalogirou, G. Froides, S. Tassou and L. Wrobel "Design and construction of a lithium bromide water absorption refrigerator." CLIMA 2000/Napoli 2001 World Congress–Napoli (I), 15-18 September 2001. 2000.

[vi] A. P. Koringa and N.S. Mehta. 2014 “Effect OF Concentration of Lithium bromide Mixture on COP for Single Effect LiBr-H2O Absorption Refrigeration System” IJMTER(International Journal of Modern Trends in Engineering and Research).

[vii] S. Aphornratana and T. Sriveerakul. "Experimental studies of a single-effect absorption refrigerator using aqueous lithium–bromide: effect of operating condition to system performance." Experimental thermal and fluid science 32.2 (2007): 658-669.

[viii] D. Micallef and C. Micallef. 2010 “Mathematical Model of Vapor Absorption Refrigeration Unit” ISSN 1726-4529 (IJSM).

[ix] V. Mittal, K. S. Kasana, and N. S. Thakur. "The study of solar absorption air-conditioning systems." Journal of Energy in Southern Africa 16.4 (2005): 59-66.

[x] K. Balaji, and R. Senthil Kumar. "Study of Vapour Absorption System Using Waste Heat in Sugar Industry." IOSR Journal of Engineering 2.8 (2012): 34-39.

[xi] S. Alam, "A proposed Model for utilizing exhaust heat to run Automobile Air-

conditioner." International conference held on Sustainable Energy and Environment (SEE-2006).

[xii] V. H. Johnson, "Heat-generated cooling opportunities in vehicles." SAE Technical Papers 2002 (2002): 01-1969.

[xiii] S. Kalogirou, G. Floriedes, S. Tassou and L. Wrobel "Design and construction of a lithium bromide water absorption refrigerator." CLIMA 2000/Napoli 2001 World Congress–Napoli (I), 15-18 September 2001. 2000.

[xiv] S. Bux and A. C. Tiwari. "Natural refrigerants based automobile air conditioning system." International Journal of Emerging Science and Engineering 2.7 (2014): 32-38.

[xv] S.D. Thakre, P.D Malwe. R.L Raut and A.A.Gawali "Cooling of A Truck Cabin by Vapor Absorption Refrigeration System Using Engine Exhaust."

[xvi] S. N. Vedil, and A. Kumar and D. Mahto. "Waste heat Utilization of vapor compression cycle."

[xvii] Y. Singh, D. Kumar, A. Kumar and A. Singla "Mathematical modeling and analysis of absorption refrigeration system using waste heat of diesel genset." Int J Emerg Res Manag Technol (2013): 46-50.

[xviii] N. K. Sharma, P Singh, and D. Gaur. "Design& Analysis Of Solar Vapor Absorption System Using Water And Lithium Bromide." International Journal of Engineering Research and Technology. Vol. 2. No. 6 (June-2013). ESRSA Publications, 2013.

[xix] S. Kaushik and S. Singh 2014 "Thermodynamic Analysis of Vapor Absorption Refrigeration System and Calculation of COP"International Journal for Research in Applied Science and Engineering Technology (I JRAS ET) ISSN: 2321-9653,Vol. 2 Issue II.

[xx] M. De Vega, J. A Almendros-Ibáñez, and G. Ruiz. "Performance of a LiBr–water absorption chiller operating with plate heat exchangers." Energy conversion and management 47.18 (2006): 3393-3407.

[xxi] S. L. Nadaf and P. B. Gangavati. "A Review on waste heat recovery and utilization from diesel engines." Int J Adv Engg Tech/Vol. V/Issue IV/Oct.-Dec 31 (2014): 39.

[xxii] P. Sharma, S.P.S Rajput and M. Pandey 2012 "Exergetic analysis of LiBr-Water absorption system for Airconditioning applications" International Journal of Latest Trends in Engineering and Technology (IJLTET) Vol. 1.

