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Recovery of Engine Waste Heat for Reutilization in Air Conditioning System in an Automobile: An Investigation

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RECOVERY OF ENGINE WASTE HEAT FOR REUTILIZATION IN AIR CONDITIONING SYSTEM IN AN AUTOMOBILE AN INVESTIGATION

Strictly as per the compliance and regulations of:

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Abstract - With the rapid changing environment and atmospheric effect, the air conditioning of the moving vehicle has become a necessity. In the same time consumers are incapable to bear the increasing operating cost of the vehicles due to continuous raise in fuel prices, component costs and maintenance costs associated with vehicles. More recently, several new philosophies for manufacturing improvement have been developed and implemented in various sectors, be it manufacturing, service or other. Keep in mind in this paper, an exploration has been done to research the possibility of waste heat recovery and its subsequent utilization in air conditioning system of a vehicle without increasing the component cost, weight, number of component and bring improvement in vehicle by making luxurious.

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I. Introduction

Industries are vying for various tools and techniques for competitive advantage over the competitors in an ever-changing global market by combining factors like quality, cost, flexibility, responsiveness, and innovation. In today's global market, there is constantly increasing pressure to make products more quickly, with more variety, at the lowest possible cost. In the end, those companies that meet and exceed customers' demands will succeed by remaining competitive. Then, the question is, how do companies become competitive and retain their competitiveness? This question may not be easy to answer because manufacturing systems are complex, and simple solutions to manufacturing problems may not exist. Therefore, companies must choose from available techniques to develop their own solutions in the existing products to attract the customers in their fold without adding extra cost.

With the rapid changing environment and atmospheric effect, the air conditioning of the moving vehicle has become a necessity. Air conditioning of a vehicle can be done by Vapour Compression Refrigeration System (hereinafter VCRS) and Vapour Absorption Refrigeration System (hereinafter VARS). Presently, in the vehicles VCRS is in use in most of the cases. In lieu of VCRS, if, VARS is used in vehicles the refrigeration system could be operable in a vehicle without adding running cost for air conditioning.

There is a great impact on the running cost of a vehicle due to increasing cost of fuel. The A/C system adds nearly 35 % extra cost in fuel expenses. Alternately, it is a matter of investigation that waste recovery of an engine for application in A/C can reduce the fuel economy of vehicles to what maximum extent? It has been revealed that there is great potential to reduce A/C fuel consumption because A/C systems have traditionally been designed to maximize capacity, not efficiency. From the reviews of various literatures there is an indication that reducing the A/C load decreases A/C fuel consumption. In the same line, an automobile engine utilizes only about 35% of available energy and rests are lost to cooling and exhaust system. If one is adding conventional air conditioning system to automobile, it further utilizes about 5% of the total energy. Therefore automobile becomes costlier, uneconomical and less efficient. Additional of conventional air conditioner in car also decreases the life of engine and increases the fuel consumption. For very small cars compressor needs 3 to 4 bhp, a significant ratio of the power output. Keeping these problems in mind, a car air conditioning system is proposed from recovery of engine waste heat using radiator water as source / generator for VARS.

a) *Vapour Compression Refrigeration System*

Heat flows naturally from a hot to a colder body. But, in refrigeration system there is opposite phenomena i.e. heat flows from a cold to a hotter body. This is achieved by using a substance called a refrigerant. The refrigerant absorbs heat and hence evaporates at a low pressure to form a gas. This gas is then compressed to a higher pressure, such that it transfers the heat it has gained to ambient air or water and turns back (condenses) into a liquid. Thus, heat is absorbed, or removed, from a low temperature source and transferred to a higher temperature source.

The refrigeration cycle can be broken down into the following stages (ref. Figure 1):

- 1 – 2, Low pressure liquid refrigerant in the evaporator absorbs heat from its surroundings,

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usually air, water or some other process liquid. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.

- **2 – 3,** The superheated vapour enters the compressor where its pressure is raised. There will also be a big increase in temperature, because a proportion of the energy input into the compression process is transferred to the refrigerant.
- **3 – 4,** The high pressure superheated gas passes from the compressor into the condenser. The initial part of the cooling process (3 - 3a) de super heats the gas before it is then turned back into liquid (3a - 3b). The cooling for this process is usually achieved by using air or water. A further reduction in temperature happens in the pipe work and liquid receiver (3b - 4); so that the refrigerant liquid is sub-cooled as it enters the expansion device.
- **4 – 1** The high-pressure sub-cooled liquid passes through the expansion device, which both reduces its pressure and controls the flow into the evaporator.

