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Experimental Investigation of Vapour Absorption Refrigeration Cycle for Automobile Cabin Cooling

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ABSTRACT

Because the currently used Vapour Compression Refrigeration cycle (VCRC) for air conditioning in cars, uses compressor which leads to degradation of performance of engine. This can be replaced with Vapour Absorption Refrigeration cycle (VARC). The above hypothesis was studied using Electrolux VARC setup installed in SKNCOE, Pune. The main motive behind experimentations was to check the feasibility of implementation of VARC in cars for cabin cooling. Since heat recovered from exhaust gases is utilized in VARC, it results into economical air conditioning. Implementations of this concept will after-effect into high energy conservation in tropical countries. Since performance of any thermodynamic system is dependent on temperatures, variation in performance of VARC system with respect to various temperatures is studied. Along with the performance analysis, the paper focuses on the enlightening the practical approach of implementation of above system into automobiles. When using this system, it was found that energy saving up to 10% could have been achieved based on experimental data of this system.

***Keywords*: *VARC, COP, Generator Temperature,* NH_3*-*H_2O.**

1.INTRODUCTION

Energy efficiency has been a major topic of discussion on natural resources reservation and cost reduction. The expansion of energy resources is one of the prime motivations for social and technological developments. In the last decades, strong international concern has been raised with regard to the depletion of the natural resources and an increase in pollution levels as a consequence of the higher energy consumption necessary to sustain productive activities.

Refrigeration and Air conditioning systems consume considerable amount of energy around the world. In order to reduce this, share some alterations need to be searched for example for cooling application, Vapour absorption system which is basically driven by low grade energy such as waste heat, solar energy is coming in picture for the last few decades. The advantages of this system lie in the possibility of utilizing of waste energy from industrial plants as well as of using solar energy. Aqua ammonia system is employed for applications below 32 F (0 ^{0}C) in which the refrigerating fluid is ammonia and absorbent or carrier is water. The elimination of the necessary shaft work has been the prime reason for the economic success of vapour absorption system. As these systems require only low grade energy in the form of heat and due to limited energy sources and growing demand, there is a concern in the scientific community to develop energy efficient systems.

From general observations and survey from various automobile stations it has been concluded that introduction of VCC air conditioning system in cars reduces economy of engine by 10% i.e. approximately by 1 to 2 Km-Pl.

An International report has suggested that daily Petrol consumption in India is about 3660000 barrels (581940000 litres). Also it has been stated by Government of India that out of total petrol consumption 27% fuel is consumed by 4-wheel vehicles. If it is assumed that 50% of 4-wheel Vehicles in India are air conditioned, and each AC consumes 10% of shaft power, 7500000 litres fuel can be saved on daily basis, which can save around Rs. 2000 crores can be saved annually, if the VARC based system is used in Automobiles

2. LITERATURE REVIEW

Abdullha Yildiz et al [1] did energy, exergy and thermo-economic analyses of the Electrolux vapor absorption system. He has shown that that the best performances in terms of COP were obtained from a concentration range of the rich solution of