[xxiii] Ch. Mostofizadeh, D.Bohne and Ch. mergerdt et al. "Use of Direct Heating in Sumer for cold Production With The Aid of and Absorption Process"IFEAV-German, C.Mergardt. Phujdugw#WW]_%Uhphukdyhq_GH.

[xxiv] F. Asdrubali and S. Grignaffini. "Experimental evaluation of the performances of a H 2 O–LiBr absorption refrigerator under different service conditions." International Journal of Refrigeration 28.4 (2005): 489-497.

[xxv] N. K. Sharma, P. Singh, and D.Gaur. "Design& Analysis Of Solar Vapour Absorption System Using Water And Lithium Bromide." International Journal of Engineering Research and Technology. Vol. 2. No. 6 (June-2013). ESRSA Publications, 2013.

[xxvi] P. Mahendru S. K. Agrawal, and P. Pachorkar. "Steady State Analysis Of Vapour Absorption Refrigeration System Using Li-Br-H2o As A Refrigerant." International Journal Of Emerging Technology And Advanced Engineering 2.9 (2012): 328-332.

[xxvii]R.Singh, S. Vats, N. Baghal and R. Kumar, 2014 "Integration of Water-Lithium Bromide Absorption Refrigeration System with Diesel engine: A Thermodynamic Study" ISBN 978-93-5156-328-0,International Conference of Advance Research and Innovation (ICARI).

[xxviii]Y.Wang and N. Lior. "Proposal and analysis of a high-efficiency combined desalination and refrigeration system based on the LiBr–H 2 O absorption cycle—part 1: system configuration and mathematical model."Energy conversion and management 52.1 (2011): 220-227.

[xxix]G.Grossman and K. W. Childs. Computer simulation of a lithium bromide-water absorption heat pump for temperature boosting. No. CONF-830102-2. Oak Ridge National Lab., TN (USA), 1983.

[xxx] J. M Abdulateef,M.A Alghoul, R. Sirwan, A. Zaharim and K. Sopian "Second law thermodynamic analysis of a solar single-stage absorption refrigeration system." Models and Methods in Applied Sciences (2012): 163-168.

[xxxi] M. Abbaspour and A. R. Saraei. "Thermo economic Analysis and Multi-Objective Optimization of a LiBr-Water Absorption Refrigeration System."International Journal of Environmental Research 9.1 (2015): 61-68.

[xxxii]K. Balaji, K., and R. S. Kumar. "Study of Vapour Absorption System Using Waste Heat in Sugar Industry." IOSR Journal of Engineering 2.8 (2012): 34-39.

[xxxiii]K. E. N'Tsoukpoe , N Le Pierrès, and L. Luo. "Experimentation of a LiBr H2O absorption process for long term solar thermal storage." Energy Procedia 30 (2012): 331-341.

[xxxiv]I. Raghupatruni, M. Glora, R.Diekmnn and T. Demmer "Adsorptive Waste Heat Based Air-Conditioning Control Strategy For Automotives." World Academy of Science, Engineering and Technology, International Journal of Mechanical, Aerospace, Industrial,

Mechatronic and Manufacturing Engineering 9.7 (2015): 1158- 1163.

[xxxv] Y. Zhong, K.L. Wert, and T Fang. "An adsorption air-conditioning system to reduce engine emissions and fuel consumption for heavy-duty vehicles." (2010).

[xxxvi]I. Hilali, and M. S. Soylemez. "An Application of Engine Exhaust Gas Driven Cooling System in Automobile Air-Conditioning System." Isi Bilimi ve Teknigi Dergisi/Journal of Thermal Science & Technology 35.1 (2015).

[xxxvii]A. Pathania, and D.Mahto. "Recovery of engine waste heat for reutilization in air conditioning system in an automobile: An investigation."Global Journal of Researches In Engineering 12.1-A (2012).

[xxxviii]L. Arnaud, G. Ludovic, D. Mouad, Z. Hamid and L. Vincent "Comparison and impact of waste heat recovery technologies on passenger car fuel consumption in a normalized driving cycle." Energies 7.8 (2014): 5273-5290.

