DEVELOPMENT OF VAPOUR ABSORPTION REFRIGERATION SYSTEM IN AUTOMOTIVE TRUCKS FOR COLD STORAGE

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Abstract: ***In general vapour compression refrigeration (VCR) system there are several drawbacks which we are resolving by developed vapour absorption refrigeration (VAR) system. This developed vapour absorption refrigeration system is for automotive truck cold storage. This document gives information about how much important is waste heat and using this we can develop a refrigerant system without taking input from battery, also design is developed based on vapour absorption refrigeration system which demands for future. This system is works on exhaust gas of vehicle. It can reduce the temperature of cold storage up to -11˚c compare to VCR system which can reduce temperature up to -1˚c.***

Index Terms - **Vapour absorption refrigeration, Truck VAR System, New VAR system, Truck cold storage.**

I. INTRODUCTION:

In India road transport is a major mode of transport for goods over large distances. The atmospheric temperature in some parts of India touches 45˚C.In such condition studies shows that the temperature inside the cabin of a transport truck even exceeds 55˚C (Alam, 2006) [1]. The operation in such hot condition for the truck driver is extremely difficult. Further this extreme heat reduces the working efficiency of the drivers and delays the transport duration over the road. The delay further affects the economy, which is unacceptable. So some measures have to be taken to reduce the temperature inside the cabin of the truck and to provide comfort to the driver. Considering present energy crises all over the world, it is very much necessary to explore new technology and potential to satisfy the need of society. At the same time the efficient management of the production and energy conservation is also equally important. In case of truck large amount of heat as input around 25% of the total heat supplied is going away with exhaust gases at very high temperature and around 25% is going away with cooling water. So if this waste heat can be utilized for powering an air conditioning system it will be economical and the fuel energy can be used effectively. Considering all the above factors different alternatives have been studied and the vapour absorption system is found to be the most promising alternative. The paper deals with the preliminary design of Ammonia water vapour absorption refrigeration system and a simulation model has been developed for both the systems to predict the performance of the systems, designed for given operating conditions, under various off-design operating conditions.

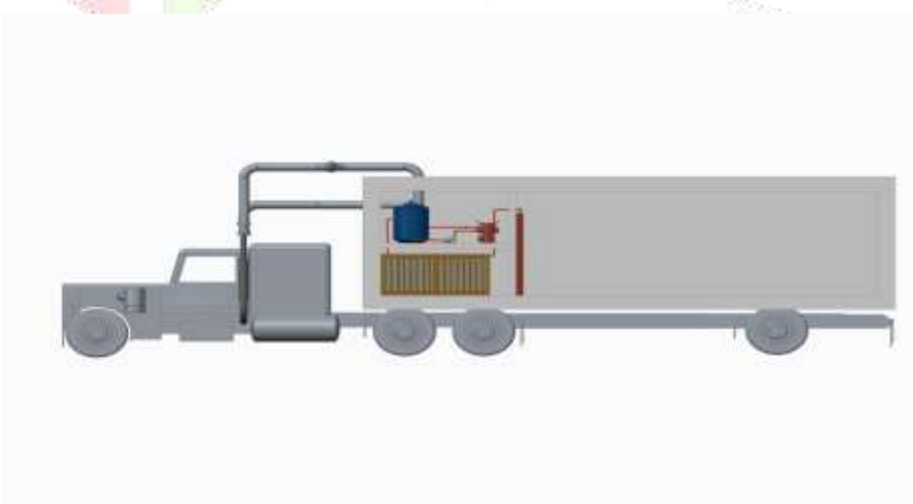

Fig. 1 VAR system truck

The significance of the work is that it will provide space cooling for the truck driver and thereby enhances his performance and efficiency without affecting performance of the engine essentially the fuel economy. Further the vapour absorption cycle use non CFC refrigerant and thereby have little effect on environment.

1.1 LITRATURE SURVEY:

To provide air cooling for the driver of a truck is never given importance in India, the basic reason is the use of available methods of air cooling affects the fuel consumption and the initial cost of the truck. For automobile air conditioning normally vapour compression refrigeration cycle is used. The cycle run on engine power and consumes around 10% of the total power produced by the engine and thereby increases the fuel consumption shown by Lambert and Jones, 2006 [2].Till date, 1 TR VAR system has been neither built practically nor simulated for analyzing the performance of the system because of its low COP (Jacob et al, 2007) [3]. Due to this reason, no information is available regarding the performance of 1 TR VAR system. The work carried out in this project holds significance not only because it shows the practicability of fabricating a 1 TR VAR system for providing cabin cooling of truck by using engine exhaust but also it makes available the information about the performance of such a system under different operating conditions.

