Experimental Set up of Air Conditioning System in Automobile Using Exhaust Energy

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ABSTRACT

The refrigeration units currently used in road transport vehicles are predominantly of the vapour compression refrigeration (VCR) type but this work represents study of air conditioning in automobile based on ammonia water vapour absorption system using hot exhaust gases as an energy source. In the study an experimental set up is designed and fabricated to use low grade heat energy i.e. exhaust gases as input heat to the system.

Keywords: *Vapour absorption system, Automobile air-conditioning, hot exhaust gases; etc.*

1. INTRODUCTION

This paper relates to air conditioning system for use in vehicles. It utilizes hot exhaust energy from an engine of an automobile without affecting the operation of vehicle. Automobile air conditioners use a refrigerating mechanism to cool the air inside the vehicle. The air conditioning system used usually in a vehicle is vapour compression refrigeration system. The components of an automobile air conditioning system include (a) refrigerating compressor driven by engine (b) condenser located in front of radiator (c) liquid line to the refrigerant control (d) evaporator and (e) blower duct system to circulate the air inside the vehicle.

The system works by compressing the refrigerant using a compressor, which increases the pressure and temperature of the refrigerant and it vaporizes. The refrigerant is then passed through the condenser where latent heat of the refrigerant is removed and is liquefied. This refrigerant is then passed through the expansion valve where its pressure reduced reducing the temperature. The chilled refrigerant is then passed through the evaporator to produce cooling effect. The blower blows the air through the evaporator to produce the required cooling inside the cabin of vehicle. The refrigerant absorbs the heat of the air and vaporizes, which is then passed through the compressor. Hence cooling effect is produced inside the vehicle. The main disadvantage of such system is that required power to run the compressor is taken from the engine main shaft, hence to maintain the same power the engine has to produce more work consuming more fuel. The air conditioning system used in automobile is shown in figure 1.1.

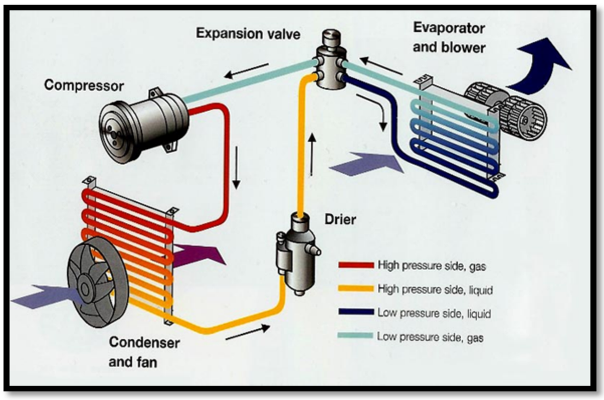

Fig. 1.1 Air Conditioning System Used in Automobiles

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1.1 Air conditioning System

In this experimental set up of vapour absorption refrigeration system is used to produce refrigerating effect. In the vapour absorption refrigeration system, the compressor is replaced by an absorber, a pump, a generator and a pressure reducing valve. The refrigerant, commonly used in the system, is ammonia. The power required for pumping is almost negligible and hence refrigerating effect is obtained from a Vapour Absorption System without any mechanical power being done on it. But the refrigerating effect produced from a Vapour Compression Refrigeration System is comparatively higher than that produced from a Vapour Absorption Refrigeration System of same Capacity. The advantages of vapour absorption system over vapour compression system are many as there is no moving part in the entire system, the operation is essentially quiet and essentially subjected to a very little wear, so that the maintenance cost is very low. The pump motor is comparatively small as compared to the motor required for a compression system of same capacity. The common method used in air conditioning of automobiles is vapour compression refrigeration system. Here in present work vapour absorption refrigeration system ammonia as a refrigerant and water as absorbent is used which is very lucrative option of producing refrigerating effect in automobiles due to availability of heat in hot exhaust coming from engine of automobiles. As an IC engine has an efficiency of about 35-40%, converts only one-third of the energy in the fuel into useful work and about 60-65% is wasted to environment. In which about 28-30% is lost by cooling water and lubrication losses, around 30-32% is lost in the form of exhaust gases and remainder by radiation, etc. For the purpose of study this experiment uses the electrical heating coil equivalent to exhaust temperature. The formulae used