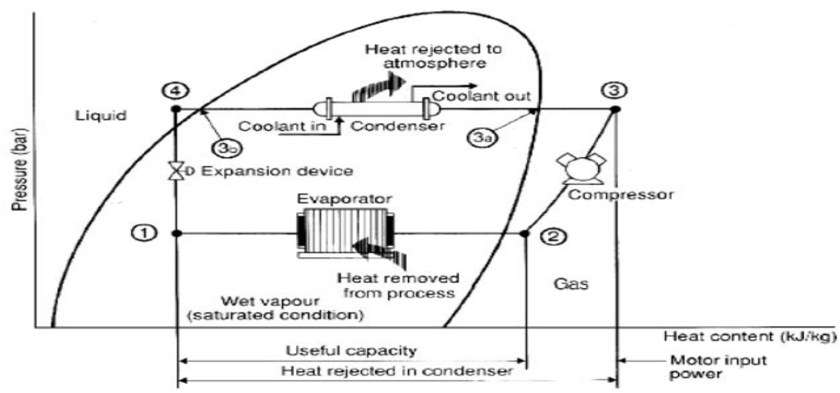

Fig. 1 : Schematic diagram of a Basic Vapour Compression Refrigeration System

It can be observed that the condenser has to be capable of rejecting the combined heat inputs of the evaporator and the compressor; i.e. (1 – 2) + (2 – 3) has to be the same as (3 – 4). There is no heat loss or gain through the expansion device. The existing refrigeration system in a vehicle is shown diagrammatically in figure 2

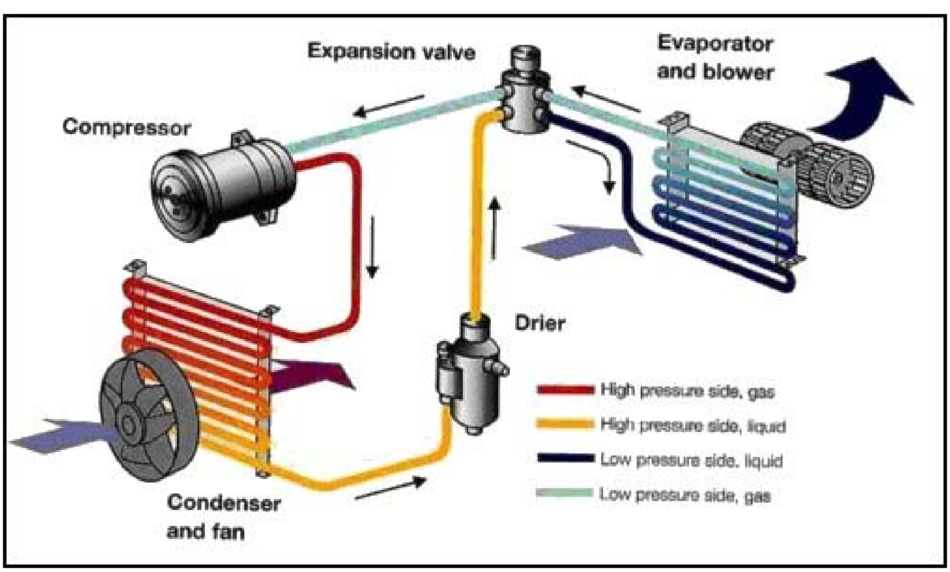

Fig. 2 : Existing Refregiration system in automobiles

b) Absorption Cooling Systems; a brief

Absorption is the process of attracting and holding moisture by substances called desiccants. Desiccants are sorbents, i.e., materials that have an ability to attract and hold other gases or liquids, which have a particular affinity for water. During absorption the desiccant undergoes a chemical change as it takes on moisture, as for example the table salt, which changes from a solid to a liquid as it absorbs moisture. The characteristic of the binding of desiccants to moisture makes the desiccants very useful in chemical separation processes.

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-15ºC = 1314 kJ/kg.
- Critical temperature of NH_3 = 132.6ºC.
- Boiling point at atmospheric pressure = -33.3ºC

The NH_3-H_2O 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, is between 0.6 to 0.7. Ammonia is highly soluble in water and this ensures low solution circulation rates. Both constituents are obtainable at minimal cost. The choice of Ammonia-water combination is not made without considering certain disadvantages: ammonia attacks copper and its alloys when it has been hydrated. Therefore, all components are made from mild steel or stainless steel.

