Design and Fabrication of Solar Assisted Vapor Adsorption Refrigeration System

Gaurav Agrawal[1] Prashant Tripathi[2] Tariq Anwer Khan[3] Ashish Kumar Yadav[4] Arjun Kumar[5]
[1,2,3,4]Student [5]Assistant Professor
[1,2,3,4,5]Department of Mechanical Engineering
[1,2,3,4,5]Galgotias University, Gr Noida, India

Abstract— The proposed analysis deals with double bed vapor adsorption refrigeration system (VARS) combined with low grade heat discharge from condenser of Rankine-Reheating power plant and ETC type solar collector respectively for effective space cooling purpose for large area. The source temperatures available for both bed of VARS are 60ºC from condenser exhaust and 70-80oC from ETC solar system. The adsorbent and adsorbate pair for double bed VARS has been recommended by activated charcoal and silica gel as adsorbents and methanol and water as adsorbate respectively.

Keywords: vapor adsorption refrigeration system (VARS), ETC type solar collector

I. INTRODUCTION

The conventional refrigeration technology VCRS have reached a significant state of maturity up with wide use for food retail and food preservation sectors. All of these systems consume precious fuel or electricity to achieve refrigeration. Along with a consideration for energy efficiency, increasing attention is being given also to the use of waste heat. Adsorption systems are heat-operated units that need little electricity, so they can utilize waste heat or renewable energies. Other advantages of solid sorption machines (noiseless, safety). In comparison with the vapor compression refrigeration and absorption refrigeration systems, the adsorption refrigeration system has its drawbacks, such as low mass and heat transfer performance, expansion and agglomeration phenomenon for chemical adsorbent, low coefficient of performance (COP) and low specific cooling power. Some advanced cycles have been proposed and investigated, such as the multi-bed cycles, the thermal wave cycle, the forced convection cycle, the heat and mass recovery based on different adsorbent bed and different control strategies, heat pipe technologies hybrid. Research has shown that solid-adsorption technology has a promising potential, commercial solid adsorption systems are still limited for air-conditioning applications and lower temperature adsorption refrigeration systems are still under laboratory testing stage, so we find all research and laboratory based experimental results of adsorption machines explained in the present paper literature work. The present combination of adsorbent-adsorbate pair is suitable for low grade heat recovery with solar thermal integration for continuous cooling effect generation and applicable for space cooling purpose.

II. LITERATURE REVIEW

In the current economical and energetic context, implementing technologies using renewable energy as heating source is offering a double advantage: the reduction of pollution and of the fuel cost. One of the main concerns of the modern human is to provide comfort in buildings. The main utilities that make a building „alive" are: electricity, domestic hot water, heating/cooling according to external ambiance. In this study the attention is focused on providing cooling during summer for a public establishment. In 1824 Faraday was conducting the experiment regarding liquification of gases, so one of his experiment he took silver chloride (AgCl) powder in flask 1 and created a vacuum in flask 2 and connected the flask and flask 2 was placed inside the continuous water supply. He injected ammonia vapor and stared heating the falsk1 which was containing AgCl. The ammonia starts liberate and collected in flask 2 and he stopped heating flask 1. After sometime he observed that the ammonia starts to vaporize and was absorbed by the silver chloride powder again. This gives birth to the vapor adsorption refrigeration system. Faraday observed that the liquid NH3 started boiling and reabsorbed by the silver chloride. this means the solubility of ammonia differs at different temperature. At lower temperature solubility of ammonia in silver chloride was high, but when it was heated solubility becomes low and vapors were generated and subsequently vapor were condensed in the flask 2 in liquid form. However, when heating was removed its tendency of absorbing the ammonia started increasing and absorbed the ammonia again. Pressure inside the circuit reduced and that temperature became correspond to the saturation temperature of the liquid NH3 and it started boiling and vapors were absorbed by the silver chloride powder (AgCl). The size of the compressor is decided by the volume of the vapor. If the capacity of the system is large then automatically the volume of the saturated vapor will be large. suppose a plant of 1000 or 3000 TR capacity then the size of the compressor will be very large. In case of refrigerant if volume of vapor is converted into the liquid then volume of the fluid can be reduced by (1/200) of the volume of vapor. Suppose if we condense 200 lit of vapor into liquid then it would be around 1 lit. so 1 lit of liquid is easily handled as compared to 200lit of vapor because much less energy is used. Therefore, to reduce the energy consumption and cost of the plant we are requiring the vapor adsorption refrigeration system. K. Sumathy et al (2003) studied about the adsorption of methanol onto carbon based adsorbents and founded that the D-R equation is the most appropriate adsorption isotherm model to correlate the adsorption equilibriums for the both assorted adsorbent/refrigerants pairs. N.M khattab (2004) designed adsorbent bed and evaporative system, the net COP achieved by him was 0.159 in June and 0.136 in November in Egyptian climatic conditions. EE Anyanwu (2005) studied about the thermodynamic design procedure for solid adsorption solar refrigeration system and concluded the application of thermodynamic approach to system using different pairs of adsorbent-adsorbate pairs. Khairul Habib