for COP = $= \frac{\text{Heat absorb in evaporator}}{\text{Work done by pump} + \text{Heat supplied in generator}} = \frac{Q_e}{(W_p Q_g)}$

where, Q_e = Heat absorbed in evaporator, W_p =Work done by the pump, Q_g = Heat supplied in generator. The schematic diagram of vapour absorption system is shown at fig. 1.2 below.

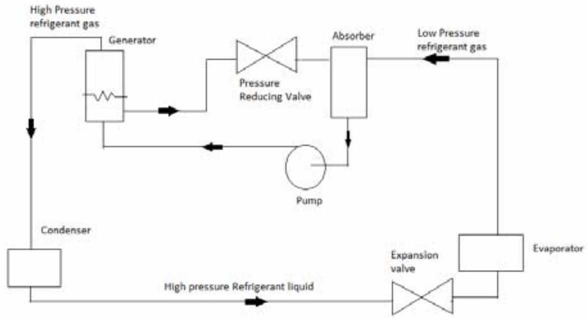

Fig. 1.2 Schematic Diagram of Vapour Absorption System

1.2 *Refrigerants*

The refrigerant is heat carrying medium which during their cycle (i.e. compression, condensation, expansion and evaporation) in the refrigeration system absorb heat from a low temperature system and discard the heat so absorbed to a higher temperature system. The suitability of a refrigerant for a certain application is determined by its physical, thermodynamics, chemical properties and various practical factors. Refrigerants are classified into two groups viz. Primary refrigerants and Secondary refrigerants. Primary refrigerants are further classified into group like Halo-carbon refrigerants, Azeotropic and azeotropic mixture, Inorganic refrigerants, Hydrocarbons and derivatives, Organic compounds. The inorganic refrigerants shall be assigned a number in the 700 series, identification numbers are formed by adding the relative molecular mass of components to 700. Some of the inorganic refrigerants are shown in table 1.

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Table :1. Inorganic refrigerants

Refrigerants No,	Chemical formula	Chemical Name	Boiling Temp. (^oC)	Freezing Temp. (^oC)
R-717	NH_3	Ammonia	-33.3	-78
R-729	-	Air	-	-
R-744	CO_2	Carbon Dioxide	-73.6	-
R-764	SO_2	Sulphur Dioxide	-10	-
R-118	H_2O	Water	100	0

2. FABRICATION OF THE EXPERIMENTAL SET UP

2.1 Generator

Generator is simply type of heat exchanger in which heat is transferred from external sources to vaporise the ammonia from rich aqua-solution. During the heating process, the ammonia vapour is driven off the solution at high pressure leaving behind the hot weak ammonia solution in the generator. This weak solution flows back to the absorber at low pressure after passing through the pressure reducing valve. The high pressure ammonia vapour from the generator is condensed in the condenser to the high pressure liquid ammonia. This liquid ammonia is passed to the evaporator through expansion valve. In this experimental set up heat is supplied to the generator from electric heater (equivalent to exhaust energy).

Specification: Outer diameter of generator = 33 mm, Inner diameter of generator = 27 mm, Diameter of hole (1) =11mm, Diameter of hole (2) = 5 mm, Diameter of hole (3) = 6 mm, Diameter of pressure nut hole (4) = 9 mm, Length of the pipe = 760 mm, Thickness of pipe = 3 mm.

Both end of the GI pipe is closed by iron lockers. On the surface of GI pipe four holes of different diameters are drilled. The half size union, quarter size union, five-eight union and a pressure nut are connected to it by gas welding process using brass as filler metal to prevent the leakage of gas from GI pipe. This tube is covered by a high temperature insulation tape before heating coil is wound on it to connect with electric connection. The heating coil is further covered to reduce the heat losses.

