DESIGN OF WASTE HEAT DRIVEN VAPOUR ADSORPTION COOLING SYSTEM FOR VEHICLE AIR-CONDITIONING AND REFRIGERATION

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Abstract

In this present era more & more focus is to be given on energy conservation. Refrigeration & air conditioning is one of the growing field of engineering, the existing system are hampering the environment as they are suffering from various environmental problems such as depletion of ozone layer & global warming due to emission of harmful gases such as HFC's ,CFC's & CO2 as they were using traditional refrigerants. Waste heat driven Vapour adsorption cooling system is eco-friendly, efficient, & reliable in nature. But on the other hand this system having lowers COP as compare to existing systems which is Due to the lack of research and advancement in the system. By considering the environmental aspects & need of energy conservation it is necessary to design and developed the VAR's system which will successfully compete the existing systems. This paper will give the idea about the Design of waste heat driven vapour adsorption system of 2KW capacity for vehicle air-conditioning & refrigeration application. The adsorber bed is the heart of the cooling system and it can affect the performance of the system to the greater extent. So that while designing the VAR cooling system more focused is given on design and selection of adsorber bed. This article mainly focused on the various and important design parameters of the vapour adsorption cooling system Such as Adsorber bed design, adsorber and adsorbate mass, design of evaporator & condenser, Coefficient of performance(COP), Specific cooling power (SCP) and the other performance affecting parameters.

Keywords: *Vapour Adsorption, Design Parameters, Low Grade Thermal Energy, Adsorbate & Adsorbent.*

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1. INTRODUCTION

Vapour Compression Refrigeration (VCRs) system have been practically used for variety of application such as for domestic, industrial, transport refrigeration, automobile air conditioning, food preservation & cold storage etc. from past few year very efficiently. The VCR's are almost used in 85% of refrigeration system successfully all over the world but due to the use of traditional refrigerants which leads to ozone depletion & global warming. Therefore there is need of development of green, sustainable refrigeration system which should uses eco-friendly refrigerants. On the other hand the thermodynamically driven refrigeration (VARs) system draws attention in recent days. The system uses waste heat as input and it uses the environment friendly refrigerants which have no impact on environment. Nowa days almost all the automobile air-conditioning system is driven by conventional mechanical Vapour compression system which adds more load on engine, consumes the more fuel and decreases efficiency of engine.

Ramji&Leo[1] performed the parametric study and simulation of heat driven adsorber for air-conditioning application they have found that wall thickness is important parameter for proper heat transfer rate and it should be 15-20mm of stainless steel. The data obtained by this study is 0.65Kw of cooling power & C.O.P is 0.25 with the cycle time of 1200sec. Also the adsorber could produce the higher cooling power but it requires higher input temperature and longer cycle time.

Review on adsorption refrigeration cycle by Bhushan Dusane[2] had presented the need of the development of thermal power driven system due energy awareness amongst the people, increasing fossil fuel price and environmental hazardous such as ozone depletion and global warming etc. They also concluded that the cost of power generation by solar sorption system will be much lower than Conventional systems. Ahmed Shamroukh&Ahmed [3] Ali investigated adsorption capacity of variety of activated carbon with the different adsorbate at the different adsorption temperature and successfully mentioned the designed parameters required development of adsorption chiller (adsorber, condenser and evaporator) having cooling capacity of 5Kw.

Wang &oliveira[4] have developed the silica gel-water chiller having the temperature of water is higher than 55 ^oC, the C.O.P recorded was 0.2-0.6 & the development of solar powered icemaker for producing the daily 4-7kg of ice per m^2 area of solar collector having the C.O.P in between range of 0.10-0.15.they also present the achievement and interest take on the sorption system at the end of 1970s. Harish Tiwari [5], have successfully developed the prototype having 1KW cooling capacity for cabin cooling of trucks by using activated carbon and ammonia as working pair. The designed system is compact and it can be easily installed in the truck having the estimated weight is 30kg.