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etal (2006) studied theoretical analysis of the solar powered combined adsorption refrigeration cycles using evacuated tube solar collector and founded that The net COP and chiller efficiency was 0.12 and 0.25 respectively for cycle time between 450 to 500 seconds. El-Sharkawy(2009) Studied on adsorption of methanol onto carbon based adsorbents and founded that the (D-R) equation is the most appropriate adsorption isotherm model to correlate the adsorption equilibriums for the both assorted adsorbent/refrigerant pairs. The Dubinin Raduskevich (D-R) equation is used to fit the adsorption isotherms of adsorbate and refrigerants pairs ; $w = w_0 \exp[-D(T \ln(\frac{P_s}{P}))^2]$ where W stands for the equilibrium uptake and W0 is the maximum uptakes P is the equilibrium pressure and Ps is the saturation pressure corresponding to the adsorption temperature T. The term D is an adsorption parameter that depends on the adsorbent/adsorbate pair. Mahmoud Salem Ahmed et al (2010) worked on different types of adsorbent adsorbate pair which used in solar adsorption systems and concluded that, Silica gel and chlorides with water gives maximum COP whereas zeolite with water shows poor performance working under similar conditions. Mohand Berdia (2014) worked on cold production by solar adsorption refrigeration in Algeria's climate and Founded that COP and specific cooling power increased with increase in heat source temperature and decreased with decreasing evaporative temperature.

III. EXPERIMENTAL SET UP

The solar-assisted adsorption refrigeration system consists of a parabolic solar concentrator, water tank, adsorbent bed, condenser, expansion device(capillary tube), evaporator and heat exchanger as shown in fig1. The specifications of the components used in the system are given in Table 1. As per the study by Mahmoud Salem Ahmed et. al [3] founded that Silica gel and chlorides with water pair was had the highest COP value. Zeolite with water pair has the minimum value for COP. So we are using activated charcoal/ methanol and silica gel/water as the adsorption working pairs for this project of two bed vapor adsorption refrigeration system. Comparison of different adsorption working pairs given in table 2.

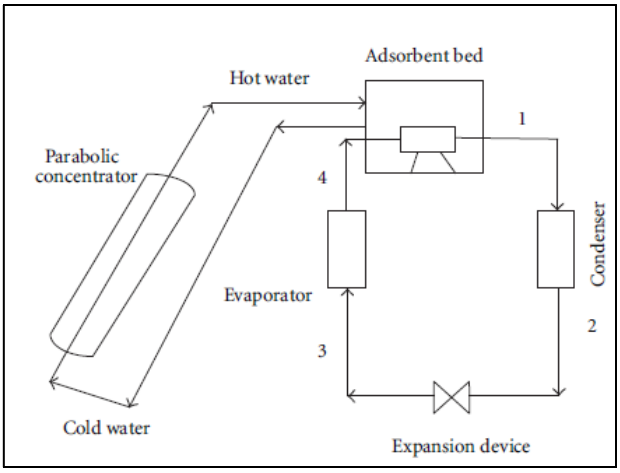

Fig. 1: schematic of Basic Vapor Adsorption refrigeration cycle.