Fig 2.1 Diagram of Generator

2.2 Analyser

When ammonia is vaporized in the generator, some water is also vaporized and will flow into the condenser along with the ammonia vapours in the simple system. If these unwanted water particles are not removed before entering to the condenser, they will enter to the expansion valve where they freeze and choke the pipeline. In order to remove these unwanted particles flowing to the condenser, an analyser is used. The analyser may be built as an integral part of generator or made as a separate piece of equipment. It consists of a series of trays mounted above generator. The strong solution from the absorber and the aqua from the rectifier are introduced at the top of the analyser and flow downward over the trays and into the generator. In this way, considerable liquid surface area is exposed to the vapour rising from the generator. The vapour is cooled and most of the water vapour condensed, so that mainly ammonia vapour leaves the top of analyser. Since the aqua is heated by the vapour, less external heat is required in generator.

Fig 2.2 Diagram of Absorber

2.3 Absorber

In the absorber the low pressure ammonia vapour leaving the evaporator enters and is absorbed by the cold water. The water has the ability to absorb very large quantities of the ammonia vapour and the solution thus formed, is known as aqua-ammonia. The absorption of ammonia vapour in water lowers the pressure in the absorber which in turn draws more ammonia vapour from the evaporator and thus raises the temperature of solution. Some form of cooling arrangement (usually water cooling) is employed in the absorber to remove the heat of solution evolved there. This is necessary in order to increase the absorption capacity of water, because at higher temperature water absorbs less ammonia water. Absorber is made of galvanised iron sheet and having cylindrical shape by riveting and brazing. **Specification:** Length of absorber = 762mm, Diameter of low pressure ammonia suction hole = 11mm, Diameter of discharge strong solution hole = 11mm, Diameter of PRV hole = 6mm, Diameter of filling water hole = 10mm

On a circular GI pipe the suction and discharge hole with flare nut and union by means of gas welding process are joined and one end of absorber is connected with discharge of evaporator (low pressure ammonia) and another end of absorber is connected with suction of pump (strong ammonia solution). One hole of the absorber connects with pressure reducing valve for taking low pressure vapour ammonia and another hole connects with the valve which controls the pressure of aqua-ammonia solution.

2.4 Heat Exchanger

The heat exchanger provided between the pump and generator is used to cool the weak solution returning from the generator to absorber. The heat removed from the weak solution rises the temperature of the strong solution leaving the pump and going to analyser and generator. This operation reduced the heat supplied to the generator and the amount if cooling required or the absorber. Thus the economy of the plant increases. The heat exchanger provided between the condenser and the evaporator may also be called liquid sub-cooler. In this heat exchanger, the liquid refrigerant leaving condenser is sub-cooled by the low temperature ammonia vapour from the evaporator. This sub-cooled liquid is now passed to the expansion valve and then to the evaporator. In this experimental set up heat exchanger is not used.

2.5 Evaporator

Evaporator is simply a cooling chamber which consists of a coil of pipe in which the liquid vapour at low pressure and temperature is evaporated and change into vapour refrigerant at low pressure and temperature. In evaporating, the liquid vapour refrigerant absorbs its latent heat of vaporisation from the medium (air, water or brine) which is to be cooled. **Specification:** Diameter of suction hole = 6mm, Diameter of discharge hole = 11mm.

There are two holes in the evaporator in which one hole is connected with suction of absorber for taking low pressure liquid ammonia and another hole is connected a receiver dryer. A regulator is provided on an evaporator which regulates the flow of cold air.

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Fig 2.3 Evaporator and Expansion Device

2.6 Expansion Devices

It is also called throttle valve or refrigerant control valve. The function of the expansion valve is to allow the liquid refrigerant under high pressure and temperature to pass at a control rate after reducing its pressure and temperature. Some of the liquid refrigerant evaporates as it passes through the expansion valve, but the greater portion is vaporised in the evaporator at the low pressure and temperature. The expansion devices which are used in industrial and commercial refrigeration and air conditioning system are viz. capillary tube, hand operated expansion valve, automatic or constant pressure expansion valve, thermostatic expansion valve, low side float valve, high side float valve.