0.2–0.3 ammonia mass fraction and that concentration of the weak solution of 0.1. The COP of the system working with helium was higher up to 40% than that of the system working with hydrogen. Exergy is defined as the maximum amount of work potential of a material or an energy stream, in relation to the surrounding environment. In the exergy analysis, measured ambient temperature is evaluated as the dead state temperature (T_0). The above paper was extremely helpful in understanding the overall characteristics of Electrolux VAR. Some of the points that need attention were sufficient amount of insulation on the generator. Abdullah et al [2] has shown through analyses, the energy conservation concept alone is not adequate in gaining a full understanding of all the important aspects of energy utilization processes. Rahul Yadav [3] concluded in this research that water (H2O) and Ammonia (NH3) combination is the most suitable working fluid pair for vapour absorption refrigeration system and that the problem of fossil fuel and ozone layer depletion together with some other advantages of ammonia water vapour absorption system and this system is showing tremendous potential for (NH3- H2O) absorption refrigeration system to flourish. Arun bangotra [4] et al designed a 3TR refrigeration system. Also the data was analyzed using first and second law of thermodynamics. Satish et al [5] have analyzed the ammonia-water vapour absorption system based on First Law of Thermodynamics and presented empirical relations for evaluating the characteristics and performance of a single stage Ammonia-water VAR system. Micallef D et al [6] presented a simple linear model for a vapour absorption unit which could be based on aqua-ammonia or Libr-water refrigerants-absorber pairs. Simulation results showed that system performance seriously deteriorates from maximum COP of 0.75 to 0.55 as generator temperature was decreased and absorber temperature was increased. The results obtained were in good agreement with other similar studies which showed that the COP decreased with increase in the absorber temperature. Sachin et al [7] carried out analytical study of Li-Br vapor absorption system. A little consideration has also been given to comparison of Li-Br mixture and NH_3-H_2O mixture, highlighting the working ranges of the said refrigerant-absorbent mixtures.Rahul et al [8] observed that with increase in generator temperature coefficient of performance increases but after certain range it starts decreasing. They also could observe that with increase in condenser pressure coefficient of performance decreased and circulation ratio increased. Omer et al [9] carried out analysis of vapor absorption system based on entropy generation. The result showed that high coefficient of performance (COP) value was obtained at high generator and evaporator temperatures, and also at low condenser and absorber temperatures.The generator had the highest entropy generation. The next highest entropy generation was found in the absorber. Z. Crepinsek [10] et al compared the performance of vapour absorption system using different refrigerants. In further study, the performances of a single-stage triple pressure level (TPL) absorption cycle with four HFC refrigerants namely: R32, R125, R134a and R152a with combination with absorbent dimethylethylenurea (DMEU) was compared. Nahla et al [11] studied the performance of ammonia-water VAR system which operates at three pressure levels, absorber is at an intermediate pressure (Pint) taken between the evaporator pressure (PEV) and the condenser pressure (PCD), unlike the single stage machine, which works between two pressure levels. The analysis found that the new proposed absorption machine, the coefficient of performance was higher than that relative to the classic system which is about 0.58, while for the conventional configuration, the COP could not exceed 0.51. Ahmed Ouadha [12] et al presented the thermodynamic analysis of a vapour absorption refrigeration system driven by waste heat of the diesel engine. The analysis showed that COP increases with increase in generator temperature. However, it decreases as the condenser temperature increases. The comparison between evaporator temperature and COP showed that COP improves significantly as the evaporator temperature increases. Shubhash et al [13] did a comparative study of VAR system with refrigerants as Ammonia-Water NH_3-H_2O and Water-Lithium Bromide (LiBr-H_2O). The paper also suggests that (LiBr-H_2O) system finds applications for moderate temperatures (50ºC and above) applications especially air conditioning. Ammonia-Water (NH_3-H_2O) system is used for low temperature (less than 50 ºC) refrigeration applications with NH_3 as refrigerant and H_2O as absorbent. Cristy v et al [14] designed, built and tested a breadboard prototype of an absorption system for refrigeration using heat from the exhaust-gases. For the experimentation for 1500 rpm the exhaust temperature was found to be in the range of 125^0 C to 250^0 C. François et al [15] have developed a 5 KW cooling capacity vapour absorption chiller which is driven by solar energy. Simulation study found out that heat exchanger efficiency improved significantly the thermal COP as compared to sub-cooler efficiency. It also revealed that the absorber and the sub-cooler are the only components which are sensible to pressure drop in terms of thermodynamic cycle's performance. J.L Rodriguez et al [16] reviewed diffusion–absorption refrigeration technologies in this work in order to promote their main characteristics in terms of the refrigeration process, their applications, work fluids, current trends and limitations, among others. Nevertheless, it has been demonstrated that this technology is around 40% less efficient than conventional absorption systems. Wael et al [17] studied the thermal performance of a Electrolux refrigeration system aka diffusion absorption refrigerator (DAR) driven by the waste heat of a diesel engine exhaust gas as an energy source was investigated experimentally. The heat exchanger designed as a shell and tube heat exchanger with a shell length of 50 cm and a diameter of 8 cm. The authors recommended that the optimum exhaust temperature supplied to the generator should be between 210 and 220 °C. it was seen that when the exhaust temperature changed from 220°C to 230°C, the refrigeration effect dropped by 30 to 40 percent.

The above literature survey has provided a very good insight of Electrolux vapour absorption system. Some of the critical points to be paid attention have been identified. Particular the generator design, the operation of generator and its performance is an important area that needs to be stressed upon.

