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Original Research Article

Thermodynamic (Energy-Exergy) Analysis of Combined Coal based Thermal Power Plant and Solar Integrated Double Bed Vapor Adsorption System for Heat Recovery and Space Cooling

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Abstract: The thermal performance of proposed model deals with combined double bed vapor adsorption refrigeration system and 9MW of Rankine thermal cycle .The provision of evacuated tube type solar collector (ETC) is available with adsorption system to support the system for continuous cooling effect. The energy-exergy analysis refers live operational data of thermal power plant, and proposed cooling system is adopted as per thermal gain from condenser and solar heater for adsorbent-adsorbate pair of adsorption system. Major units of combined plant (boiler, turbines, condenser, pump, solar collector, adsorption bed etc.) have been investigated in thermodynamic analysis. The main objective of energy-exergy modeling is to identify the magnitude of process, cause of losses and rectifying the components. The source temperatures available for both beds of Vapor Adsorption Refrigeration systems (VAdRS) from condenser exhaust and ETC solar system. The adsorbent and adsorbate pair for double bed VAdRS has been recommended by activated carbon as adsorbent and methanol and R134a as adsorbate respectively. This analysis shows the 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. The major findings of present work, the maximum irreversibility found in boiler as 47% in thermal power plant and solar generator as 12% of adsorption machine, whereas overall cooling effect from adsorption system is increasing by 15% in double bed combination. EES software is used for all analysis.
Keywords: Rankin power cycle, Vapor adsorption refrigeration system, $\eta_{rankine}$, COPth, SCP, Irreversibility, EES

INTRODUCTION

This paper focus on the performance analysis of double bed VADRS integrated with ETC type solar thermal system for heat recovery of condenser part and integrated for cooling of large space area with zero impact on environment. It is recognized that the energy is one of the key factors that required for social, economic and industrial development. The interdependency of energy sector with industrial development is major concern for developing countries. The infrastructure of industry determines the amount and form of energy needed. Similarly, the availability and cost of supplies energy has a major influence on industrial development. The world energy council (WEC) reported that energy generation is from fossil based resources are 76%, although it is decreases by 10-13% from 1993 by increases hydro power nuclear power and renewable energy technologies. Worldwide industrial sector energy consumption is to increase by an average of 1.2%/year, from 222 quadrillion Btu in 2012 to 309 quadrillion Btu in 2040 [1-2].Shah N. *et al* [3] presented over the decade 2010-2020, the incremental electricity demand in from commercial and as well as from residential ACs alone (600 TWh/yr) are estimated to consume more than half of the total generation. This additional electricity demand will put tremendous pressure on the power sector of countries. The growth of HVACs poses environmental issues due to the GHG emissions emitted during the production of electricity needed to power them, and due to the refrigerants that are used in their system. Askalany *et al* [4] described vapor compression refrigeration systems operated with refrigerants, such as CFCs, HCFCs or HFCs. When released into the atmosphere, such refrigerants deplete the ozone layer and contribute to greenhouse effect. In the late 1980s,it was estimated that 33.3 % of greenhouse gas effect by using refrigeration machines and other heating/cooling thermal utilities, after this observation, the several protocols, like the Montreal protocol [28] and the Kyoto protocol [29] were established in order to reduce the emission of these refrigerants and introduce green concepts of heating/cooling technologies by using new trends of refrigerants, which has low ODP and GWP values for environmental safety aspects in Refrigeration & Air-Conditioning Industry. Turboden survey [5] shows the typical cement plant production capacity of 2000-8000 Tons/day consumes 3.5-5GJ of energy per ton. The energy produce by wastage heat recovery systems can account for 10-20% of total energy consumed by cement plant. The above described energy status and its future demand indicates the research and development in area of energy efficient technological development, its utilization with proper management in cost effective and eco-friendly nature for commercial, domestic and industrial purpose. The technology of vapor adsorption refrigeration system has potential for recover heat of low and high grade both, as well as integrated with solar thermal energy utilization. Many researches have been conducted in past, but implementation of technology and its development is still awaited. Kai Wang and A.Edward[6] explained basic adsorption cycle with the help of Chaperon diagram (Figure 1), it consists of four steps heating and pressurization, desorption and condensation, cooling and depressurization, and adsorption and evaporation. BaijuV.andMurleedharan C [7] tested cooling output is not continuous in single adsorption refrigeration cycle system. A minimum of two adsorbed is required to obtain a continuous cooling effect (when the first adsorbed is in the adsorption phase, the second adsorbed is in desorption phase). These absorbers will sequentially execute the adsorption-desorption process. The efficiency of the basic adsorption refrigeration cycle is low, and the cooling output is not continuous, many advanced adsorption refrigeration cycles (such as the heat recovery cycle, mass recovery cycle, thermal wave cycle, forced convective thermal wave cycle, etc.) have been developed by different investigators with improve efficiency and practicability [10,12,13,15]. The technology of solar adsorption refrigeration is satisfied the Montreal protocol and Kyoto protocol on ozone layer depletion and global warming concern [8]. The solar power based refrigeration system is simple and is adaptable for small, medium or large type low grade energy recovery systems because adsorption unit of solar adsorption refrigeration does not possess any problems of emission of greenhouse gases [9]. Since 1980's large efforts have been made to improve the performance of the adsorption refrigeration system. Sasha *et.al* [14] has analyzed two stage non-regenerative adsorption chiller prototype with experimental results show that the system operated with temperature range of 55-30 ^{0}C. Douses and Meniere [11] had reported experiments on two stage adsorptive heat pump. The cycle consisted of two adsorbed zeolite-water system at higher temperature stage and activated carbon-methanol at the low temperature stage. The COP of the system was reported as 1.06, which is higher than the COP of an intermittent cycle.