c) Engine Cooling System

The cooling system on liquid-cooled cars circulates a fluid through pipes and passageways in the engine. Temperatures in the combustion chamber of the engine can reach 4,500 F (2,500 C), so cooling the area around the cylinders is critical. As this liquid passes through the hot engine it absorbs heat, cooling the engine. After the fluid leaves the engine, it passes through a heat exchanger, or radiator, which transfers the heat from the fluid to the air blowing through the exchanger. The engine in your car runs best at a fairly high temperature. When the engine is cold, components wear out faster, and the engine is less efficient and emits more pollution. So another important job of the cooling system is to allow the engine to heat up as quickly as possible, and then to keep the engine at a constant temperature. To handle this heat load, it may be necessary for the cooling system in some engines to circulate 4,000 to 10,000 gallons of coolant per hour. The water passages, the size of the pump and radiator, and other details are designed as to maintain the working parts of the engine at the most efficient temperature within the limitation imposed by the coolant. The fluid that most cars use is a mixture of water and ethylene glycol ($C_2H_6O_2$), also known as antifreeze. By adding ethylene glycol to water, the boiling and freezing points are improved significantly. The finding of the condition of coolant and temperature is shown the table 1.

Table 1 : Condition of coolant and temperature

Condition of Coolant	Pure Water	50/50, $C_2H_6O_2$ / Water	70/30, $C_2H_6O_2$ / Water
Freezing Point	0 C / 32 F	-37 C / -35 F	-55 C / -67 F
Boiling Point	100 C / 212 F	106 C / 223 F	113 C / 235 F

Normally water boils at 212°F. However, for every pound of pressure increase, the boiling point increases by 3°F. The temperature of the coolant can sometimes reach 250 to 275ºF (121 to 135ºC). Even with ethylene glycol added, these temperatures would boil the coolant, so something additional must be done to raise its boiling point. Typical radiator cap pressure is 12 to 16 psi. This raises the boiling point of the engine coolant to about 250°F to 260°F. Many surfaces inside the water jackets can be above 212°F.

d) Comparison between Vapour Compression and Absorption system

A comparative study has been conducted between Vapour Compression and Absorption system. The salient findings are enumerated below in table 2

Table 2 : Comparison between Vapour Compression and Absorption system

S.No.	Absorption System	Compression System
1	Uses low grade energy like heat. Therefore, may be worked on exhaust systems from I.C engines, etc.	Using high-grade energy like mechanical work.
2	Moving parts are only in the pump, which is a 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 evaporator pressures also without affecting the COP.	The COP decreases considerably with decrease in evaporator pressure.
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	Liquid traces in suction line may damage the compressor
6	Automatic operation for controlling the capacity is easy.	It is difficult.

II. Objectives of the Study

The objectives of the study on the subject "Recovery of engine waste heat for reutilization in air conditioning system in an automobile: An investigation" are as follows

1. Identify the form of "muda" (waste) in traditional VCRS.
2. Compare the key characteristics of traditional VCRS and proposed VARS
3. Differentiate between existing refrigeration cost and proposed target cost
4. Identify data and tools useful for planning and assessing strategies for leadership in refrigeration quality in vehicle by use of SWOT analysis.

III. Scope of the Work

Our scope of work is confined and limited to the study of VARS in lieu of VCRS through recovery of engine waste heat using radiator water as source / generator for VARS. The arrangement of various components of air conditioning system is also a challenge because of the fix size of cars. However, the dsigning aspects will be given due consideration after intial exeperimentation. In the proposed model condenser and evaporator will be arranged same as the conventional unit.

IV. Review of Literatures

There are various works available on the Adsorption cooling with exhaust gas heat of engine. But, no significant wok has been carried out by recovering and utilizing Engine heat in refrigeration system of a vehicle.

According to Palm [1], Corberan et al.[2], Domanski and Yashar,[3]) ,most HFC refrigerants have a relatively high global warming potential (GWP) which is also being regulated by the Kyoto Protocol. They have cited that recent passage of legislation in the European Community requires the use of refrigerants with GWPs of less than 150 in all new-type vehicles starting in 2011 and in all new vehicles by 2017

Recently, Sami et al. [4] presented an improved dynamic model to study the single absorber and/or double absorber systems with heat recovery. The systems they studied employed an air cooled evaporator and an air cooled condenser. Hot oil, superheated steam or exhaust gas could be used as heating fluids for the absorbers. In these respects, they are similar to the automobile waste heat cooling system we propose. And it gave an insight into the thermodynamics for some of the system components. However, in their analysis, the cycle time was quite long and an equilibrium adsorption state was assumed.

Colbourne [5] summarized a study analyzing over 50 published technical documents comparing the performance of fluorinated refrigerants and HCs. A significantly higher number of tests showed an increase in performance when using HCs as compared to using fluorinated refrigerants (Colbourne and Suen,)[6].Similarly, Colbourne and Ritter[7] investigated the compatibility of non-metallic materials with HC refrigerant and lubricant mixtures. They performed experiments in compliance with European standards for the testing of elastomeric materials and ASHRAE material compatibility test standards.