[xxxix]T. Tiwatne and S. Barve .2015 "Experimental Study of Waste Heat Recovery Using Heat Pipe Heat Exchanger with Hybrid Nano fluid: A Review" International Journal of Mechanical and Industrial Technology ISSN 2348-7593 (Online) Vol. 3, Issue 1, pp: (40-47), Available at: *www.researchpublish.com*.

[xl] S. K. Murya ,S. Awasthi and S. A. Saddiqi, 2014 "A Cooling System for an Automobile Based on Vapour Absorption Refrigeration Cycle Using Waste Heat of an Engine" Satish K. Maurya et al Int. Journal of Engineering Research and Applications www.ijera.com ISSN : 2248-9622, Vol. 4, Issue 3(Version 1), pp.441-444.

[xli] M.Gawadrea and K. Kupie, 2011 "Absorption Cooling as an Effective Method of Waste Heat Utilization"CTTT 1 Ch/2011 Zeszyt 8 Rok 108 Issue 8 Year 108.

[xlii] J. S.Jadhao and T. G. Thanbure, 2013 "Review on Exhaust Gas Heat Recovery for I. C. Engine" ISSN: 2277-3754 ISO 9001:2008 Certified International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, Issue 12.

[xliii] G. Prudhvi, G. Vinay and G. S. Babu, 2013 "Cooling Systems in Automobiles & Cars" International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-2, Issue-4.

[xliv] W. Aladayieh and A. Alahmer.2015 "Recovery of Exhaust Waste Heat for ICE Using the Beta Type Stirling Engine" Hindawi Publishing Corporation Journal of Energy,Volume 2015, Article ID 495418, 8 pages *http://dx.doi.org/10.1155/2015/495418*

[xlv] F. L. Lansing "Computer Modeling of a Single-Stage Lithium Bromide/Water Absorption Refrigeration Unit" JPL deep space network progress report 42-32.

[xlvi] X.Yuan , S. Yuan, C.Chen and Y. Deng, 2012 "Simulation on Cooling System of Automotive Waste Heat Thermoelectric Generator" Research Journal of Applied Sciences, Engineering and Technology 6(5): 866-871, 2013 ISSN: 2040-7459; e-ISSN: 2040-7467 © Maxwell Scientific Organization, 2013.

[xlvii] P. R. Ubarhande, S.J. Sankhe "International Journal for Engineering Applications and Technology" http: // www.ijfeat.org (C) International Journal For Engineering Applications and Technology [314 322].

[xlviii]F. Will, 2013 "Comparison of Advance Waste Heat Recovery System With a Novel Oil Heating System"f.Will/International Journal of Automotive Engineering 4(33-40).

[xlix] D. J. Jotava, D. J. Parmar, J. V. Shah 2014 "Experimental Investigation of Heat Recovery from Engine Exhausts Gas And Its Application in Electrolux Refrigeration System: A review" International Journal of Engineering Research & Technology (IJERT),Vol. 3 Issue 1, ISSN: 2278-0181.

[l] I. Horuz ,1997 "An Alternative Road Transport Refrigeration" Tr. J. of Engineering and Environmental Science 22 (1998) , 211 - 222.

[li] D. M. Ghose S. M. Nakate,2015 "Experimental Evaluation of Vapour Adsorption Cooling System Powered by Exhaust Heat of Automobile System" International Engineering Research Journal (IERJ) Volume 1 Issue 5 Page 204-207, ISSN 2395-1621.

[lii] P. G. Karale and J. A. Hole, 2015 " A Review on Waste Heat Recovery and Utilization from Exhaust Gas of I. C. Engine" IJSRD - International Journal for Scientific Research & Development| Vol. 3, ISSN (online): 2321-0613.

[liii] J. S. Condle, 2012 "Analysis of a novel waste heat recovery mechanism for an I. C. engine"MichigaTechnological University Digital Commons @ Michigan Tech