Meanwhile R.Z.Wang [6] presented the effective use of low grade thermal energy (60-150 ^oC) for sorption refrigeration system and the results shows that for silica gel-water C.O.P is 0.35-0.6, however for ice making with $cacl_2$& ammonia as working pair shows C.O.P 0.2-0.4.Wang found that with the combination of an internal heat recovery and double bed adsorption cooling working on low grade temperature range 150-250 ^oC gives the C.O.P value of 1.5 or more than that. In another research conducted by I.A.Tan & M.Abdullah[7] they has carried out an experimentation by using the three different working pair for waste heat driven adsorption A/C system, the experimentally conducted data shows that activated carbon-ammonia pair able to produce chilled water outlet of 19 ^oC with C.O.P 0.4 and cooling capacity of 0.50Kw.On the other hand the activated carbon-methanol & water produces C.O.P of 0.37 & 0.58 respectively with a cooling power of 0.65 Kw and 1Kw approximately.

In a research performed by Tso C.Y [8] for application of green buildings by utilising double bed with copper u-tube and circular plate fin structure and silica gel-water as working pair. The investigation shows 74% of improvement as compared to standard operating condition where the C.O.P and SCP of the system where noted as 0.3 & 39.1 W/kg with 15 minutes of cycle time. In another research carried out by Amir Sharafian [9], they had presented the nine types of heat exchanger and the effects of it on the performance of waste heat driven ACS & the study shows that among the conventional and existing type of heat exchanger which is used as adsorber, fin tube adsorber bed design is promising for practical application of vehicle A/C-Refrigeration. Zhong & Wert [10] have proposed an A/C system for heavy duty vehicle to reduce the fuel consumption and engine emission thus improves the engine efficiency. The data tabulated shows that C.O.P of the system increases considerable with the increasing the cycle time but at the same time the total cooling capacity goes on decreasing during the same period.

2. MATHEMATICAL MODELLING AND DESIGN CALCULATIONS

As the main elements of sorption system are adsorber bed (generator unit), condenser, and evaporator & expansionvalve & the all of the components are designed for 2w refrigeration capacity & some of the other important parameters of the sorption system which will evaluate the performance of it.

2.1 Adsorber Bed

Adsorber bed is one of the key element of the system&the main function of it is provide adequate amount of thermal energy to the adsorbent particle which are present inside it. The adsorber provides the necessary compression effect required for refrigeration in an Adsorption refrigeration system by absorbing and rejecting heat of adsorption and desorption. It works like generator as well as absorber both in an adsorption refrigeration system. Two adsorber beds as separate heat exchangers are proposed to be used in the present system. The proper selection and design of adsorber bed will lead to increase in performance of the system.

So it is needed to do more focused on design and performance of adsorber bed. In a research carried out by Amir Sharafian [9] they studied different types of adsorber shows that for smaller cooling capacity shell and tube shows which shows SCP around 200-250 W/Kg of dry adsorbent. As we are designing the adsorber bed of small capacity of 2 Kw shell and tube type of adsorber bed is selected.

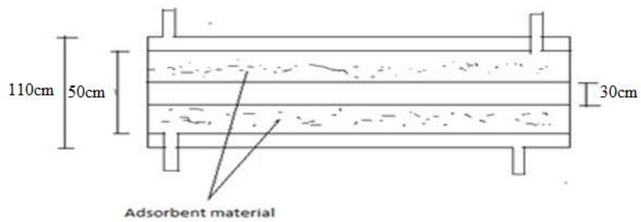

Fig-1: Adsorber bed

Fig-1 shows the shell and tube type of adsorber bed, In this casewe have taken the adsorbent as granular activated carbon of mesh size 3-4mm and adsorbate as R-717(NH3). The adsorber bed contains the three concentric pipe in which innermost pipe is utilised for heating and the adsorbing material is placed in between the inner and middle tube by taking care of the radial space between it should be approximately equal to 4mm for better performance of adsorber bed and the outer tube is required for adsorber bed cooling which is cooled by circulating cooling water.The system is designed for cooling effect of 2Kw by taking cycle time as 300 sec (5minutes) and The adsorber temperature is decided as Tad=90^oC [6] as the adsorber bed is designed for utilising the low amount (grade) of thermal energy between the Range of 60-150 ^oC&With the increasing in adsorber bed temperature the adsorption capacity of activated carbon and ammonia pair is decreases [12].