2.7 Condenser

The condenser or cooler consists of coils of pipe in which high pressure and temperature vapour refrigerant is cooled and condensed. The refrigerant, while passing through the condenser, gives up its latent heat to the surrounding condensing medium which is normally air or water. In condenser super-heated vapour is cooled to saturation temperature (called de-superheating) corresponding to the pressure of the refrigerant then saturated vapour refrigerant (called condensation). Then the temperature of the liquid refrigerant is reduced below its saturation temperature (i.e. sub-cooled) in order to decrease the refrigeration effect.

The heat transfer capacity of a condenser depends upon material, amount of contact and temperature difference. The heat transfer capacity of a condenser greatly depends upon the temperature difference between the condensing medium and vapour refrigerant. As the temperature difference increases, the heat transferred rate increases and therefore the condenser capacity increases. According to the condensing medium used the condensers are classified in to three groups viz. Air cooled condensers, Water cooled condensers and Evaporative condensers. **Specification:** Diameter of suction hole = 6 mm, Diameter of discharge hole = 10 mm.

Fig 2.4 Condenser and Connecting Pipes

2.8 Connecting Pipes

In vapour compression system generally the chloro-fluro refrigerants is used. The tubing is made of copper or aluminium. But in this experiment ammonia as refrigerant is used which has great affinity with steel (reacts with copper) therefore instead copper tubing steel tubing should be used. In this experiment aluminium tube is used.

2.9 Digital Thermometer

Digital thermometer is the devices which are used to measure the temperature. Another device which is used measure the temperature is thermocouple. Thermocouples for practical measurement of temperature are junctions of specific alloys which have a predictable and repeatable relationship between temperature and voltage different are alloys are used for different temperature ranges. Thermocouples are usually standardized against a reference temperature of 0^0C; practical instruments use electronic method of cold junction compensation to adjust for varying temperature at the instrument terminals.

2.10 Receiver Drier

The receiver-drier is used on the high side of systems that use a thermal expansion valve. This type of metering valve requires liquid refrigerant. To ensure that the valve gets liquid refrigerant, a receiver is used. The primary function of the receiver-drier is to separate gas and liquid. The secondary purpose is to remove moisture and filter out dirt.

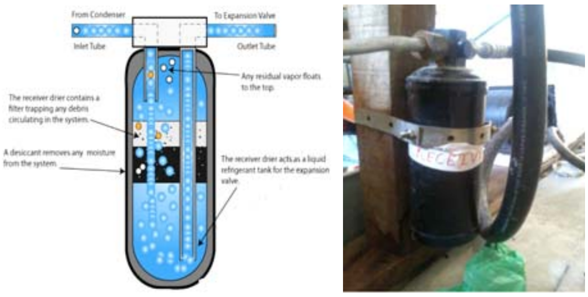


Fig 2.5 Reciever Drier

2.11 Pump

Pump converts the mechanical energy from a motor to energy of a moving fluid; some of the energy goes into kinetic energy of fluid motion, and some into potential energy, represented by a fluid pressure or by lifting the fluid against gravity to a higher level. When a strong solution of the refrigerant-absorbent (ammonia-water) is formed, this solution is pumped by the pump at high pressure to the generator. Thus pump increases the pressure of the solution to about 10 bars.

Fig 2.6 Pump

2.12 Insulation Tape and Sealant

A high temperature bearing tape is used to insulate tube. An adhesive tape is combination of two material asbestos and clothes. It bears approximate 500 to 600^0C. An adhesive sealant is used to hold the asbestos industrial insulating tape on a GI pipe.

2.13 Heating Coil

Heating coil is used to generate heat. It is made of nichrome and molybdenum. It has a 1500 watt and 250 AC/DC voltages. It generates approximately 300 - 400°C. Nichrome is a non-magnetic alloy of nickel, chromium, and often iron, usually used as a resistance wire. A common alloy is 80% nickel and 20% chromium, by mass, but there are many others to accommodate various applications. It is silvery-grey in colour, is corrosion-resistant, and has a high melting point of about 1400 °C. Typically, Nichrome is wound in coils to a certain electrical resistance, and current is passed through to produce heat.