1.2 INTRDUCTION OF VAPOUR ABSORPTION REFRIGERATION SYSTEM:

Vapour absorption cycle is a refrigeration cycle (VAR) which produces refrigerating effect by using heat as input and a very little mechanical work is required to operate VAR cycle (figure. 1). The working fluid is usually an Ammonia water or Lithium bromide solution in water. French scientist Ferdinand Carrey developed the first absorption refrigeration machine in 1816.

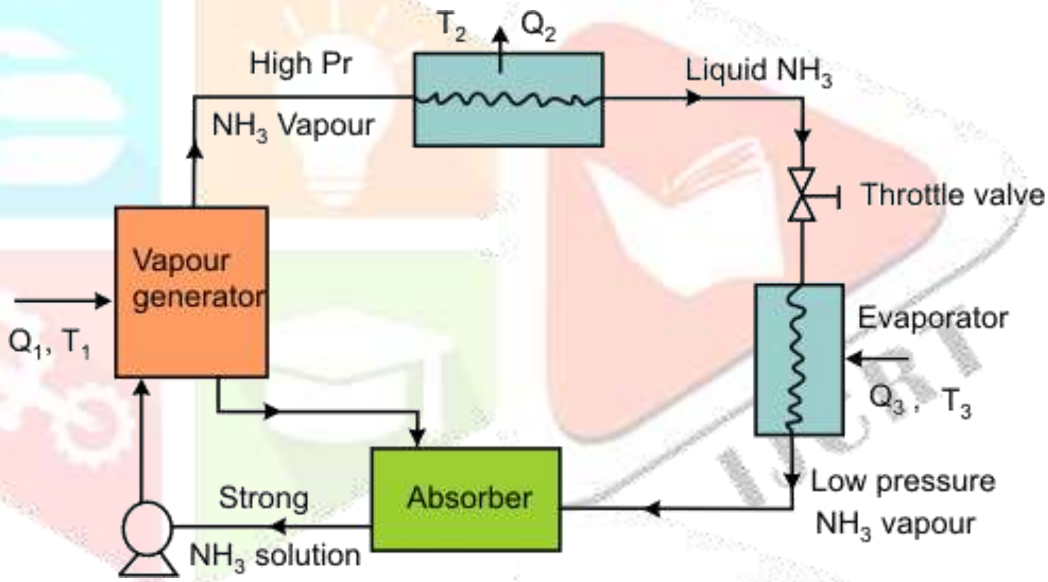

Fig. 2 Vapour absorption refrigeration cycle

Practically the VAR cycle were first developed as Ammonia water system around the start of the 20th century with the Lithium Bromide system around. Since the 1950's (Monique, 1991) [4], A historic perspective shows that air conditioning of building has been practiced from about 120 years and the first systems were heat driven absorption system (Wicks, 1989) [5] . Vapour absorption cycle could not become popular because of its low Coefficient of Performance (COP). Some efforts have been concentrated towards the improvement in COP of the VAR cycle. Jakob (2007) [2] has presented an experimental investigation work in which average COP of 0.3 at heating inlet temperature of 125˚C was obtained. Some theoretical investigation claims COP of the order of 0.7 to 1. The COP is still well below that of VC cycle. For this reason vapour absorption cycle is mainly used in systems where heat energy is available free of cost like solar energy or waste energy such as exhaust from automobile engines. Since the end of 1970, many kinds of solar air conditioning systems has been developed with technical success. In most of the solar cooling systems hot water driven single stage lithium bromide absorption chillers were commonly used. Relying on the success of the above systems, an integrated solar cooling and heating systems was constructed for cooling capacity of 100 kW successfully. (Sumathy et al, 2001) [6], (Bell et al, 1996) [7]. Some efforts have been made to integrate absorption and vapour compression systems. Results show that some efforts were successful to achieve a good value of COP driven by solar energy (Riffat and Shankland, 1993) [8]. Salim Munther (2001) [9] in his theoretical study and analysis has claimed that exhaust heat energy is capable of powering and producing cooling effect up to 1.4 tons of refrigeration using VAC. A broadband prototype of an absorption system for truck refrigeration for the transported food stuff by using heat from the exhaust gases was designed, built and tested. Measured C.O.P. values of the less optimized single stage ammonia water absorption cycle varied between 23 to 30 % (Koehler, 1997) [10]. A procedure has been presented for the thermodynamic analysis of a combined naturally aspirated diesel engine and absorption refrigeration machine. (Mostafavi and Agnew 1997) [11].Venkatesh and Praveen (2005) [12] have suggested that it is possible to drive a vapour absorption refrigeration system for air conditioning of a car using the exhaust gases from the engine. A case study for "Honda city ex" has been presented in which a cooling potential of 2.5 T has been justified. A dynamic simulation of an ammonia water absorption system has been presented for 10.5 kw. absorption systems (Kim and Park, 2007) [13].An optimization analysis is presented for estimating the proper size of absorption type automotive air conditioning system that use waste exhaust heat as input.