IV. WORKING PRINCIPLE

Water gets heated while flowing through the solar concentrator by natural circulation. When the hot water is circulated around the adsorbent bed, the temperature in the adsorbent bed increases. This causes the vapor pressure of the adsorbed refrigerant to reach up to the condensing pressure. The desorbed vapor is liquefied in the condenser. The high pressure liquid refrigerant is expanded through the expansion device to the evaporator pressure. The low pressure liquid refrigerant then enters the evaporator where it evaporates by absorbing the latent heat of evaporation. The hot water from the tank drained off and is refilled with cold water. The temperature of the adsorbent bed reduces rapidly and the pressure in the adsorber drops below the evaporator pressure. The experiments are carried out keeping the evaporator temperature constant. The same procedure is repeated for the different evaporator loads.

component	Technical specifications
condenser	Capacity: 200 W
Evaporator	Capacity: 150 W Material: copper
Expansion Devices	Capillary tube
Adsorbent bed	Material: stainless steel
solar concentrator	Area: $3m^2$ made of stainless steel
Adsorbent	1.Activated charcoal of 0.25mm granular size 2. Silica gel of 3nm granular size
Adsorbate	1. Methanol 2. water
Heat exchanger	counter flow heat exchanger

Table 1: The specifications of main components of solar adsorption Refrigeration system.

PAIRS	WORKING	COP	T_e(*C)	Td(* C)	SCP (w/kg)
PHYSICAL ADSORBENT	Activated carbon /ammonia	0.61	-5	100	2000
	Activated carbon /methanol	0.78	15	90	16
	Activated carbon/ethanol	0.8	3	80	NA
	Silica gel/water	0.61	12	82	208
	Zeolite/water	0.25	6.5	350	200
CHEMICAL ADSORBENT	Metal chloride/ammonia	0.6	-10	52	NA
	Metal hydrides/hydrogen	0.83	-50	85	300
	Metal oxides/water	NA	100	200	78

Table 2: Comparison of different adsorption working pairs

V. RESEARCH GAP

It is clear that the vapor adsorption system has a strong potential to be used as an alternative cooling system.In this PROJECT we are working on the high efficiency (COP) and highly effective refrigerants and adsorbents. High Efficiency can be achieved by installing heat exchangers.Using the solar thermal energy as waste energy to provide heat to the generator. Use of regenerative cycles, in which two

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adsorption cycles are operated out of phase such that when one is being heated, the other is being cooled.

COP increases by installing heat exchangers, heat exchangers are installed at 2 positions.Between fluid coming out from the condenser and the fluid coming out from the evaporator evaporator & Between fluid coming out from the generator and fluid coming out from the pump as shown in fig2. At first position, hot fluid comes out from condenser gets heat exchanged with fluid coming out from the evaporator after cooling. Firstly, before going to the evaporator fluid will be subcooled and we know that the subcooled system will generate more refrigeration effect thus cop will be increased. Secondly, less heating will be required in adsorber to heat the adsorbent. At second position, Fluid coming out from generator is low solution. It will be richer after getting heat exchanged with the fluid coming out from the pump which is at high temperature, hence less heating will be required in adsorber.