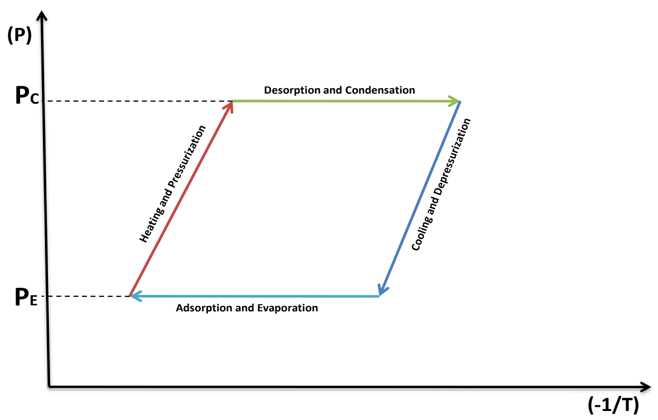

Fig-1: Chaperon diagram- Basic Adsorption cycle [6]

The projected VADRS model in present research work adopted from Mahesh and Kauirik [16] model, that model were used as single bed solar integrated, here double bed VADRS is proposed with two different pair of adsorbent &adsorbate under different source temperature level for more cooling effect with the source of low grade heat.

Many researches have been conducted in thermodynamic (energy-exergy) analysis of thermal utilities for actual performance estimation. Energy of system defines the true performance of system. Dicer and Rosen [19] stated that the exergy is the maximum rate of work, which is obtained from it and passes reversibly to the environmental state. Energy analysis is the theoretical limitations upon a system, clearly pointing out that no real system can conserve exergy and that only a portion of the input energy can be recovered. A. Began [20] introduce entropy generation minimization mechanism, if entropy production is minimized, than useful energy is maximized. Khaliq and Kaushik [21] concluded the combustion chamber exergy destruction is 50% of overall exergy destruction of cycle, and effect of intermediate pressure-ratio and effect two stage of reheating on combined GT-ST power cycle performance by using 2nd law thermodynamic approach. Yang *et al* [22] compared conventional and advanced approach of exergy analysis of supercritical coal thermal power plant. Conventional approach identified exergy destruction of all components, whereas advanced exergyanalysis conclude thermodynamic interactions among thermal utilities for energy saving potential. Kaushalendra and Mishra found maximumexergy destruction in boiler part of thermal power plant analysis. Compressor of conventional refrigeration consumes larger amount of electrical energy with high destruction rate in VCRS, and author also summarize different thermodynamic systems for low to high grade energy recovery from industrial & power plant sector for combined heating-cooling and power generation by using new trends of working fluid in advanced thermal cycles like organic ranking cycle, kalian cycles supercritical organic ranking cycle etc. in efficient manner with environmental aspect [23-27]. More than 45% of energy generation supply to industrial purpose. The industrial sector (oil refineries, cement, glass, steel etc.) and power plant discard large amount of heat with useful energy generation or energy in production into the atmosphere. The novel concepts of wastage heat (low and high grade) recovery technology like ORC, Tri-Generation, Co-Generation, HRSG, Vapor absorption and adsorption refrigeration system with and without integration of solar energy utilization recover waste heat from several process like, kiln and clinker gas flow recovery in cement production plant, oven exhaust heat recovery in glass industry, pre-heating exhaust heat recovery of rolling process in steel industry, and produce power, heating and as well as cooling generation [26].