1.3 AMONIA - WATER ABSORPTION CYCLE:

An Absorption Cycle can be viewed as a mechanical vapour-compression cycle, with the compressor replaced by a generator, absorber and liquid pump. Absorption cycles produce cooling and/or heating with thermal input and minimal electric input, by using heat and mass exchangers, pumps and valves. The absorption cycle is based on the principle that absorbing ammonia in water causes the vapour pressure to decrease.

The basic operation of an ammonia-water absorption cycle is as follows. Heat is applied to the generator, which contains a solution of ammonia water, rich in ammonia. The heat causes high pressure ammonia vapour to absorb the solution. Heat can either be from combustion of a fuel such as clean-burning natural gas, or waste heat from engine exhaust, other industrial processes, solar heat, or any other heat source. The high pressure ammonia vapour flows to a condenser, typically cooled by outdoor air.

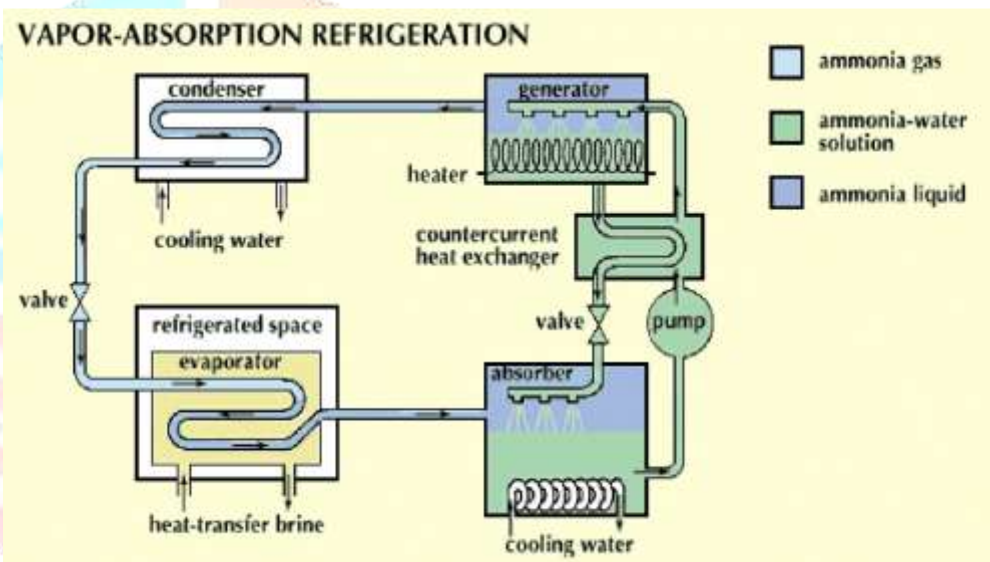

Fig. 3 Ammonia – water based VAR system cycle

The ammonia vapour condenses into a high pressure liquid, releasing heat which can be used for product heat, such as space heating. The high pressure ammonia liquid goes through a restriction, to the low pressure side of the cycle. This liquid, at low pressures, boils or evaporates in the evaporator. This provides the cooling or refrigeration product. The low pressure vapour flows to the absorber, which contains a water-rich solution obtained from the generator. This solution absorbs the ammonia while releasing the heat of absorption. This heat can be used as product heat or for internal heat recovery in other parts of the cycle, thus unloading the burner and increasing cycle efficiency. The solution in the absorber, now once again rich in ammonia, is pumped to the generator, where it is ready to repeat the cycle.