Maclaine-Cross and Leonardi[8] compared the refrigerant performance of HCs based on refrigerant properties and concluded that the COP improvements, commonly reported in literature, were consistent with better thermodynamic properties of HCs. R600a properties and their influences on system performance were discussed. Joudi et al. [9] studied the performance of MAC systems with alternative refrigerants. A computer model was developed to determine the most suitable alternative refrigerant to R12. The influence of evaporating temperature, condensing temperature and compressor speed in an ideal cycle was considered.

Ghodbane [10] investigated the use of R152a and HCs in MACs. Based on thermo physical data. He has proposed a quantitative analysis of MACs with flammable refrigerants. Razmovski [11] and Rajasekariah [12] experimentally evaluated possible ignition sources in a car by connecting a welding torch to a HC refrigerant cylinder.

The basic adsorption cycle [13-15] has a theoretical coefficient of performance of about 0.5. Meunier [16] showed that the performance of an ideal regenerative cycle with an infinite number of cascades can be as high as 1.85, about 68% of the ideal Carnot COP. These researches are very significant in improving the market competitiveness of commercial adsorption cooling/heating machines.

Zhu et al. [17] measured the cooling capacity of a cooling element of a fishing boat diesel engine waste heat chiller and the temperature variation of the adsorbent bed. Their study was purely experimental and no numerical analysis was presented. Suzuki [18] theoretically studied the effects of UA (overall heat transfer coefficient) on SCP of a passenger car waste heat adsorption air conditioning system; however, no details were outlined with respect to the effects of other parameters which play equal important roles in adsorption refrigeration. However, in the case of automobile waste heat cooling, mechanical simplicity and high reliability will prevail on efficiency. And the waste heat recovery cannot affect the mechanical energy output from the engine. So a two-bed basic zeolite-water adsorption cycle is considered in this study. The feasibility of adsorption cooling for automobile/engine waste heat recovery was studied before [17, 18]. However, information on its dynamic performance, which is necessary for the design and optimization of the system, is insufficient.

The SL refrigeration systems are frequently used in industrial refrigeration and commercial comfort cooling and are also known as ‘‘Liquid-Chilling Systems’’ (ASHRAE) [19]. As with all the reviewed refrigerants, the environmental properties are far superior to that of R134a. R600a is in the safety classification A3 by the ASHRAE Standard 34[20], meaning that it is highly flammable and has a lower flammability limit (LFL) of 1.7 vol. %, which makes it the easiest to ignite among the reviewed refrigerants. The minimum ignition energy (MIE) needed is 0.25 mJ. The acute toxicity exposure limit (ATEL), a measure of the toxicity of a refrigerant, is 25,000 ppm and therewith the lowest of the reviewed refrigerants. The acute toxicity exposure limit (ATEL) is a value used by ASHRAE Standard 34[20] and ISO 817[21] to establish the maximum refrigerant concentration limit for a refrigerant in air.

Granryd [22] and Corberan et al. [2] summarized the environmental safety considerations and standards applied for the safe use of flammable refrigerants. Both ASHRAE Standard 34[20] and European standard prEN378 [23] classify refrigerants in three classes 1–3, where Class 1 is used for non-flammable fluids and Class 3 for highly flammable fluids. The group of Class 3 refrigerants, which includes the HCs, is limited in use for industrial applications in the USA and France. Several standards allow the use of HCs without restrictions, if the charge amount is less than 0.15 kg in hermetically sealed and safely designed systems. As a result, the use of HCs in household refrigerators, freezers and small heat pumps has increased in European countries. Furthermore, Granryd [22] compared the performance of HCs, such as R600a and R290 and their mixtures to the well Colbourne [5] summarized a study analyzing over 50 published technical documents comparing the performance of fluorinated refrigerants and HCs. A significantly higher number of tests showed an increase in performance when using HCs as compared to using fluorinated refrigerants (Colbourne and Suen)[6].

The average improvements from using HCs were 6.0% for domestic refrigeration applications, 15.0% for commercial refrigeration applications, 8.8% for air conditioning and 9.6% for heat pumping Colbourne and Ritter[7] investigated the compatibility of non-metallic materials with HC refrigerant and lubricant mixtures. Experiments were performed in compliance with European standards for the testing of elastomeric materials and ASHRAE material compatibility test standards. Test results were presented for swell rates, hardness rating, mass changes and the change of tensile strength. In a study about HC refrigerant leakages in car passenger compartments, Maclaine-Cross [8] referred to the report made by European company (Arthur D. Little Ltd), who noted that serious injury to occupants through use of flammable refrigerant would only be possible if the car crashed, due to overpressure in the compartment after a fatigue damage of the liquid line.