3. SYSTEM DESCRIPTION

As shown in figure 1 setup of vapour absorptionsystemhas following components:

(1) Absorber
(2) Generator
(3) Air cooled condenser
(4) Temperature indicators
(5) Energy meter

Figure1. VARC setup

The System shown above in figure is Electrolux Vapour Absorption Refrigeration system, available in IC Engine Laboratory, Department of Mechanical Engineering, Smt. Kashibai Navale College of Engineering,

Table1. Specifications of VAR system

Technical data	Specifications
Total volume (lit)	30
Height (mm)	552
Width (mm)	380
Depth (mm)	445
Weight (kg)	13
Internal dimensions (H*W*D) (mm)	438*295*245
Maximum input	230 V (W) 90
Energy consumption annum (kW-hr)	266

Table2. Specifications of IC engine

Model	Maruti 800(4S-Vertical)	Lubrication System	Pressure Feed System
Maximum Output	27.6 KW @ 5000 rpm	Cooling System	Water Cooling with Thermostat
Maximum Torque	59 NM @ 2500 rpm	Fuel Supply System	MPFI

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No. of Cylinders	3	Dynamometer	Hydraulic Dynamometer
Bore* Stroke	66.5 * 72 mm	Calorific Value	42500 KJ/Kg
Compression Ratio	9.2:1	Dynamometer Radius	200mm
Cubic Capacity	796 cc	Coefficient of Discharge for Orifice	0.64
Firing Order	1/3/2002	Orifice Diameter	36mm

4. RESULTS AND DISCUSSIONS

Graph shown figure.3 is of most significant since it is cooling curve of air inside cabin. The graph States that the cabin temperature initially rises with time and then starts decreasing. This happens because though generator temperature is increased it requires a particular generator temperature for commencement of refrigeration effect. Since at lower temperatures no separation of refrigerant and absorbent takes place, evaporation of refrigerant does not take place. Since high temperature mixture of refrigerant-absorbent comes in contact with evaporator coils, heat is transferred from mixture to evaporator coil and thus heating of air takes place. However once the sufficient generator temperature is achieved cooling effect is obtained very rapidly. Also apparently cooling curve states requirement of high generator temperature and time span it proves to be a base of future work. The graph shown in figure 4 confirms that, COP initially increases with Condenser temperature and then starts decreasing after a particular value. This nature is exactly opposite to that of VCC system. As in VCC system, Carnot COP depends on only 2 parameters, i.e. Evaporator temperature and Condenser temperature, Lesser Condenser temperature result into less heat rejection and good performance. However, this is not the case with VAR system since COP of VAR system is function of various temperatures. High temperature vapours coming out from condenser result into fast flash evaporation. Again, if temperature is too high it causes reversible heat transfer from condenser vapours to evaporator, which results into decreased refrigeration effect. Also, if it is to concern about Temperature Limitation of refrigerator, Cold fluid available for heat exchange is air and its temperature is almost constant throughout driving intervals. Thus it becomes very difficult to alter the performance of system by varying condenser related parameters. However, use of extended surfaces may definitely improve the condenser performance.