1.4 DESIGN CONSIDERATION OF VAPOUR ABSORPTION REFRIGERATION SYSTEM

1.4.1 PROPERTY OF AMONIA AND CONSIDERATION:

Ammonia is a naturally occurring substance that is produced and used in large quantities (in the US alone 20 million tons per year IPCS, ammonia health and safety guide, publ. World health org. Programmed on chemical safety, Geneva, 1990) for agriculture as fertilizer and as the source material for fibres, plastics and explosive .consequently it is shipped in large quantities by rail and ship. Ammonia is also used as a cleaning and de - scaling agent and food additives. Ammonia is a colourless gas of flow density at room temperature with a pungent smell. It has relative molecular mass of 17.03 and is lighter than air and atmospheric conditions. It can be stored and transported as a liquid under a pressure of 1 MPa 25˚c. The critical point of ammonia is at 132.30c and 11.3 MPa. The critical density is 235 kg/m3 since ammonia is highly soluble in water generating NH4+ and OH- ions, it reacts very quickly with mucus membranes. However, it is not absorbed through the skin. It can be smelled by humans in concentration of very few ppm at about 50 ppm, the order is almost unbearable. This is also the concentration range (25 ppm) to which long-term exposure is limited from an occupational health point of view, (IPCS,1990,ammonia health and safety, Geneva)at high dosages ammonia exposure can be lethal. Ammonia is flammable and explosive in the range of 16 to 25 vol. % (IPCS, 1990, ammonia health and safety, guide, publ. World health org. Programmed on chemical safety, Geneva) in air. The strong order of ammonia can be seen as an asset. It is self alarming. Even very small leak in system are easily noticed and therefore a significant incentive exists for early repairs and consistent maintenance.

One method of leak detection is to use wet indicator paper, which will quickly change its colour once it is exposed to air with a few ppm of ammonia content. However, traditional leak detection devices such soap (or bubble) solutions do not work since the ammonia is dissolved in the water without creating bubbles.

1.5 METHODOLOGY:

VAR truck use for cold storage by using it we can easily travel long distance without Highway Cold Storage as well as without taking many holds.

VAR System has different types of components:

- Evaporator
- Pump
- Absorber
- Generator
- Condenser
- Expansion valve

In which Generator runs by Exhaust gas of the vehicle. Whole VAR system works on Power which developed by Generator.

Figure shown below:

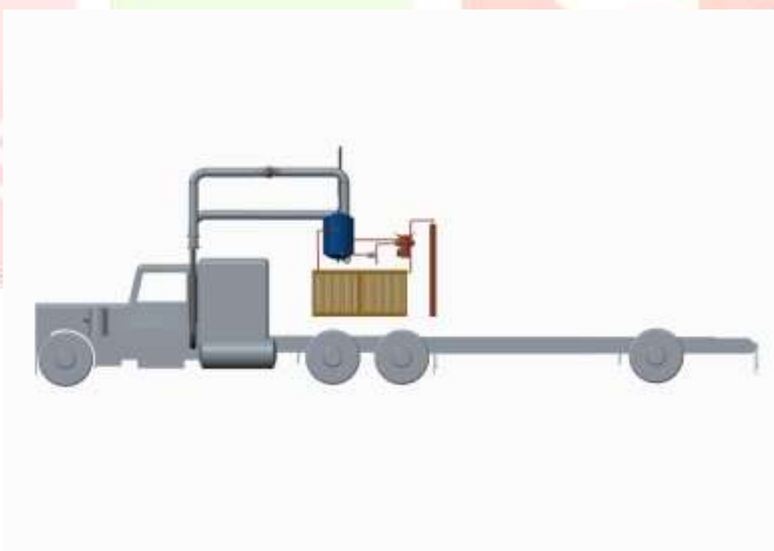

Fig. 4 VAR system truck chassis connect with exhaust manifold

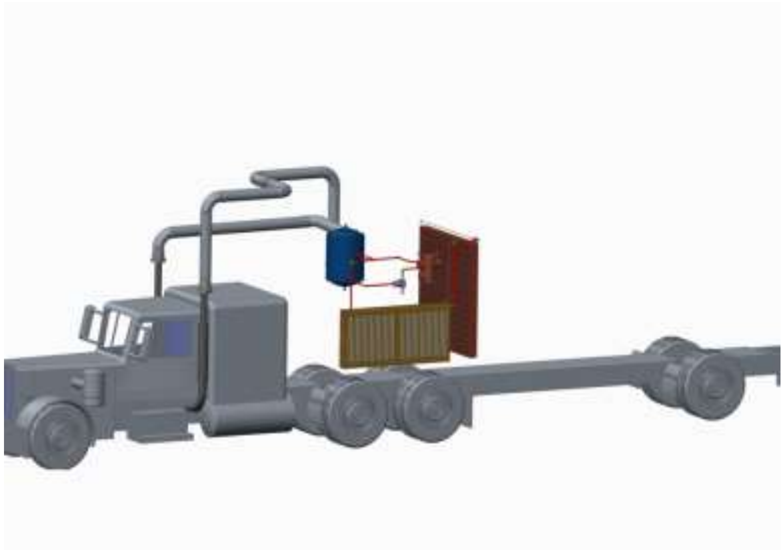

Fig. 5 VAR system truck chassis

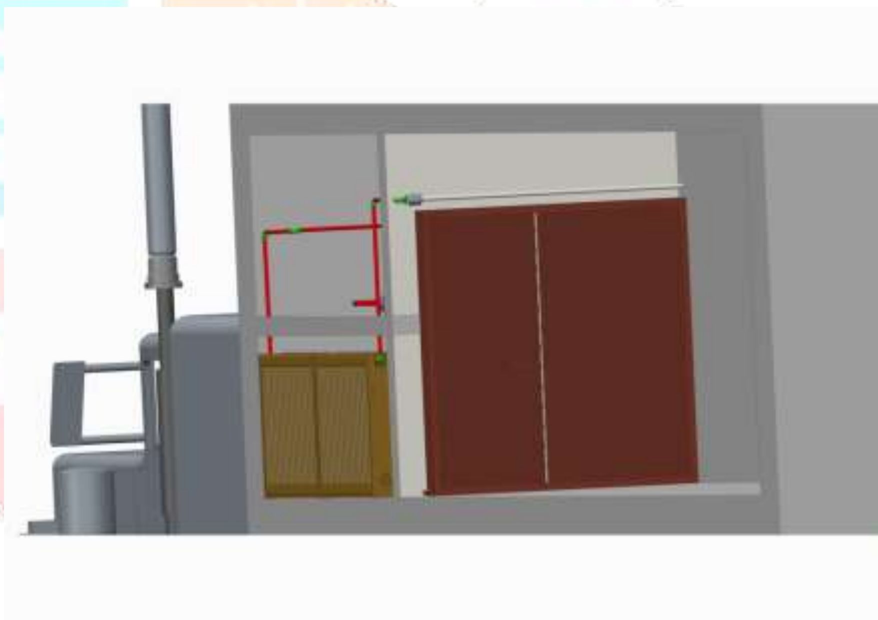

Fig. 6 VAR system truck cold storage compartment

As per shown in figure Generator runs on exhaust gas. Generator will increase pressure in the Refrigerant and then it will be in Condenser. After releasing heat in Condenser, it will be in Expansion valve where refrigerant will be depressurized. Then it will be in evaporator where temperature will drop till -11 ̊C. By this Product will be in good condition for long term.
After that Refrigerant Will is back to generator and again in condenser and so on.
This is how cycle works and if Refrigerant's mixture is not proper then it'll be in absorber again and then in generator.
So, this is how VAR truck is useful and VAR system is more efficient than VCR system.

1.6 THERMODYNAMIC DESIGN:

To perform a thermodynamic analysis for an absorption refrigeration system, the mass and energy balance equations were applied to each component in the absorption system a standard set of condition for Li-Br and ammonia-water system is referred. With reference to the figure and applying the heat balance the operating conditions are obtained for a 1TR VAR system. The limiting conditions are decided. Engine cooling water assumed to be at 95˚C, atmospheric air at 45˚C and exhaust gas temperature at 200 ˚C.