Ritter and Colbourne further [7] published a review on HC risk assessment from 1991 to 1998. The use of background risks as a basis for comparison of the risk of fire with HC was presented. A report from Dieckmann et al [24] for the U.S. Department of Energy was reviewed, which assessed the risk of using flammable refrigerants in MACs. Field data from car crashes and car fires was used as basis for the analysis. A similar risk assessment, performed by Elbers and Verwoerd [25], considered an R290 heat pump system used for residential heating. To provide a context for

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these safety estimates, Ritter and Colbourne [7] presented estimations of so-called background Risks

Jetter et al. [26] used a fault tree analysis to estimate the number of refrigerant exposures of automotive service technicians and vehicle occupants in the USA. A quantitative risk assessment model was developed by Colbourne and Suen [27] to examine the influence of design, installation of equipment and external conditions on the frequency of ignition and the associated consequences for indoor refrigeration and air-conditioning units using HC refrigerants. Safety testing of domestic refrigerators was conducted by Gigiel [28] based on the current international standard EN/ IEC 60335-2-24 (2001).

The single-phase secondary refrigerant can be divided into two categories, aqueous and non-aqueous solution (Ure, [29] Ubaldo [30]).

Melinder [31] reported the performance of aqueous secondary fluids and non-aqueous secondary fluids for indirect systems. Compared to all the water solutions, the non-aqueous fluids such as diethylbenzene mixtures, hydrocarbon mixtures, hydrofluoroether, polydimethylsiloxan require a much larger volume flow rate under the same refrigeration capacity and temperature change. Ure [29, 32] ascertained several requirements that any secondary refrigerants must satisfy:

- low viscosity
- high specific heat
- good thermal conductivity
- good chemical corrosion inhibiting
- chemically stable, no separation or degrading
- non-toxic
- non-flammable
- food grade for food refrigeration

Numerous authors presented experimental and simulation results on fundamental research of ice slurries in terms of ice particle shape and growth behaviour (Kauffeld et al., [33]; Okawa et al.,[34]; Sari et al., [35]), physical properties (Hansen et al.,[36]; Inaba, [37]; Meewisse and Ferreira,[38] and fluid dynamics (Ayel et al.,[39]; Jensen et al., [40]; Kitanovski and Poredos, [41]). Kauffeld et al. [42] published a handbook of ice slurries in 2005 as well. The main disadvantage of CO_2 appeared to be the relatively low critical temperature and the availability of components (Hinde et al.)[43]. A few applications, which utilize CO_2 as a volatile secondary refrigerant, have been implemented in low-temperature application (Melinder, [44]; Pachai, [45]; Pearson, [46]).

Palm [1] reported that HC producers listed the compressor manufactures whose compressors are compatible for HCs. Janssen and Beks[40] evaluated hermetic compressor performances when changing from R12 to a HC mixture of R600a and R290.Corberan et al.[5] investigated the performance of a positive displacement hermetic refrigerant piston compressor working with R290 as refrigerant. Cooling capacity of R22 compressor that was switched to R290 was lowered to an amount ranging from 13 to 19%. On the other hand, the COP of the system increased from 2 to 6%. Devotta and Sawant [47] carried out the life cycle test of the hermetic compressor with R12, R134a, R410A and various HCs. They found that the HC mixture was more compatible with the hermetic compressor materials than R12 and R134a, even under the retrofit conditions. Pellec et al. [48] tested two types of heat exchangers working with ammonia and silicone heat transfer fluid as the secondary refrigerant [49-52]. Setaro et al. [53] tested and compared the heat transfer and pressure drop through a brazed plate heat exchanger and a tube-and-fin coil for two different refrigerants, R22 and R290 in an air-to water heat pump system.

Hrnjak and Hoehne [54] reported that the air-to-R290 mini channel heat exchanger developed for a 2 kW cooling capacity refrigeration system needed less than 0.13 kg of R290 due to its smaller internal volume than that of traditional fin-and-tube heat exchanger. Hrnjak and Litch [55] also presented the experimental results of mini channel heat exchanger utilized as an air-cooled condenser in a prototype ammonia chiller.

Fernando et al. [56] studied liquid-to-refrigerant heat exchangers using flat multiport with 1.4mm hydraulic diameter tubes and showed a lower charge compared to plate heat exchangers. Fernando et al. [57-59] also carried out comprehensive tests on performance of mini channel aluminium tube heat exchangers working as evaporator and condenser.