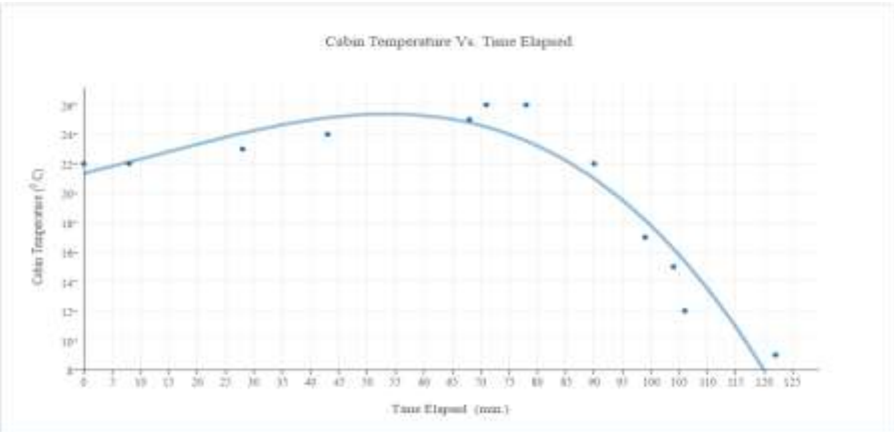

Figure2. Cabin temperature vs. time elapsed

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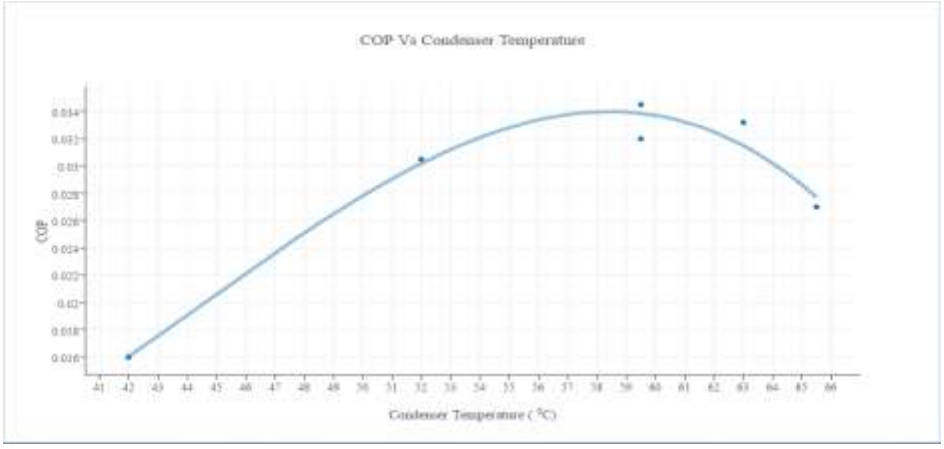

Figure 3.COP vs. average condenser temperature

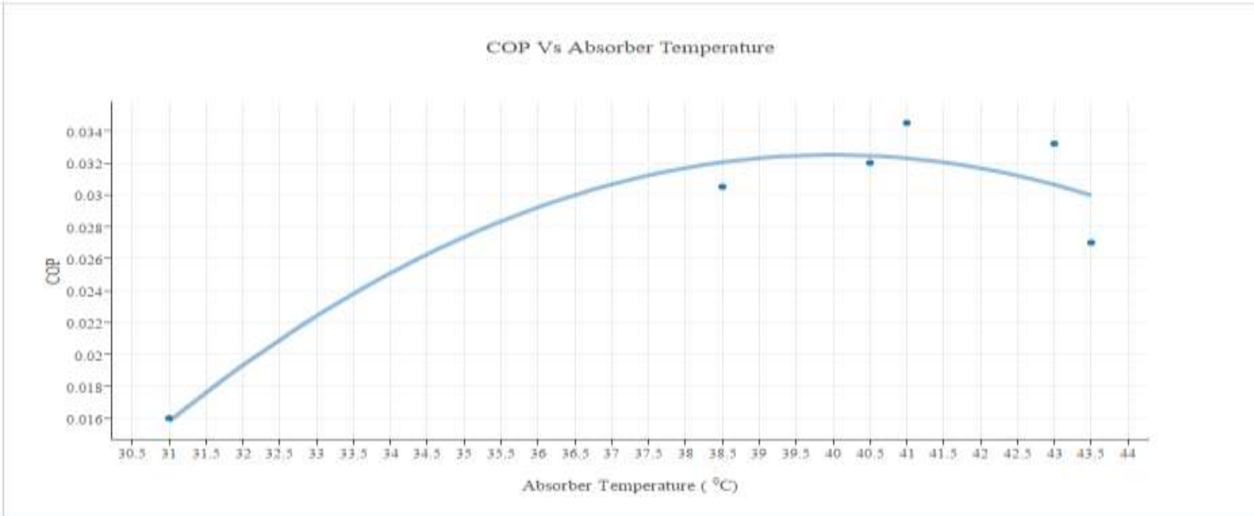

Figure 4.COP vs. average absorber temperature

As it can be clearly noticed from figure 5 that COP increases with Absorber temperature and then starts decreasing, it can be concluded that nature of COP vs. Condenser temperature and Absorber temperature is similar in nature. Absorption is an exothermic reaction, thus temperature of absorbent increases during the process and hence the temperature of absorber.