2.14 Drier or Rectifier

Filter-driers play a pivotal role in the operation of air conditioning and refrigeration systems. At the heart of the unit the desiccant is held in its cylindrical metal container. The word desiccate means to dry out completely and a desiccant is a material or substance that accomplishes the moisture removal. The filter-drier is an accessory that performs the functions of filtering out particles and removing and holding moisture to prevent it from circulating through the system.

Fig 2.7 Rectifier

The experimental set up is assembled like absorber one end is connected to the evaporator and other end to the pump. Further, thereafter the pump is connected to the inlet of generator through rectifier, condenser receiver drier inlet and receiver drier to evaporator. A pressure gauge provided on generator with the help of pressure nut. A P.R.V or expansion device connected between generator and absorber which hold the weak solution of the ammonia. A sump provides under the absorber which hold water for cooling of absorber with help of water pipe which turns on the absorber and goes to the sump again. A valve is mounted on the evaporator for charging of ammonia gases. In our experimental set up all the components which are driven by electric, are connected with the help of bridge rectifier and electric switch. Three digital thermometers are provided on condenser, generator and evaporator for measuring the temperature. For calculation of COP, first plug ON the system and leave for ten minutes for maintaining the temperature of generator with water pump switch OFF. After that switch ON the water pump and measure the temperatures of experimental set up at different conditions. The observed readings of experimental set up are tabled at Table 1.2 ahead and based on the readings the variation of COP at different temperature of generator, evaporator and condenser are shown in figure 3.1, 3.2 and 3.3 respectively.

3. RESULTS AND DISCUSSION

In the experimental set up the high pressure ammonia vapour enters the condenser, where it transfers heat to the neighbourhood. Liquid ammonia leaves the condenser and passes through an expansion valve, reaching the evaporator pressure. The refrigerant then enters the evaporator, where it receives heat from the cold source, turning into low pressure vapour. In the sequence, ammonia vapour enters the absorber, where a weak solution of water and low concentration ammonia absorbs the refrigerants and, at the same time, transfer heat to the neighbourhood. This solution has now a high ammonia concentration, and is pumped to the vapour generator, where it receives heat from a hot exhaust. Ammonia in the solution then evaporates, separating from water and flowing to the condenser to start a new cycle. A weak water-ammonia solution leaves the vapour generator and enters the absorbers to absorb ammonia vapour from the evaporator. The absorption refrigeration system instantaneous coefficient of performance (COP) is given by $COP = Q_{ref} / Q_{hc,}$ where Q_{ref} is the rate of absorption system instantaneous cooling capacity (W) and Q_{hc} is the rate of instantaneous heat transfer from the energy source (here hot exhaust gases of the engine is used) to the absorption refrigeration system.

The experiment considered to be implemented on an engine of an automobile for analysis while vapour absorption refrigeration system is retrofitted has specification like TATA MOTORS: Model: - TATA INDICA VISTA TURBO, Engine Type- 475IDI turbo, Capacity (displacement) - 1405cc (85.7cu inch), Power- 71P5 (52KW, 70HP)@4500rpm, Torque – 135N-m (100ft-1bf)@2500rpm, No of Cylinder- 4, Fuel Type- Diesel, Fuel System- 1DTC, Wheel Size- 14inch (360mm), Tyres- 175/65 R14 (tubeless), Ground clearance- 165mm (6.5 inch), Air-Fuel Ratio (A/F) - 15:1

The heat carried away by the exhaust gas at higher temperature is utilised and a required approx temperature of 80-85^{0}C is considered equivalent to heat generated through heating coil in the generator for separating ammonia from water and this heat required in the generator is

$$Q = m_{ammonia} C_p \Delta T = 0.003 \times 4.6 \times 133 = 1.8354 \text{ KW}$$

The heat required in generator is 1.8354 KW where mass flow rate of ammonia ($m_{ammonia}$) is 0.19 kg/min (0.003 kg/s), Specific Heat of ammonia, C_p is 4.6kJ/ kg K; and temperature difference between ammonia & water is 133^{0}C.

