

# Air conditioner using engine exhaust heat

[Environment](#), [Air](#)



This paper describes the development possible in the field of vehicle air conditioning based on vapour absorption cooling. The cooling effect is produced by waste heat energy recovered from engine exhaust. The advantages of such a system are drastic reduction of fuel over consumption and emissions associated with vehicle air conditioner usage. The current air conditioning system used in automobile is based on vapour compression cycle which necessarily consists of a compressor driven by engine output and thus increases fuel consumption rate and pollution proportion. The introduction of vehicle air conditioning using vapour absorption cycle eliminates the need for compressor; here compressor is replaced by generator and absorber unit. Engine waste heat from exhaust gases is used as heat source for generator of vapour absorption system. This paper describes the development possible in the field of vehicle air conditioning based on vapour absorption cooling. Some limitations are outlined and suggestions for future improvement are pointed out.

Keywords - Vapour Absorption Refrigeration Cycle, Vapour Compression Refrigeration Cycle.

Introduction Motivating factors for the designing this system is continuous optimization of the performance of internal combustion engines and the increasing utilization of air conditioning in vehicles, as it reaches the status of essential need for modern life. Internal combustion engines are potential energy sources for absorption refrigeration systems, as about one third of the energy availability in the combustion processes wasted through the exhaust gas. Thus, use of the exhaust gas in an absorption refrigeration system can increase the overall system efficiency.

<https://assignbuster.com/air-conditioner-using-engine-exhaust-heat/>

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. It 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 engine exhaust as source of generator for VARS.

### **Introduction to VARS: –**

### **Figure 1 Schematics of Ammonia Water Absorption Refrigeration System**

Fig. 1 shows a schematic of the basic aqua-ammonia refrigeration cycle.

High pressure ammonia vapor enters the condenser, where it transfers heat to the neighborhood. 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 vapor. In the sequence, ammonia vapor enters the absorber, where a weak solution of water and low concentration ammonia absorbs the refrigerant and, at the same time, transfers heat to the neighborhood. The solution has now a high ammonia concentration, and is pumped to the vapor generator, where it receives heat from an external source. The 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 vapor generator and enters the absorber to absorb

ammonia vapor from the evaporator. A heat exchanger between the absorber and the vapor generator transfers heat from the weak solution leaving the vapor generator to the high ammonia concentration solution going into the vapor generator.

The coefficient of performance (COP) of the absorption system is usually much lower in magnitude than the compression system. But this low value of the former is not of much importance since it uses the waste heat such as engine exhaust heat. The most important thing about VARS is even if the evaporator temperature falls, the same COP can be maintained by elevating the generator temperature. Hence the capacity of the system remains almost the same.

### **Design procedure of heat extraction device: –**

Since VARS is a heat-operated cycle, we need a heat extraction device to extract heat from a high temperature source and to deliver this heat to the generator of the system. In order to enhance the performance of the refrigeration cycle, we need to optimize the design of the Heat Extraction device. Because of its simplicity in operation, less installation as well as maintenance cost, we select a Heat Exchanger as a heat extraction device.

C: Users\LENOVODesktop\A4\heatex. jpg

### **Figure 2- Schematic of Heat Exchanger**

In order to find the dimensions of the Heat Exchanger, we have to assume a certain cooling capacity of the cooling system. Let's assume it as 2.5 kW

that is  $Q_{ref} = 2.5 \text{ kW}$ . Calculations for Heat Extraction Device that is in our case a Heat Exchanger are as follows

Calculation for Ammonia site: -

Calculation of mass flow rate

$$Q_{ref} = \dot{m} \cdot c_p \cdot (T_g - T_e) \quad \text{--- (1) Where } c_p \text{ - specific heat capacity}$$

$T_g$  - Temperature of the generator

$T_e$  - Temperature of evaporator

$\dot{m}$  - Mass flow rate

From this equation we can determine mass flow rate of refrigerant.

Calculation of velocity

$$\dot{m} = A \cdot v \cdot \rho \quad \text{--- (2)}$$

Where,  $\rho$  = density of the refrigerant (taken from design data book)

A - Flow Area for Refrigerant Ammonia

In order to find A we have to take diameter of the tube according to availability in the market. "v" is the velocity of the refrigerant .