The amount of heat required to heat the adsorber bed in order to get the 2Kw cooling power is determined by taking the summation of sensible heat and latent heating which is determined by following equations,

$$Qadsorber = Qsensible + Qlatent \quad [5] \qquad (1)$$

$$Qsensible = \frac{[(mad \times Cpad \times \Delta Tad) + (mtube \times Cptube \times \Delta Tad)}{\Delta\tau cycle} [5] \qquad (2)$$

$$Qlatent = \frac{[mad\ (X2-X1)\times(H2-H1)]}{\Delta\tau\text{cycle}} \quad [5] \qquad (3)$$

In this case from equation (1),Qadsorber is calculated as 3Kw& the heat transfer area available in this case is determined as $A_{avail.ad}$ is 0.96 m^2.Now it is necessary to determine the area required for suppling the heat of 3Kw which is determined as follows.

$$Qadsorber = Uadsorber \times Areq.ad \times \Delta Tad \qquad (4)$$

Whereas Qadsorber is 3Kw, Uadsorber is calculated as $25 W/m^2K$, ΔTad is 90 ^oC and the $A_{req.ad}$ is calculated from above equation is $1.33 m^2$. Here $A_{avail.ad}$ is less than the area required,In order to enhance the heat transfer area required for adsorber, fins are provided and aluminium chips are mixed in the adsorbent material.

Adsorption & desorption are the two phenomenon by which the cooling effect is produced in sorption system, during desorption the adsorber bed is heated at high temperature and pressure then refrigerant is desorbed from the porous adsorbent material where it is liquefied in the condenser followed by expansion valve & evaporator where it the evaporates by absorbing the heat from surrounding. As we are using R-717, the mass of adsorbate required for producing the 2kW cooling power is calculated by following equation.

$$\text{madsorbate} = \frac{\text{Qevap (Kw)}\times\Delta\,\tau\text{cycle (sec)}}{L.H.NH3\ @\ evap\ .press} \qquad (5)$$

$$= \frac{2\times 300}{1250} = 0.48Kg$$

Where Qevap(Kw) is evaporative cooling power2Kw, $\Delta\,\tau$cycle is the cycle time (300) sec &$L.H.NH3\ @\ evap.press$ is the latent heat of ammonia at evaporator pressure (5bar).

In order to determine the amount of adsorbent required per adsorber bed it is necessary to known the adsorption capacity of the sorption pair. The adsorption capacity of the pair can also greatly influence the performance of the adsorber bed. In a research conducted byChristiano Rodrigues, de Moraes Jr [12] the concentration of ammonia on activated carbon at 40 ^oC is 0.6-1.8 mg NH_3/ g activated carbon & at 120 ^oC it varies from 0.15-0.35 mg NH_3/g activated carbon. The adsorption capacity of activated carbon-ammonia pair is obtained as 17.19mg g-1 or 0.1719 kg/kg of adsorbent from Langmuir & Freundlich equilibrium isotherm model [11]. By taking adsorption capacity of pair as 0.1719 kg/kg of dry adsorbent, the amount of adsorbent required per adsorber bed is obtained as follow.

$$madsorbent = \frac{madsorbate}{\Delta X} = \frac{0.48}{0.1719} = 2.79kg(6)$$

2.2 Condenser Design

Condenser and evaporators are the heat exchangers and design of it done by using heat transfer equations. In this case both the condenser and evaporator are designed for 2kW capacity. For this proposed design double pipe heat exchanger is decided with water as cooling medium and the pressure & temperature are kept in the range of 14-16 bar and 80 ^oC respectively. The mass flow rate of adsorbate is calculated as follows.

$$\dot{m}\text{adsorbate} = \frac{\text{R.E(Kw)}}{L.H.NH3\ @\ cond\ .press\ \left(\frac{Kj}{Kg}\right)} \qquad (7)$$

$$= \frac{2}{1090} = 1.83\times 10^{-3}\text{Kg/sec}$$

The amount of heat removed in condenser is given by;

$$Qcond = \dot{m}\text{adsorbate (hcond in} - \text{hcond out)} \qquad (8)$$
$$= \text{Ucond} \times \text{Acond} \times \Delta\text{TLMTD.Cond}$$

Whereas$Qcond$ is the condensing power in Kw, $\dot{m}$adsorbateis 1.83×10^{-3} Kg/sec, hcond in & $hcond\ out$ are the enthalpies of NH3 at condenser inlet and outlet which is calculated from the refrigeration table as the 1550 Kj/Kg and 320 Kj/Kg respectively. The condensing power is obtained as$Qcond = 2.25kw$.