Walker [60] shows the typical layout of the SL system in a supermarket refrigeration application. The primary loop is composed of the parallel compressors

- air-cooled condenser
- expansion device
- evaporator
- secondary refrigerant pump
- Secondary refrigerant coil.

Kruse [61] compared the energy consumption of DX system and an indirect refrigeration system with a secondary fluid loop. Kauffeld [62] reviewed the trends and perspectives in supermarket refrigeration and compared an indirect, distributed cascade and two-stage refrigeration systems theoretically.

Delventura et al. [63] took an evaluation of the SL supermarket refrigeration system and compared it with the traditional DX refrigeration system. Kazachki and Hinde [64] compared the SL system with the traditional centralized DX system for the supermarket. Evenmo [65] cited a supermarket in the United Kingdom using R407C as the primary refrigerant and a commercial fluid as the secondary fluid, since first used in February 1997.Horton et al. [66] tested a drop-in SL refrigeration system for medium temperature supermarket applications. Arias and Lundqvist [67] reported field test results of advanced systems in three

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supermarkets (floor area ranging from 720 to 2700m^2). Minea [68,69] reported a supermarket refrigeration system with SLs installed near Montreal, Canada.

Faramarzi and Walker [70] installed and tested the performance of the SL refrigeration system in U.S. supermarkets. Nyvad and Lund [71, 72] reported that a supermarket in Denmark replaced its existing (H) CFC-plant with a new indirect SL system. Rolfsman [73] also reported that a supermarket in Sweden had been converted to a SL system. NH_3 was used as the primary refrigerant and CO_2 was used as the secondary refrigerant for freezing. Thomas [74] cited the supermarket in the United Kingdom that installed a SL refrigeration system. In this system, NH_3 was used as the primary refrigerant and propylene glycol as the secondary refrigerant.

Rivers [75] reported for a SL refrigeration system designed for a supermarket in Greenwich, England. The HC was chosen as the primary refrigerant. Baxter [76] reported a case study for a small Danish supermarket where the old refrigeration plant has been replaced with a cascade plant. Pearson [77] submitted patents on the use of CO_2 as a volatile secondary refrigerant, including a novel hot gas defrost system. Pearson [46] used CO_2 as a volatile secondary refrigerant in supermarket systems for the Swedish market. Christensen [78] investigated the SL system using CO_2 as primary and secondary refrigerant in supermarket applications. Tests and measurements have been carried out and compared with the original cabinet.

Pachai [45] reported a SL system installed in Helsingborg, Sweden. The primary refrigerant was HC, a mixture of R290/ R170, and the low- and intermediate-temperature side secondary refrigerants were CO_2 and propylene glycol, respectively. Nilsson et al.[79] reported an ice rink refrigeration system with CO_2 as the secondary fluid. Hinde et al. [43] reported that at least nine low-temperature CO_2 systems were operational in the U.S. and Canada in early 2008. Kaga et al. [80] developed a compact variable capacity refrigerating system with an inverter compressor using R600a as the primary refrigerant and CO_2 as the secondary refrigerant, which is circulated by ''thermosiphon'' effect.

Wang and Goldstein [81] installed the district heating and cooling system with ice slurry generation system in Osaka, Japan. The total energy consumption was reduced by 19%. Wang et al.[82] installed a SL ice slurry system using ethylene glycol/water binary solution in the Ritz Carlton Plaza in Japan. Christensen and Kauffeld [83] described the application of ice slurry as the secondary refrigerant in a SL with ice slurry accumulation tank.

Meewisse and Ferreira [38] compared two freezing point depressants, sodium chloride and ethanol. Soe et al. [84] studied two milk-cooling systems utilizing R290 as the primary refrigerant that were installed in Demark. Ballot-Miguet et al. [85] tested and compared the energy efficiency of the R22 DX system, single-phase secondary refrigerant system, SL system using ice slurry and two-phase CO_2 as the secondary refrigerant. Fukusako et al. [86] reviewed studies related to the cold thermal storage systems and components using ice slurry and recent research activities on ice slurry in Japan. Saito [87] reviewed the recent research on cold thermal energy storage including the SL ice slurry system.

Choi et al. [88] evaluated the performance of R22, R290, R290/600a (70/30%), and R32/152a (50/50%) used in a water-to water residential heat pump for space cooling and heating. Chang et al. [89] reported the performance and heat transfer characteristics of a heat pump system filled with HC refrigerant (R290, R600a, R1270 and binary mixture of R290/R600a and R290/R600). The secondary fluid was ethyl alcohol. Pelletier and Palm [90] tested a domestic heat pump using R290 as compared to the R22 baseline system. For R290, the heating capacity was 7–10% lower, while the heating COP was 4–5% higher than R22. Payne et al. [91] investigated and compared the performance of R22, R290 and zeotropic mixtures of R32/R290 and R32/152a. The SL fluid was 70/30% mixture of water and ethylene glycol. Stene [92] investigated the performance of a residential brine-to-water CO_2 heat pump for combined low-temperature space heating and hot water heating. Yanagisawa et al. [93] investigated a SL refrigeration system, using a vapour compression NH_3 cycle as the primary loop and a CO_2 thermo siphon loop almost all of currently manufactured air-conditioning systems for automobile and light duty truck vehicle use R134a as the refrigerant.