Calculation of Reynolds number

$$Re = (\rho \cdot v \cdot D) / \mu \quad \text{--- (3)}$$

Where D = diameter of the refrigerant tube

$\mu$  = dynamic viscosity of refrigerant at mean temperature (taken from design data book)

Calculation of Prandtl number

$$\text{Pr} = (\mu \cdot C_p) / k \quad \text{--- (4)}$$

Where,  $C_p$  = specific heat of the refrigerant

$k$  = thermal conductivity of the refrigerant

Calculation of Nusselt number

Calculation of the Nusselt number is based on the co-relations and the selection of the co-relation is based on the magnitude of the  $Re$ ,  $Pr$ , and the nature of the heat transfer surface. In our particular condition we select Gnielinski co-relation, since it involves less uncertainty (6%) so mathematical result will be more accurate.

$$\text{Nu} = \left( \frac{\mathcal{A}'}{2} \right) \cdot (\text{Re} - 1000) \cdot \text{Pr} / \left( 1 + 12.7 \cdot \left( \frac{\mathcal{A}'}{2} \right)^{1/2} \cdot (\text{Pr}^{2/3} - 1) \right) \quad \text{--- (5)}$$

Where,  $\mathcal{A}'$  = friction factor its value depends on the  $Re$

$$\mathcal{A}' = 0.079(\text{Re})^{-0.25} \quad 4 \cdot 10^3 < \text{Re} < 10^5 \quad \text{----- (6)}$$

$\mathcal{A}' = 0.046(\text{Re})^{-0.2}$   $3 \cdot 10^4$  Calculation of convective heat transfer coefficient

$$\text{Nu} = (h_r \cdot D) / k \quad \text{--- (8)}$$

Where,  $h_r$  = Convective heat transfer co-efficient

$k$  = Thermal conductivity of the ammonia

Similar way we can find out these parameters for exhaust gases by following the same procedure.

Calculation of Log Mean Temperature Difference (LMTD)

$$\Delta T_m = (\Delta T_1 - \Delta T_2) / \ln(\Delta T_1 / \Delta T_2) \quad \text{--- (9)}$$

Where,  $\Delta T_1$  = Temperature difference between the exhaust inlet temperature and refrigerant exit temperature

$\Delta T_2$  = Temperature difference between exhaust outlet temperature and refrigerant inlet temperature

Calculation of Total Thermal Resistance

$$Q_{ref} = U \cdot A \cdot \Delta T_m \quad \text{--- (10)}$$

Since  $\Delta T_m / Q_{ref}$  is the total thermal resistance we will get the value of  $1 / U \cdot A$

Calculation of the length of heat exchanger

$$R_{total} = R_{conv.} + R_{cond.} + R_{conv.} \quad \text{--- (11)}$$

$$1 / (U \cdot A) = 1 / (h_e \cdot A) + (\ln(r_o / r_i)) / (2 \pi \cdot L \cdot k) + 1 / (h_{ref} \cdot A) \quad \text{--- (12)}$$

Where,  $h_e$  = Convective heat transfer coefficient of the exhaust gasses

$h_{ref}$  = Convective heat transfer coefficient of the refrigerant

A = Heat Transfer Area

From equation (12) we can easily calculate optimum value of the length of heat exchanger.

Now Effectiveness of Heat Exchanger changes as Inlet Temperature Difference between hot exhaust gases and cool refrigerant varies.

Effectiveness of Heat exchanger can be calculated by following procedure.

Calculation of the effectiveness of the heat exchanger

In case of the counter flow the effectiveness  $\epsilon$  is given by

$$\epsilon = \frac{1 - \exp(-1 + C) \cdot \text{NTU}}{1 - C \cdot \exp(-1 - C) \cdot \text{NTU}} \quad \text{--- (13)}$$

Where, NTU = Number of Transfer Unit

$$\text{NTU} = \frac{U \cdot A}{(\dot{m}) \cdot \text{CP})_{\min}} \quad \text{--- (14)}$$

C = Capacity Ratio

$$C = \frac{(\dot{m}) \cdot \text{CP})_{\min}}{(\dot{m}) \cdot \text{CP})_{\max}} \quad \text{--- (15)}$$