Assuming thatcooling water temperature rise in the condenser is 10 ^oC and the temperature of water at the inlet & outlet of the condenser is 30 ^oC & 40 ^oC respectively. The temperature profile of condenser is shows as follows. The logarithmic mean temperature difference is calculated as,

$$\Delta\text{TLMTD.Cond} = \frac{\theta 1-\theta 2}{\ln\left(\frac{\theta 1}{\theta 2}\right)} = \frac{(80-30)-(80-40)}{\ln\left(\frac{50}{40}\right)} = 44.81\ ^\circ\text{C} \qquad (9)$$

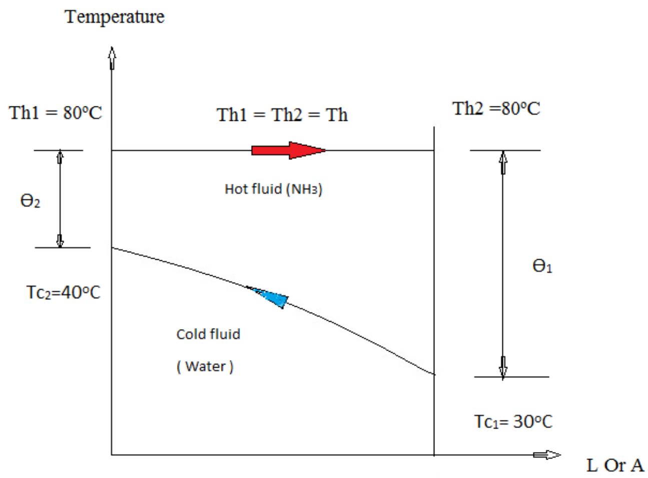

Fig.Temperature profile of Condenser

Fig-2: Temp profile of condenser

The overall heat transfer coefficient Ucond in this case is calculated as 1000 W/m^2K and area of condenser coil required for condensation of the refrigerant is calculated as follows

$$Qcond = Ucond \times Acond \times \Delta\mathrm{TLMTD.Cond} \qquad (10)$$

The area of condenser required is Acond=0.0503m² & Taking the diameter of condenser coil Dcond is 8mm then the length of condenser coil required is obtained by following equation.

$$Acond = \pi \times Dcond \times Lcond \qquad (11)$$
$$= 2.0037m \approx 2m$$

3. EVAPORATOR DESIGN

The refrigerant is flowing inside the evaporator coil and it is get evaporated by absorbing the heat. The quantity of heat removed in the evaporator is 2 kW& Drop in temperature of water was considered as 14^{o}C .The pressure to be maintained in the evaporator is 5 bar for which the saturation temperature of the refrigerant is 5 ^{o}C.

$$\mathrm{Qevap} = \dot{m}_{c.w} * Cp_{c.w} * \Delta T_{c.w} = \dot{m}_{adsorbate} * (h_{evap\ in} - h_{evap\ out})$$
$$= U_{evap} * A_{evap} * \Delta T_{LMTD.Evap} \quad [3] \qquad (12)$$

From the above equation the chilled water mass flow rate $\dot{m}_{c.w}$is calculated as 0.0398Kg/sec & the velocity of cooling or chilled water is determined as follows,

$$vc.w = \frac{\dot{m}c.w}{\rho c.w \times Aevap} = \frac{0.0398}{1000 \times 0.1680} \quad [3] \qquad (13)$$
$$= 0.2369 \times 10^{-3} m/sec$$

The evaporator temperature is assumed as 10 ^{o}C, the temperature profile of evaporator is as shown as follows. Logarithmic mean temperature difference in case of evaporator is calculated as.

