Vapor absorption refrigeration cycle for automobile engineering essay

This paper describes the development possible in the field of vehicle air conditioning based on vapor 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 an automobile is based on a vapor compression cycle which necessarily consists of a compressor driven by engine output and thus increases the fuel consumption rate and pollution proportion. The introduction of vehicle air conditioning using vapor absorption cycle eliminates the need for compressors; here compressor is replaced by the generator and absorber unit. Engine waste heat from exhaust gases is used as a heat source for generator of vapor absorption system. This paper describes the development possible in the field of vehicle air conditioning based on vapor absorption cooling. Some limitations are outlined and suggestions for future improvement are pointed out.

Keywords: – Vapor Absorption Refrigeration Cycle, Vapor Compression Refrigeration Cycle.

Introduction Motivating factors for the designing this system is a continuous improvement in the performance of engines and the need for air conditioning of vehicles, as it reaches the status of the essential need for modern life. About one third of the energy available in the combustion processes in the internal combustion engines is wasted through the exhaust gas, it makes internal combustion engines a possible potential energy sources for absorption refrigeration systems. Thus, use of the exhaust gas in an absorption refrigeration system can increase the overall system efficiency.

An automobile engine utilizes only about 35% of available energy and rests are lost to cooling and exhaust system. If one is adding a conventional air conditioning system to the automobile, it further utilizes about 5% of the total energy. Therefore automobile becomes costlier, uneconomical and less efficient. It also decreases the life of the engine and increases the fuel consumption. For very small car 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 a 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 refrigerant (ammonia) vapor enters the condenser, where it transfers heat to the neighborhood. Liquid ammonia leaves the condenser and passes through a throttle (expansion) valve, reaching the evaporator pressure. The refrigerant then enters the evaporator, where it removes heat from the space to be cooled, turning into low pressure vapor. In the sequence, refrigerant (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 in the neighborhood. The solution has now a high ammonia concentration, and is pumped to the vapor generator. In a generator, 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 aqua-ammonia solution leaves the 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 heat extraction device to extract heat from 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 Heat Exchanger as a heat extraction device.

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Figure2- Schematic of Heat Exchanger

In order to find the dimensions of the Heat Exchanger we have to assume certain cooling capacity of the cooling system. Let’s assume it as 2. 5 kW that is Qref = 2. 5 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

Qref = á¹ *cp* (Tg – Te) —– (1) Where , Cp – specific heat capacity

Tg – Temperature of the generator

Te – Temperature of evaporator

á¹ – Mass flow rate

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

Calculation of velocity

á¹ = A*v*Ï —– (2)

Where, Ï = density of the refrigerant (taken from a design data book)

A – Flow Area for Refrigerant Ammonia

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

Calculation of Reynolds number

Re = (Ï *v*D) /µ —– (3)

Where D = diameter of the refrigerant tube μ = dynamic viscosity of refrigerant at mean temperature (taken from a design data book)

Calculation of Prandtl number

Pr = (μ*Cp) / k —– (4)

Where, Cp = 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.

Nu = ((Æ’/2) * (Re – 1000) *Pr) / (1+12. 7* (Æ’/2)1/2* ((Pr) 2/3 – 1)) —– (5)

Where, Æ’ = friction factor its value depends on the Re

Æ’= 0. 079 (Re) -0. 25 4*103 < Re <105 ----- (6)

Æ’= 0. 046 (Re) -0. 2 3*104 Calculation of convective heat transfer co-efficient

Nu = (hr*D) /k —– (8)

Where, hr = 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)

âˆ†Tm = (âˆ†T1-âˆ†T2) / ln(âˆ†T1/âˆ†T2) —– (9)

Where, âˆ†T1 = Temperature difference between the exhaust inlet temperature and refrigerant exit temperature

âˆ†T2 = Temperature difference between exhaust outlet temperature and refrigerant inlet temperature

Calculation of Total Thermal Resistance

Qref = U*A *âˆ†Tm —– (10)

Since âˆ†Tm / Qref is the total thermal resistance we will get the value of 1/ U*A

Calculation of the length of heat exchanger

Rtotal = Rconv.+Rcond.+Rconv. —– (11)

1/(U*A)= 1/(he*A) + (ln(ro/ri)) /(2Ï€*L*k) + 1/(href*A) —– (12)

Where, he = Convective heat transfer coefficient of the exhaust gasses

href = 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 É› is given by

É› = (1-EXP((-1+C)*NTU) /(1- C* EXP((-1-C)*NTU)) —– (13)

Where, NTU = Number of Transfer Unit

NTU = (U*A) /(á¹🚺 * CP) min. —– (14)

C = Capacity Ratio

C = (á¹🚺 * CP)min / (á¹🚺 * CP)max —– (15)

Calculation of amount of heat transfer to the generator

É› = (actual heat transfer / maximum heat transfer) —– (16)

Maximum heat transfer Qmax = á¹🚺*CP*âˆ†Tmax —– (17)

Where, âˆ†Tmax = 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

COP= (Cooling Effect Produced / Heat Energy Input to Generator) —– (18)

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

COP= (Te* (Tg-Ta)) / (Tg* (Ta-Te)) —– (19) Where Te = Temperature of the evaporator

Tg = Temperature of the generator

Ta = Temperature of the absorber

Results and Discussion: –

For optimization of the design of the 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 the VARS system will have a 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 a 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 the effective heat transfer area required decreases as well as effectiveness of heat exchanger reduces. Optimum heat transfer area and effectiveness of the 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 the inlet. As this temperature difference increases, the effectiveness of the heat exchanger decreases. Effectiveness of heat exchanger is not of prime concern. We can maintain the effectiveness of certain levels by varying refrigerant inlet temperature by some means, for example, electric heating. It will maintain the temperature difference between the two fluids at the inlet. The small amount of energy will be utilized to elevate the refrigerant temperature. The prime concern of the study is to obtain the desired cooling effect by utilizing exhaust waste heat. So the effectiveness of the heat exchanger can be compromised to a certain level.

Practically, a COP of system will be much lower as compared to mathematically obtain values but sufficient to produce a 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 the 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 the 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 the 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 a heat exchanger. In order to increase the performance of VARS we have to operate heat exchanger at the optimum condition mentions 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 a heat ammonia generator using heating coil.