Considering the temperature of evaporator and condenser as the saturation temperature of the refrigerant used, the pressure in the evaporator and condenser are decided.

1.7 HEAT AVAILABLE FROM ENGINE:

Actual heat available from the engine is calculated as follows;

$$FP = mf \times CV$$

Where, mf = fuel mass flow rate
CV = calorific value of the fuel 42000 kJ/kg

Taking 12 litters per hour fuel consumption for a 150 BHP engine. The available heat rejected by the cooling system can be expressed as:

$$Q_{rejected} = 0.3 \times mf \times CV$$
$$Q_{rejected} = 34 \text{ kW}$$

1.8 LOAD CALCULATION:

The cooling load required for cabin cooling is calculated by using standard method of load calculation. The various factors of heat load like solar radiation (roofs, walls, glasses) normal heat gain through glass, normal heat gain through wall, air infiltration, number of persons in cabin sensible heat load, Latent heat load can be calculated using ASHRAE Hand book. (Alam, 2006) [1]. (Venkatesh and Pravin 2005) [12].

Table 1 System observations

Parameter	Value
Cabin Dimensions	(2×1.75×1.5) m3
Ambient Temperature	45 0C
Cabin Temperature without cooling	55 0C
Design temperature of cabin	30 0C
Solar radiation (roof, walls glasses)	300 kJ/hr
Normal heat gain through glasses	1200 kJ/hr
Normal Heat gain through walls	4300 kJ/hr
Air leakage	1000 kJ/hr
Passenger including driver	1200 kJ/hr
Heat radiated from engine	2000 kJ/hr
Total	**10000 kJ/hr**

Total heat load to the truck Cabin is 2.8 kW therefore a cooling system of 1 TR (3.5kW) should be sufficient. A transport truck of 150 B H P is considered and the heat available in exhaust is 50 kW and cooling water = 45 kW (Engine running at 50% of maximum power.)

Heat required for 1 TR with COP 0.2 =17.5 kW.

It is very clear that available heat potential is sufficient and engine cooling water can run the proposed cooling system.

1.9 THERMODYNAMIC ANALYSIS BASED ON VAR TRUCK:

To perform a thermodynamic analysis for an absorption refrigeration system, the mass and energy balance equations were applied to each component in the absorption system.

A standard set of condition for ammonia-water system is referred. With reference to the figure and applying the heat balance the operating conditions are obtained for a 1TR VAR system. The limiting conditions are decided. Engine cooling water assumed to be at 95˚C, atmospheric air at 45˚C and exhaust gas temperature at 200˚C. Considering the temperature of evaporator and condenser as the saturation temperature of the refrigerant used, the pressure in the evaporator and condenser are decided. The other pressures and temperature are decided based on data from references and practical conditions. Values of enthalpy are obtained from Steam Table & Enthalpy Concentration Diagram for Li-Br system and for Ammonia/water system Enthalpy Concentration Diagram & Pressure Temperature Diagram are referred. The configuration of a single effect absorption system is shown in table 2 below.

The system is to operate under following conditions:

Table 2 System observations

Parameter	Symbol	Value
Refrigeration capacity	Qe	3.5 kW
Evaporator temperature	Te	5˚C
Condenser temperature	Tc	55˚C
Generator temperature	T2	200˚C
Heat Exchanger Effectiveness	€	0.70
Generator and condenser	P2	20 bar
Absorber and evaporator	P1	5 bar
Weak solution	X1	0.368
Strong solution	X2	0.268

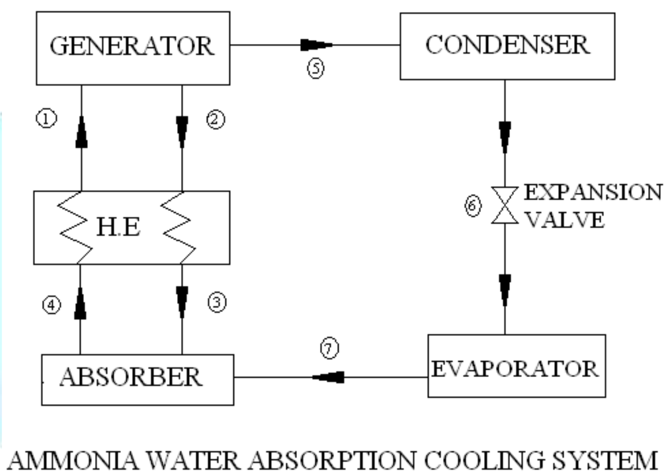

Fig. 7 VAR system truck diagram

In the figure above state points represent the conditions as stated below:

1. Strong solution entering the generator (X1 = 0.368)
2. Weak solution leaving the generator (X2 = 0.268, T2 =200˚C)
3. Weak solution leaving the heat exchanger (X3 =0.268)
4. Weak solution entering the absorber (X3=0.268)
5. Strong solution entering the heat exchanger (X4 = 0.368, T4 =55˚C)
6. Strong solution leaving the absorber (X4 =0.368, T4 =55˚C)
7. Refrigerant vapour leaving the generator (Superheated to 200˚C at the pressure of 20 bar T5 =200˚C, P5 =20 bar)
8. Refrigerant liquid leaving the condenser (Saturated at 55˚C, T6 =55˚C, P6 =20 bar)
9. Refrigerant vapour entering the absorber (Saturated at 5˚C, T7 =5˚C, P7 =5 bar)
10. Refrigerant liquid entering the evaporator (Saturated at 55˚C, T6 =55˚C, P6 =20 bar) Heat and mass balance is applied to each component to determine the heat transfer and mass flow rates.

Table 3 Properties of absorbent and refrigerant at various state points

State	h(kJ/kg)	T(˚C)	m(kg/hr)	X
1	478.1	158	92.88	0.368
2	750	200	80.28	0.268
3	260	98.5	80.28	0.268
4	20	55	92.88	0.268
5	1447.76	200	12.726	1
6	290	55	12.726	1
7	1280	5	12.726	1

2. RESULT:

Brief summary of the parameters required for plotting the graph to determine the characteristics from the plot. The performance of system under operating conditions has been studied by varying the generator and condenser temperatures. The results of generator and condenser temperature variation on COP by different components of the system are presented in form of several graphs as shown.

Table 4 Generator load of system for different generator and condenser temperature

Generator temperature (˚c)	**Condenser temperature (˚c)**					
	50	**54**	**58**	**62**	**66**	**70**
150	9.919	10.08	10.24	10.41	10.58	10.77
160	10.01	10.17	10.33	10.5	10.68	10.86
170	10.09	10.25	10.42	10.59	10.77	10.95
180	10.18	10.34	10.51	10.68	10.86	11.05
190	10.26	10.43	10.6	10.77	10.95	11.14
200	10.35	10.52	10.69	10.87	11.05	11.24

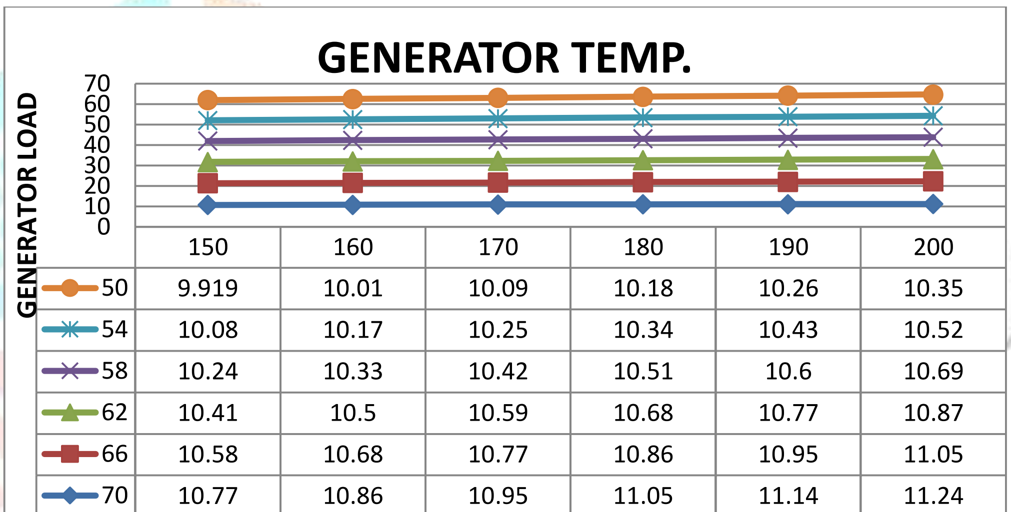

Fig. 8 Generator load vs. generator temperature for different condenser temperature