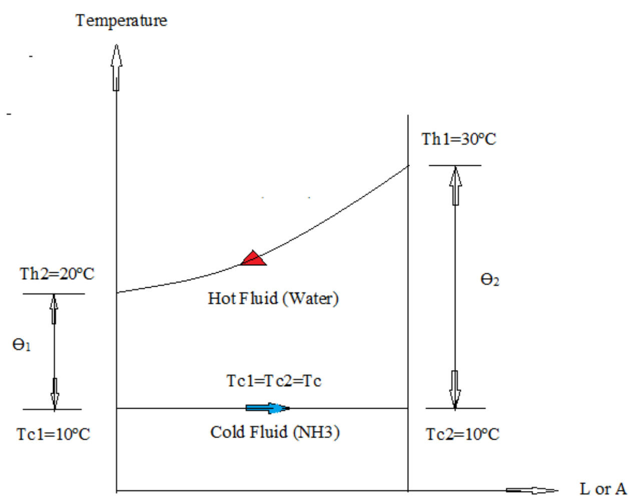

Fig. Temperature Profile of Evaporator

Fig-3: Temp profile of evaporator

$$\Delta TLMTD.Evap = \frac{\theta 1 - \theta 2}{\ln\left(\frac{\theta 1}{\theta 2}\right)} = \frac{(30-10)-(20-10)}{\ln\left(\frac{20}{10}\right)} = 14.43℃ \quad (14)$$

The overall heat transfer coefficient U_{evap} for refrigerant to water is calculated as 825W/m^{2}K and the A_{evap} is0.1680 m^{2} calculated by equation number 3.Taking the outer diameter of evaporator tube is 14m &the length of evaporator tube is determined by,

$$Aevap = \pi \times Devap \times Levap \qquad (15)$$
$$= 3.81m$$

3.1 Important Performance Evaluating Parameters of Adsorption Cooling System

The performance of Vapour adsorption is evaluated by the deterring the coefficient of performance (C.O.P) & Specific cooling power (SCP) In this case.

3.1.1 Coefficient of Performance (C.O.P)

It is a dimensionless parameter which is used to determine efficiency of Refrigeration as we as air-conditioning cycle. In this C.O.P is defined as the ratio of evaporative cooling power in (Kw) to the amount of waste heat supplied as input in (Kw).

$$C.O.P = \frac{Qevap\ (Kw)}{Qwaste\ \ heat\ (Kw)} [9] \qquad (16)$$

3.1.2 Specific Cooling Power (SCP)

It is defined as the ration of evaporative cooling power in Kw to the ratio of mass of adsorbent in kg multiplied by the cycle time in sec.

$$\mathrm{SCP} = \frac{Qevap\ (Kw)}{madsorbent\ \ (Kg) \times \Delta\ \tau\mathrm{cycle\ (sec)}} \mathrm{W/Kg\ of\ dry\ adsorbent}$$

All of the above parameters discussed should be taken into the consideration while designing the waste heat driven sorption system.

CONCLUSION

From the past few years continuously research has been carried out to replace the conventional refrigeration system as these system have bad impact on environment as well as need of energy conservation and development of eco-friendly system. Low grade Waste heat from the different application which losses its heat to surrounding, so there is a loss of energy. By employing the Vapour adsorption system there will be effective utilisation of heat. The performance of adsorption cooling system depends on the various parameters such as adsorption-desorption temperature, proper selection of working pair, type of adsorber bed used & adsorption capacity of pair etc. In this study we calculated the different design & important parameters of the performance evaluation of adsorption system having cooling capacity of 2Kw.Such small capacity of system can be used in applications such as domestic water cooling & low duty vehicle A/C applications.

More focused should be made on design and selection of adsorber bed as it served as important parameter. In this study we selected double bed (provides continuous cooling) and Shell and tube type of adsorber. Thermal driven cooling system can compete the conventional system after further advancement in the performance of the system more research should be aimed to improve the C.O.P & S.C.P by reducing the cycle time as well as input source temperature required.

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