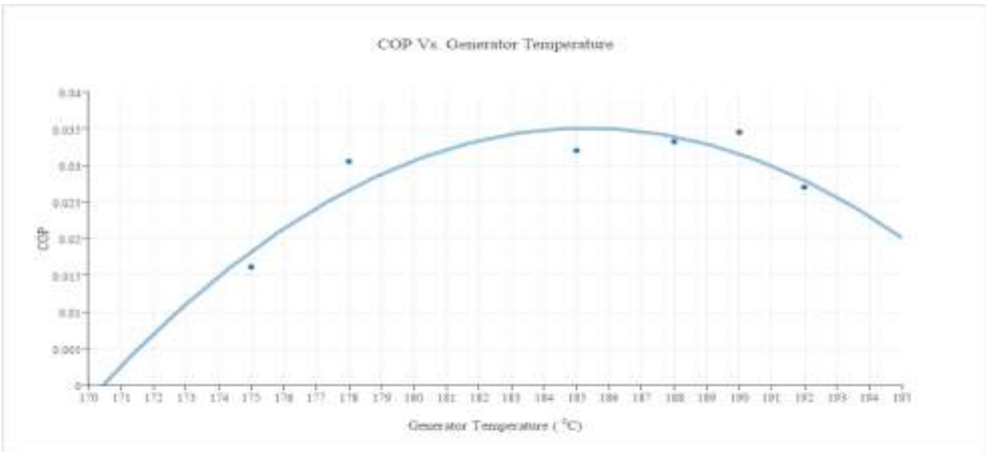

Figure 5.COP vs. generator temperature

It should be noted that generator temperature is most important parameter that affect performance of system and which can be vary effectively to alter the performance of system. From figure 7 it is clearly understood that COP initially increases with generator temperature and then starts decreasing. Very important interpretation is that it requires a particular value of generator

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temperature to achieve refrigeration effect. At a temperature less than this temperature there will not be any cooling effect, but the heating of cabin. Thus achieving a high generator temperature at faster rate is very essential in VAR systems. Also along with getting high generator temperature it is also quite necessary to maintain the temperature, since any deviation from optimum generator temperature is going to hamper the performance of system.

Very important interpretation made from graph of cabin temperature vs. generator temperature is that it requires a particular value of generator temperature to achieve refrigeration effect. At a temperature less than this temperature there will not be any cooling effect, but the heating of cabin. Thus achieving a high generator temperature at faster rate is very essential in VAR systems. Also along with getting high generator temperature it is also quite necessary to maintain the temperature, since any deviation from optimum generator temperature is going to hamper the performance of system. However, the mentioned nature of graph can be proved very effective in different seasons, for heating or cooling the air inside cabin