Natural refrigerants, such as HCs, present a potential alternative option to R134a due to their good thermodynamic and transport properties, heat transfer characteristics, material compatibility, low cost, low toxicity and low GWP (Domanski and Yashar,[3]; Fernando et al.,[56]; Mani and Selladurai,[94];Palm, [1]). Ghodbane [10] investigated the potential of R152a and HC refrigerants as alternative refrigerants to R134a, and a comparative assessment of a SL when applied to MACs. Dentis et al. [95] compared the SL system with R152a and HC refrigerants and the R134a system in a test bench, and demonstrated that the performance of SL system was similar to, and in some cases exceeded the performance of the R134a system. Ghodbane [96] also compared the performance of SL system to conventional R134a system used in a small size passage car under the same test conditions.

According to Srikhirin et al. [97] the absorption refrigeration system went through ups and downs, being the antecessor of the vapor compression refrigeration system in the 19th century. Systems operating on lithium bromide–water were commercialized in the 1940's and 1950's as water chillers for large buildings air conditioning (Costa[14]; Perez-Blanco [98]). Substitution of petroleum-based combustion fuels in the 1970's affected the application of absorption refrigeration, but, at the same time, new opportunities arose, such as usage of solar energy to operate this system (Costa [14]; Zhai et al. [99,100]). Increasing energy costs and other factors has contributed to frequent use of low temperature energy waste from chemical and commercial (supermarket) industries to operate absorption refrigeration systems (Horuz and Callander [101]; Varani [102]; Maidment et al. [103]).

Among the most applied working fluids are the pair ammonia refrigerant– water absorbent (NH_3–H_2O) and water refrigerant–lithium bromide absorbent (H_2O–LiBr). A limitation of the pair water–lithium bromide is the difficulty to operate at temperatures lower than 0°C. Besides, lithium bromide crystallizes at moderate concentration, and, at high concentration, the solution is corrosive to some metals and is of high cost (Horuz [104]; Srikhirin et al. [97]). The system water–lithium bromide operates below atmospheric pressure, resulting in system air infiltration, which requires periodical purge.

On the other hand, operation above atmospheric pressure is a considerable advantage. Though ammonia–water systems were previously applied to refrigeration and ice production, recent applications are predominantly on air conditioning, for which the pair water–lithium bromide can also be employed (Chuaa et al. [105]; Costa [14]; Lazarrin et al. [106]). Wu and Schulden [107] presented a modified Carnot cycle for a heat engine using high-temperature waste heat. The authors adopted the power per heat exchanger surface unit area for performance analysis of the heat engine. The relation between the maximum obtainable specific power and the temperature range in which the high-temperature waste heat engine operates was found. Koehler et al. [108] designed, built and tested a prototype of an absorption refrigeration system for truck refrigeration using heat from the exhaust gas. The refrigeration cycle was simulated by a computer model and validated by test data.

Zhao et al. [109] studied two combined absorption/compression refrigeration cycles using ammonia and water as the working fluid. The combined cycle with one solution circuit was a conventional absorption chiller with a mechanical compressor, using both the work and heat output from an engine. The combined cycle with two solution circuits was a generalized version of the previous cycle, which condenser and evaporator were replaced by a second absorber and a second generator. The primary energy ratio, defined as the ratio of the design cooling capacity and the total energy input to the engine, increased considerably for the combined cycles compared to a conventional engine driven compression cycle working with pure ammonia. The authors concluded that the combined cycle with two solution circuits was the best option.

Jiangzhou et al. [110] presented an adsorption air conditioning system used in internal combustion engine locomotive driver cabin. The system consists of an absorber and a cold storage evaporator driven by the engine exhaust gas waste heat, and employs zeolite–water as working pair. The mean refrigeration power obtained from the prototype system was 5 kW, and the chilled air temperature was 18°C. The authors described the system as simple in structure, reliable in operation, and convenient to control, meeting the demands for air conditioning of the locomotive driver cabin.

Qin et al. [111] developed an exhaust gas-driven automotive air conditioning working on a new hydride pair. The results showed that cooling power and system coefficient of performance increase while the minimum refrigeration temperature decreases with growth of the heat source temperature. System heat transfer properties still needed to be improved for better performance.