If the refrigeration of system is of 0.5 ton and the temperature of generator (T_G) = 85^{o}C, temperature of condenser (T_C) = 40^{o}C and temperature of evaporator (T_E) = 20^{o}C, then COP is 1.841 as given below:

$$COP = \frac{\text{Heat absorb in evaporator}}{\text{Work done by pump} + \text{Heat supplied in generator}} = \left(\frac{T_E}{T_C - T_E}\right)\left(\frac{T_G - T_C}{T_G}\right)$$

= (293/ (313-293)) ((358-313)/358) = 1.841

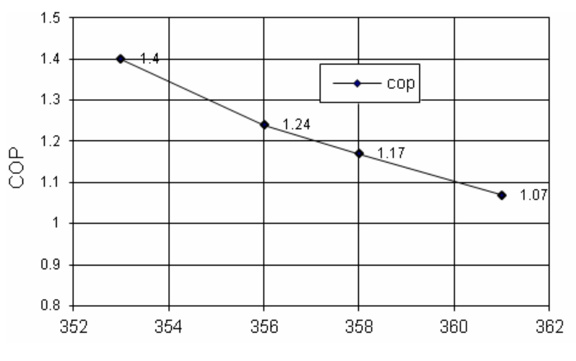
When several readings are taken in terms of the temperatures $T_{G,}$ T_C and T_E of the experimental set up the COP of the experimental set up varied as shown in the table below:

Table 1.2 Temperature and COP of the System

Readings	$T_{G,}$ (K)	$T_{C,}$ (K)	$T_{E,}$ (K)	COP
1st	353 (80^{0}C)	318 (45^{0}C)	297 (24^{0}C)	1.40
2nd	356 (83^{0}C)	320 (47^{0}C)	296 (23^{0}C)	1.24
3rd	358 (85^{0}C)	321 (48^{0}C)	295 (22^{0}C)	1.17
4th	361 (88^{0}C)	322.7 (49.7^{0}C)	293.6 (20.6^{0}C)	1.07

3.1 Variation of Cop with Generator Temperature

The optimum value of the generator adopted is 80-85^{o}C. The fig. 3.1 shows that as the value of generator temperature increases then there is linear fall in the value of the C.O.P of the system. At temperatures of 353K, 356K, 358K and 361K the C.O.P values of the system are 1.40, 1.24, 1.17 and 1.07 respectively which reveals COP $\alpha \frac{1}{T_g}$, where COP is coefficient of performance and T_g is generator temperature.

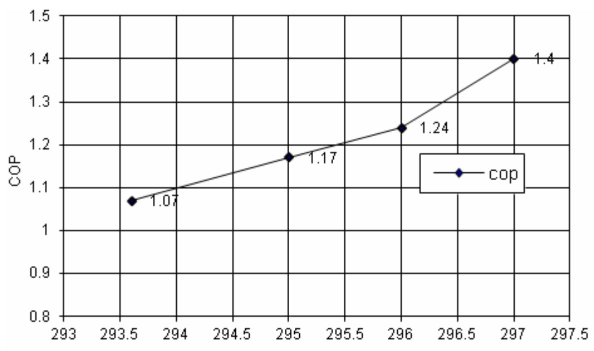


Generator Temperature, K

Fig. 3.1 Variation of COP with Generator Temperature

3.2 Variation of Cop with Evaporator Temperature

Contrary to fig.3.1 the fig. 3.2 shows the variation of COP with evaporator temperature. Here as evaporator temperature increased the practical COP of the system also decreases as shown in the figure that at different evaporator temperature 297K, 296K, 295K and 293.6K COP is 1.4, 1.24, 1.17 and 1.07 respectively. From the calculation and graph it is shown that practical COP of the system increases and COP T_e, where COP is Coefficient of Performance and T_e is evaporator temperature.