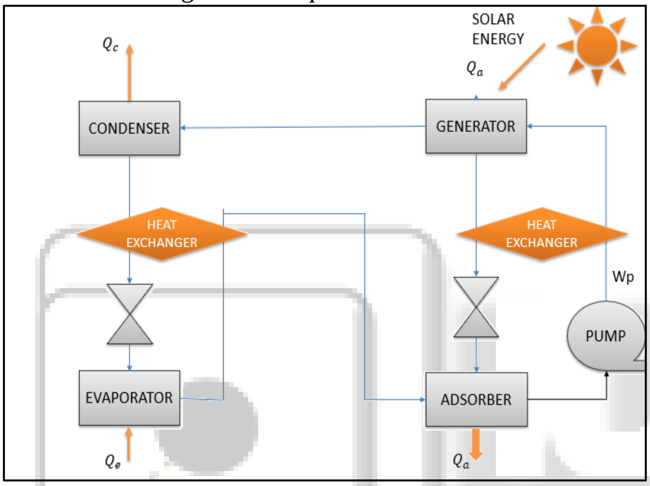

Fig. 2: Installation of heat exchanger to increase COP.

VI. PERFORMANCE PARAMETER

The main performance parameters used for the present study are cycle coefficient of performance, specific cooling power, and solar cooling coefficient of performance

1) Cycle COP is defined as the ratio of cooling effect to the total energy required for desired cooling effect:

$$COP=\frac{\text{cooling effect}}{\text{total energy input}}=\frac{Q_e}{Q_T} \quad (1)$$

the total energy input to the system is given by.

$$Q_T=Q_{\text{isotropic heating}}+Q_{\text{desorption}} \quad (2)$$

The total heat supplied to the system is equal to the Enthalpy change of solar heated water

$$Q_T=m*C_p(T_{fi}-T_{fo}) \quad (3)$$

Cooling effect is as follows:

$$Q_e=m_w C_{pw}(\Delta T_w) \quad (4)$$

2) Specific Cooling Power (SCP). Specific cooling power indicates the size of the system as it measures the cooling output per unit mass of adsorbent per unit time. Higher SCP values indicate the compactness of the system:

$$SCP=\frac{\text{cooling effect}}{\text{cycle time per unit of adsorbent mass}}=\frac{Q_e}{m_a\times\tau_{cycle}} \quad (5)$$

3) Solar COP since the system is solar-powered, the solar coefficient of performance is also to be defined. This is defined as the ratio of cooling effect to the net solar energy input:

$$\text{Solar COP}=\frac{Q_e}{Q_s} \quad (6)$$

VII. EES MODELLING

EES is a general equation-solving program that can numerically solve thousands of coupled non-linear algebraic and differential equations. The program can also be used to solve differential and integral equations, do optimization, provide uncertainty analyses, perform linear and non-linear regression, convert units, check unit consistency, and generate publication-quality plots. A major feature of EES is the high accuracy thermodynamic and transport property database that is provided for hundreds of substances in a manner that allows it to be used with the equation solving capability.

The performance parameters such as cycle COP, SCP, discharge temperature, and solar COP are predicted by using EES. In this study, the pressure, temperature and solar intensity are used as input parameters whereas the cycle coefficient of performance, specific cooling power, discharge temperature, and solar cooling coefficient of performance are predicted in the output layer.

Determination of Q _ Heat _ AQ _ Cool _ A COP_Th_A_COP_Th_B,Q_Heat_B,Q_Ref_B,Q_Heat_Net Q_Ref_NetQ_Cool_Net SCP_ Net COP _ Solar, COP _ Th _ combined of combined solar and heat recovery vapour adsorption refrigeration system"

"Known information"

m _ad _ A=[kg]; x _ max _ A = 60; x _ A=60; x _ min _ A = 20; Cp _ ad _ A =0.71 [kJ/kg-k]; Cp _ r _ A =1.66[kJ/kg-k] "Activated charcoal-Methanol pair used activated charcoal is adsorbent and methanol is refrigerant"

m_ad_B+2.93[kg]; x _ max _ B = 60;

X _ min _ B =20; Cp _ ad _ B = 0.71[kJ/kg-k]; Cp _ r _ B=1.3[kJ/kg-k] "Silica gel -Water pair used silica gel is adsorbent and water is refrigerant"

T _ gen _ A=328[k]; T _ ad _ A=293[k]; T _des _ A=363[k]

"T _ ad _ A TAKEN FOR 450 s"