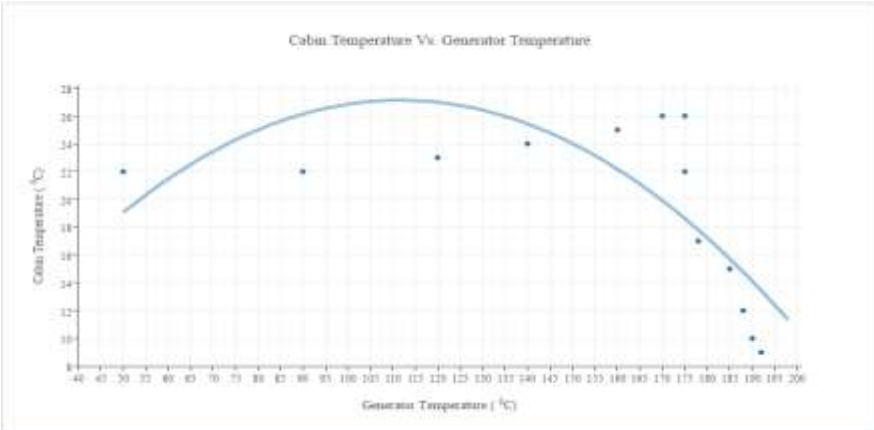

Figure 6.Cabin temperature vs. generator temperature

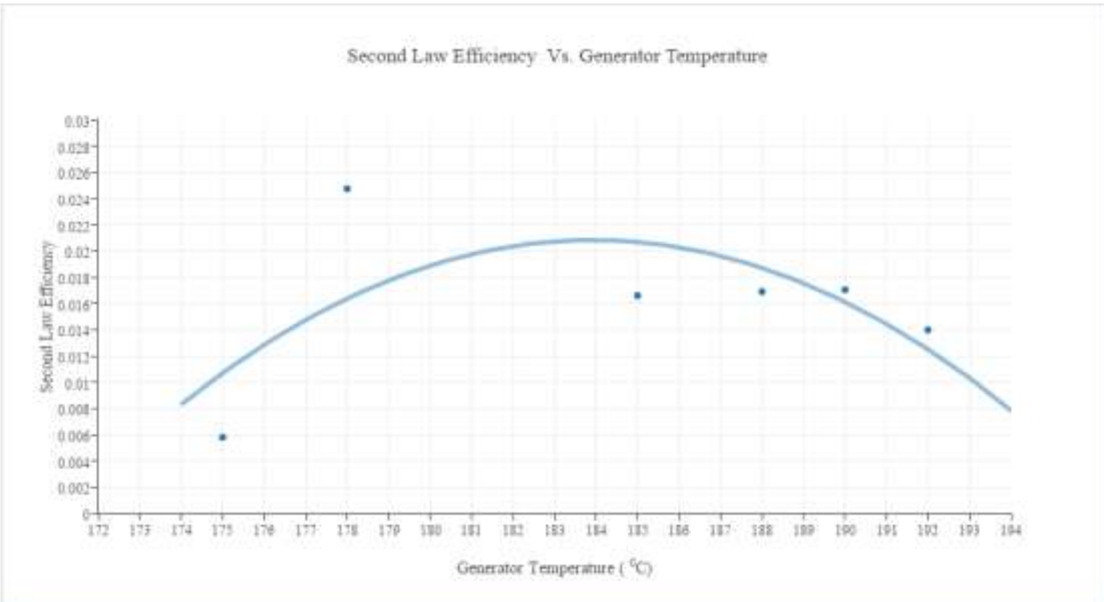

Figure 7.Second law efficiency vs. generator temperature

In thermodynamics, the first law efficiency of a refrigerator is defined as ration of refrigeration effect obtained to the net heat input supplied. Thus it is fraction of input heat energy that is converted into refrigeration effect.Thus, first law does not make any reference to the Best Possible Performance, and thus first law efficiency is not a realistic measure of performance of system. To overcome this deficiency, we defined second law efficiency of system. It gives measure of actual performance with ideal performance under same operating conditions. It can be noted from figure 8 second law efficiency initially increases with generator temperature and then it starts decreasing. Reference of this graph is very necessary while learning thermodynamic performance of system.

5. CONCLUSIONS

As it has been discovered that Refrigeration effect obtained was much satisfactory, it is proved that proposed concept of Cooling of Automobile using exhaust gas is of practical concerned. The mentioned concept can be effectively utilized for automobile cooling. As it has been observed that only a part exhaust gas is being utilized for refrigeration purpose, a system can me made where exhaust gets divided into 2 different flows and hence problem of generation of Back Pressure can be totally eliminated, which is one of the most serious issue associated with Control Volume systems. The mentioned system can be made more effective or instantaneous by the concept of Hybrid Energy Source. An Electric Heater can be implanted as partial source of heat along with exhaust gas, which will come into role only in some specific situations such as Cold Starting, Idle Condition, or when the engine is off or is just started. This system will work effectively and economically only when electric input is utilized at optimum level. Also the experiments conclude that system can work efficiently even when engine R.P.M is 3500 only. As most of Vehicles can run at much higher speed than this, system is going to work well under conditions when speed is not constant, or average speed is considered. Another very innovative concept which is utilized by Reputed Chiller manufacturing Companies is of Hybrid Refrigeration. In this hybrid system, Vapour Absorption system and Vapour Compression Refrigeration systems are coupled together to form a single system, which yields into better performance. Utilizing this concept into actual can be proved beneficial as some part of engine work is conserved, but the increased cost of the automobile could be the matter of concern. As it is common experience that cabin or truck driver is a warm place, thus a unpleasant seat to take, condition can be improved by cooling the car cabin without expense of any mechanical energy and hence the fuel. Implementation of above system into trucks would not only result into exhaust heat recovery but also in safe driving. Another application of mentioned refrigeration system can be put into providing a small capacity Refrigerator in car, which might be helpful in conserving the quality of food products and fluids, during long journeys. It has been highly noticed that proper selection of materials for various components is very necessary for good performance. A very Economical and Practical Innovation can be developed by combining mentioned refrigeration system and Catalytic Converter. Very Important limitation of system is explosive nature of hydrogen gas, which might be proved very harmful if leaked.

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