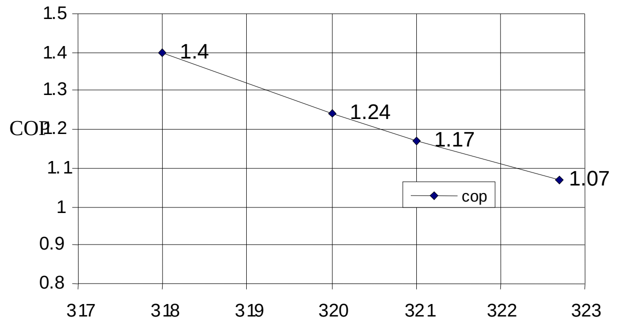
Evaporation Temperature, K

Fig. 3.2 Variation of COP with Evaporation Temperature, K

3.3 Variation of COP with Condenser (T_c) Temperature

In the figure 3.3 below it is evident that as the condenser temperature increases the C.O.P of the system decreases. At temperatures 318K, 320K, 321K and 322.7K the COPs are 1.4, 1.24, 1.17 and 1.07 respectively. Hence it is understood that COP

$\alpha \frac{1}{T_c}$, where COP is Coefficient of Performance and T_C is condenser temperature.



Condenser Temperature, K

Fig. 3.3 Variation of COP with Condenser Temperature, K

4. CONCLUSION

Based on the result and discussion and observation the following conclusions are drawn:

- This is new technique to be used in automobile air conditioning, industrial refrigeration and air conditioning system especially in food preservation.
- This experimental set up is based on utilization of waste exhaust heat of an automobile.
- COP is further increased provided heat loss is curbed down to minimum and heat exchangers are fitted.
- The heat required in generator can be saved up to 33% by using hot exhaust gases as an energy source.
- Either the decrease in the temperature of evaporator or the increase in temperature of generator, the COP of the system decrease respectively.
- The minimum condenser temperature to increase the refrigerating effect of the automobile air conditioning system.
- This kind of arrangement in an automobile as an air conditioner will utilize the waste heat of the engine to increase the thermal efficiency as well as overall efficiency of the engine.

- With small modification retrofitting kit, it is possible to produce refrigerating effect in the cabin through this system using the waste exhaust heat from the engine.
- Using heat exchangers, analyser, and pre-heater the COP of the system further improves. Even by using two evaporators the effectiveness of the system can be increased

REFERENCES

[1] Absorption refrigeration and air conditioning system (US document no. 3661200) by Thomas J.McNamara, 317 Harding Ave Des Plaines, III, 60016.

[2] Refrigeration, heating and air conditioning system for vehicles by Avigdor zur, Itzhak Shechtman, both of Haifa, Israel.

[3] Performance Improvement in Automotives Engines using Vapour Absorption Refrigeration System for Air Conditioning (document no. 2005-01-3466, published at date September 2005) by Jayaraman Venkatesam, Bhargav V.K., V M Praveen, Bharat B Moorthy (all from Sri Venkateswara college of engineering).

[4] Andre Aleixo Manzela, Sergio Morais Hanriot, Luben Cabezas-Gomez, Jose Ricardo Sodre a PETROBRAS, exploration and production, Av. Rui Barbosa, 1940-3_andar, 27915-012 Macae-RJ,Brazil.

[5] Tamura, T.Yakumaru, Y.and Nishiwaki, F. (2005) Experimental study on automotive cooling and heating air conditioning system using CO2 as a refrigerant. Int. J. of Refrigeration, 28, (8), pp. 1302-1307.

[6] Inoue et al. (2006) have described an air-conditioner that uses the cooling water of an internal Combustion engine, which includes a compressive refrigerator and an absorption type refrigerator.

[7] A.C.Deshpande, R.M.Pillai,” Absorption Air Conditioning for Automobile using Waste Heat recovered from Exhaust Gases,” icetet,pp.19-24.2009 Second International Conference on Emerging Trends in Engineering & Technology,2009.