Calculation of amount of heat transfer to the generator

$$\epsilon = \frac{\text{actual heat transfer}}{\text{maximum heat transfer}} \quad \text{--- (16)}$$

$$\text{Maximum heat transfer } Q_{\max} = \dot{m} \cdot \text{CP} \cdot \Delta T_{\max} \quad \text{--- (17)}$$

Where,  $\Delta T_{\max}$  = Maximum temperature difference between hot exhaust gases and cold refrigerant



Using Equations (14) & (15) we can calculate actual heat transferred to the generator of the VARS.

Calculation of Coefficient of Performance (COP) of VARS

$$\text{COP} = (\text{Cooling Effect Produced} / \text{Heat Energy Input to Generator}) \text{ --- (18)}$$

Since COP is the function of temperature we can calculate the COP by using following relation also,

$$\text{COP} = (T_e * (T_g - T_a)) / (T_g * (T_a - T_e)) \text{ --- (19)}$$
 Where  $T_e$  = Temperature of the evaporator

$T_g$  = Temperature of the generator

$T_a$  = Temperature of absorber

Results and Discussion: -

For optimization of design of heat extraction device, we need to determine and fix some parameters. Assume desired heat transfer to be 3 kW. Also we need to find out the specific temperature or temperature range of VARS generator so as to have optimum COP.

Graph 1: Generator Temperature Vs COP of VARS

From graph 1, it is clear that VARS system will have maximum COP in the generator temperature range of 118°C (391 K) to 127°C (400 K). Now we can fix the refrigerant outlet temperature. Furthermore we cannot reduce the exhaust gas temperature below certain level. Sudden drop in exhaust

temperature will cause the exhaust gas to slow down. The drop in exhaust temperature can be accommodated by reducing the exhaust pipe diameter.

After fixing the generator temperature i. e. , refrigerant outlet temperature, exhaust gas outlet temperature and refrigerant inlet temperature, the only parameter remaining is exhaust gas inlet temperature. Exhaust temperature varies with load conditions (no load to full load conditions) and driving conditions (idling to power mode). This results in to change in LMTD, due to which the overall heat transferred to refrigerant changes.

As a result of change in exhaust gas inlet temperature the effectiveness of heat exchanger changes. As exhaust temperature increases effective heat transfer area required decreases as well as effectiveness of heat exchanger reduces. Optimum heat transfer area and effectiveness of heat exchanger is represented by graph 2.

Graph 2: Optimum Heat Transfer Area, Effectiveness Vs Inlet Temperature Difference

Effectiveness is the function of temperature difference between hot exhaust gases and cold refrigerant at inlet. As this temperature difference increases, effectiveness of heat exchanger decreases. Effectiveness of heat exchanger is not of prime concern. We can maintain the effectiveness to certain level by varying refrigerant inlet temperature by some means, for example, electric heating. It will maintain the temperature difference between two fluids at inlet. Small amount of energy will be utilized to elevate the refrigerant temperature. Prime concern of the study is to obtain desired cooling effect

by utilizing exhaust waste heat. So effectiveness of heat exchanger can be compromised to certain level.

Practically, COP of system will be much lower as compared to mathematically obtained values but sufficient to produce desired cooling effect efficiently. Graph 1 represents the theoretical values of COP obtained by equation (19). We have used these values to determine optimum generator temperature. After fixing the parameters of heat extraction device (Heat Exchanger), the practical values of COP are obtained by using equation (18). Graph 3 represents the practical values of COP. It is clear from graph 3 that as generator temperature rises from 118°C to 127°C, COP values drops to 73% and cooling effect obtained at a point is 2.8 kW and effectiveness of heat exchanger is about 50%.

Graph 3: Generator Temperature Vs COP

### Conclusion

From the above results we can say that it is possible to extract waste heat of the engine exhaust using heat exchanger. In order to increase the performance of VARS we have to operate heat exchanger at the optimum condition mentioned in results. Some precaution we have to take care such as at the initial stages of engine operation performance of VARS is low, hence to get the same cooling effect we have heat ammonia generator using heating coil.