V. Proposed Methodology

The proposed model is based on three fluid vapour absorption systems. It will contain basic components needed for vapour absorption system as shown in Fig. 3.

- The three fluid used in this system will be ammonia, water and hydrogen.
  - The use of water is to absorb ammonia readily.
  - The use of hydrogen gas is to increase the rate of evaporation of the liquid ammonia passing through the system.
- Even though ammonia is toxic, but due to absence of moving part, there will be little chance for the leakage.
- The hot radiator water will be used to heat the ammonia solution in the generator. To remove water from ammonia vapor, a rectifier will be used before condenser. The ammonia vapor is condensed and flows under gravity to the evaporator, where, it meets the hydrogen gas.The hydrogen of gas, which is being feed to the evaporator, permits the liquid ammonia to evaporate at low pressure and temperature.
- During the process of evaporation, the ammonia will absorb the latent heat from refrigerated space and produces cooling effect. The mixture of ammonia vapor and hydrogen will be passed to the absorber where ammonia will be absorbed while hydrogen raises the top and flows back to the evaporator.

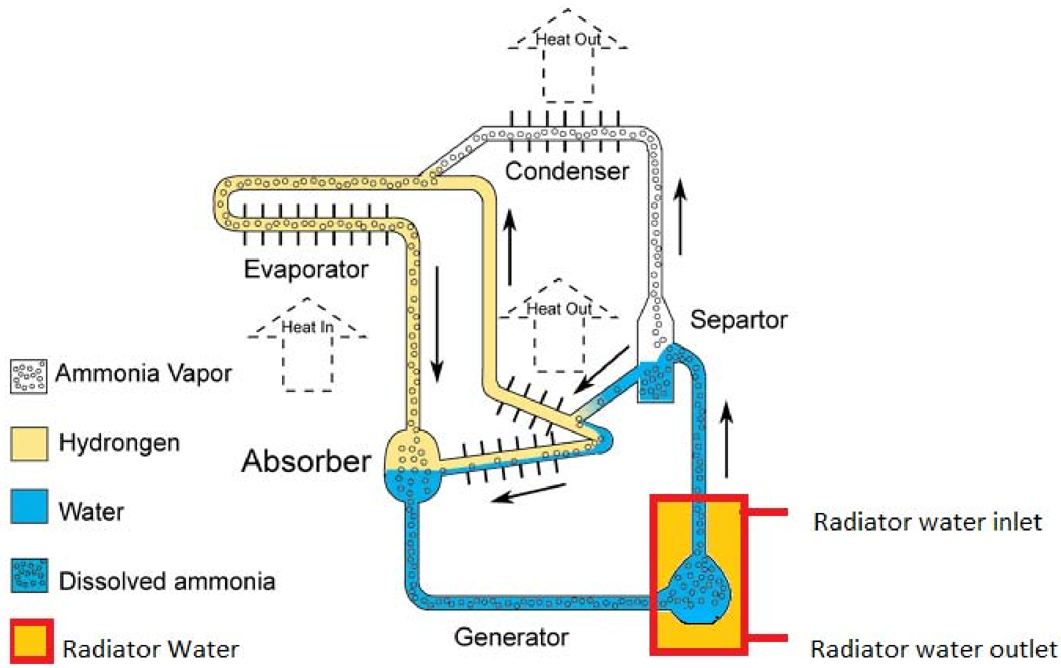

Fig.3 : Schematic of a triple fluid vapours absorption refrigeration system

a) Development of A Mathematical Model

The mathematical model will be developed considering the following elements

- Thermodynamic properties
- Absorption equation
- Conservation of energy
- Absorption process, and
- The coefficient of performance

The relation will be developed through mathematical model that what is the extent of heat generated in the engine and what quantity could be transferred for utilizing at the A/C system by recovery of waste engine heat

VI. Conclusion

The study of waste heat cooling system analyzed in this article will be experimentally investigated and the data will be captured for further analysis. This will be supported by a suitable mathematical model and a simulation tool. The study reveals that it comprises four heat exchanges, namely, an air finned forced convection condenser, an air finned forced convection evaporator, and a pair of shell and tube type absorbers, plus four one-way refrigerant valves, an expansion valve, and an exchange valve. For a refrigerant system the following things are needed

- Specific Cooling Power (SCP)
- Coefficient of Waste Heat Recovery (CWHR)
- Coefficient of Waste Heat Cooling (CWHC)

At present, for an automobile waste heat absorption cooling system, the demand for CWHC can be easily met, but for SCP, further research is needed, which will be studied in part II of this project.

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