T _ gen _ B=333[k]; T _ ad _ B=293[k]; T _ des _ B=343[k]

"T _ ad _ B TAKEN FOR 90 s"

H_D_A=2000[kJ/kg]; L_E_A=1104[kJ/kg] "L_E latent heat of evaporation can be estimated by empirical formula L_E= 5.33;55+6.2974" T_evp0.0133T^2"

H_D_B=250[kJ/kg]; L_E_B=198.6[kJ/kg] "L_E latent heat of evaporation can be estimated by empirical formula L_E= 5.33;55+6.2974 T_evp-0.0133 T^2"

T _ evp _ A=275[k]; T _ cond. _ A=303[k],t _ A=450[second] T_ evp _ B=270[k]; T _ cond _ B = 290 [k], t _B=90[second]

"Uncertainly Analysis of Waste Heat recovery Vapor Adsorption System"

Q_Heat_A=m_ad_A"(Cp_ad_A+Cp_r_A*x_max_max_A)+(T_gen_AT_ad_A)+m_ad_A*[Cp_ad_A+Cp_t_A*(x_max_A X_min_AV2)* (T _ des _ A T _ gen _ A) + m _ ad _ A*(x _ max _ A-x _ min _ A)^H_D_A

"total heat transfer through adsorption bed A"

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$Q\_Ref\_A = (x\_max\_A - x\_min\_A) * m\_ad\_A * L\_E\_A$ "refrigerating effect" $Q\_Cool\_A = m\_ad\_A * (x\_max\_A - x\_min\_A) * Cp\_r\_A * (T\_cond\_A - T\_evp\_A)$.

Performance Parameters	Resultant Value
Plant Efficiency	0.488
Net Work Output	2133 kJ/kg
Turbine work output	294.7 & 1072 kJ/kg
Pump Work	16.23 kJ/kg
COP of combined VARS	0.46 to 0.51
Specific Cooling Power	70-90 W/kg
COP gain by Solar energy	0.48-0.74 (most effective COP)

Table 3: Result outcome from EES modelling.

VIII. Merits

1) Significant energy savings.
2) Have low maintenance cost.
3) No noise as well as no vibrations.
4) Eco friendly.
5) Wide range of adsorbent.
6) No dangerous chemicals.
7) Zero ozone depletion potential refrigerant.
8) Ability to work in mobile condition.

IX. Demerits

1) Less COP as compared to vapor compression refrigeration system.
2) At nights and cloudy days, we can't attain high enough temperature
3) Large Size and weight of the system is another demerit.

X. Applications

1) Food processing industries
2) Jute industries
3) Commercial purposes
4) Air conditioning
5) Cold storages

XI. Future Scope

1) Need to improve the COP of the system
2) Size of the condenser, evaporator and generator should be reduce so as to reduce the size and weight of the system.
3) Any method that improves the efficiency even marginally would improve the economic viability of operating such devices.
4) Applications of nanotechnology in adsorbents material development would be very promising.
5) Combination of adsorption refrigeration cycle and other refrigeration cycle scan be used to improve the overall efficiency of the system.

XII. Result & Discussion

In this paper, study of adsorption refrigeration cooling technology, its working principle, limitations and applications are presented. The results outcome has shown above in table 3. We have focused on increasing the efficiency of the system by introducing two adsorption beds, the most common working pair are silica gel-water and activated charcoal-methanol due to their lower operate temperature. To minimize the problem of poor heat transfer rate in the adsorbent, heat exchangers are used. The more scope is being made to improve performance of system and to reduce the weight and cost. It is studied that the most commonly finds application where waste hot energy is abundantly available and scope to use in refrigeration field and air conditioning area. The adsorption cooling system is driven by solar energy it not only improves energy efficiency, but Waste heat utilization for the production of power and cooling simultaneously helps in reducing problems related to global environment , such as greenhouse effect from CO2 emission due to the combustion of fossil fuels in utility power plants, and the use of chlorofluorocarbon refrigerants which is currently thought to affect depletion of the ozone layer.

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