- The performance of a system under operating conditions has been studied by varying the generator and condenser temperatures. The results of generator and condenser temperature variation on COP of the system are presented in form of several graphs as shown.
- The results indicate that the COP of single effect ammonia/water system varies from 0.3528 to 0.3113, under different operating conditions being simulated. However this variation is marginal.
- From above, it can be concluded that, for providing cabin cooling for truck using engine exhaust, vapour absorption systems can be used i.e. ammonia/water vapour absorption cycle.

3. CONCLUSION:

Vapour Absorption Refrigeration system is more effective than Vapour Compression Refrigeration system because it decreases temperature till -11 ̊C and also we eliminate use of Highway Cold Storage. Because of this we developed this System.

The heat load on the generator can be met very easily by using the engine exhaust for both the systems as available energy rejected by cooling system of truck engine is more than sufficient. Even with a minimum assumed COP of 0.2, the required input to generator is 17.5 kW, while waste heat available is 34 kW. Hence from the discussion, ammonia/ water vapour absorption system is suggested for the application. Though the COP of the system is less but since waste heat is given as input, it is not a matter of concern.

REFERENCES

[1] Alam S, 2006, "*A Proposed model for Utilizing Exhaust Heat to run Automobile Air-conditioner*", The 2nd Joint International Conference on Sustainable Energy and Environment 21-23 November 2006, Bangkok, Thailand.

[2] Lambert M. A. and Jones B. J, 2006, "*Automotive adsorption air conditioner powered by exhaust heat*". Journal of Automobile Engineering. Vol. 220.

[3] Jakob. U, Eicker. U, Schneider. D and Teuber. A, 2007, "*Experimental Investigation of Bubble Pump and System Performance for a Solar Driven 2.5 KW Diffusion Absorption Cooling Machine*" Heat Set 2007, Heat transfer in components and systems for energy technologies Chambery, France.

[4] Manrique J. A., 1991, "*Thermal Performance of an Ammonia – Water Refrigeration System*", International Comm. Heat Mass Transfer Vol. 18, pp. 779 – 789.

[5] Wicks F, 1989, "*Design and Benefits of a Non-Electric Air Conditioner that Combines Compression and Absorption Cycle", SAE technical paper no. 899180.*

[6] Sumathy. K, Huang. Z. C and Li. Z. F, 2002, "Solar Absorption Cooling with Low Grade Heat source – A Strategy of Development in South China", Elsevier Science Solar Energy Vol. 72, No 2, pp 155 – 165.

[7] Bell I. A, Daini A. J, Ali H. Abdel-Gayed R. G and Duckers L, 1996, "The Design of an Evaporator/Absorber and Thermodynamic analysis of a Vapour Absorption Chiller Driven by Solar Energy" WREC - 1996.

[8] Riffat S. B. and Shankland N, 1993, "Integration of Absorption and Vapor-Compression Systems", Elsevier, Applied Energy 46, 303-316.

[9] Salim M, 2001, "Technical Potential for Thermally Driven Mobile A/C Systems", SAE technical paper, no. 2001 – 01- 0297.

[10]Koehler. J, Tegethoff. W. J, Westphalen. D and Sonnekalb. M, 1997, "Absorption Refrigeration System for Mobile applications utilizing Exhaust Gases", Heat and Mass transfer 32(1997) 333-340.

[11]Mostafavi M and Agnew B, 1997, "Thermodynamic Analysis of Combined Diesel Engine and Absorption Refrigeration Unit – Naturally Aspired Engine with Pre cooling", Elsevier Science Applied Thermal Engineering Vol. 17. No 6. pp. 593-599.

[12]Venkatesan. J, Praveen. V. M, Bhargav. V. K and Moorthy. B. B, 2005, "Performance Improvement in Automotive Engines using Vapour Absorption Refrigeration System for Air Conditioning", SAE technical paper no. 2005-01-3466.

[13]Kim B and Park J, 2007, "Dynamic Simulation of a Single-effect ammonia-water absorption chiller", International Journal of Refrigeration Vol. - 30, 535-545.