SYSTEM DESCRIPTIONS AND OPERATION.

The proposed Rankin cycle directly adopted from kaushalendra and Mishra energy-energy analysis of 9 MW thermal power plant[27]. The provision of double bed vapor adsorption system with ranking model in this paper consisted by two bed of vapor adsorption, first bed of VADRS filled by activated carbon-methanol type adsorbent-adsorbate (refrigerant) pair, which recover exhaust heat of condenser of unit and produce cooling effect, another bed of VADRSoccupied with activated carbon-R134a pair of adsorbent-adsorbate (refrigerant) and derive by solar water heater system. The selection of above pairs basically depend of source temperature for adsorption bed, and thermo physical properties of pair for required cooling load. The all components are shown in table-1 unit description. The main components of VADRS are generator for heating of bed (generators may be solar thermal system or any thermal utilities), adsorption bed, condenser, evaporator and chilling chamber. Stainless steel fabricated adsorption bed consisted of two chambers, inner chamber (9& 17), which is filled with activated carbon as adsorbent and methanol for first VADRS&activated carbon-R134a for second Verses a adsorb ate or refrigerant for adsorption cooling, and outer chamber (8& 16) for hot water chamber for desorption process of pair used, that hot water is supplied from condenser of unite bed-1, and similar from ETC solar thermal collector (24) to bed-2.In the inner chamber, one end was connected to the condenser (11 & 19,VAdRS condensers) to receive desorbed liquid condensed by the condenser. The outer chamber covers the inner chamber. The outer chamber consisted of two pipes. The two pipes were placed in the lower and upper sides of chamber (shown in fig.2). In the outer chamber, one end is connected to outlet of condenser for bed-1 and similar for bed-2, outer chamber end connected to outlet of ETC solar thermal collector. The hot water is circulated through the generators to adsorption bed (1 & 2 both)60 ^{0}C temperature of hot water from condenser caused the activated carbon to desorb the refrigerant in bed-1.Then refrigerant vapor was condensed with the help of a condenser and it was stored in the evaporator. The evaporator was placed inside the chilling chamber. Similar event happened in bed-2, during day time temperature of collector increased above 80 ^{0}C and hot water cause the desorb the R134a from activated carbon. For bed-1, valves v1 and v2 open for desorption, condensation and evaporation process and other hand valve v3 kept in close position, and during adsorption of refrigerant in adsorbent, v3 is open and v1 & v2 are closed. For bed-2, during daytime valves v4 and v5 open for same desorption, condensation and evaporation process and other hand valve v6 kept in close position. After sunset, collector temperature has been decreased to ambient temperature, the valves v4 & v5 were closed and the valve v6 kept open to allow refrigerant for adsorption process. Valves v7 & v8 regulate hot and cold water respectively from solar collector to adsorption tank and its vice-versa is valid. Desorption process occurs here during day time and adsorption process took place during night. The provision of another valves v9 & v10 are specific here, solar integrated Vader's does not work during night, so hot water from condenser can help for desorption of refrigerant from adsorbent for cooling process, valves v9 is allow to hot water from condenser and v10 is pass the cold water from adsorption tank or bed-2 and water mixed with feed water pump line and pumped to the boiler. This circuit is important part of proposed model for effective cooling during night time.

PROPOSED MODEL OF COMBINED POWER AND VADRS SYSTEM

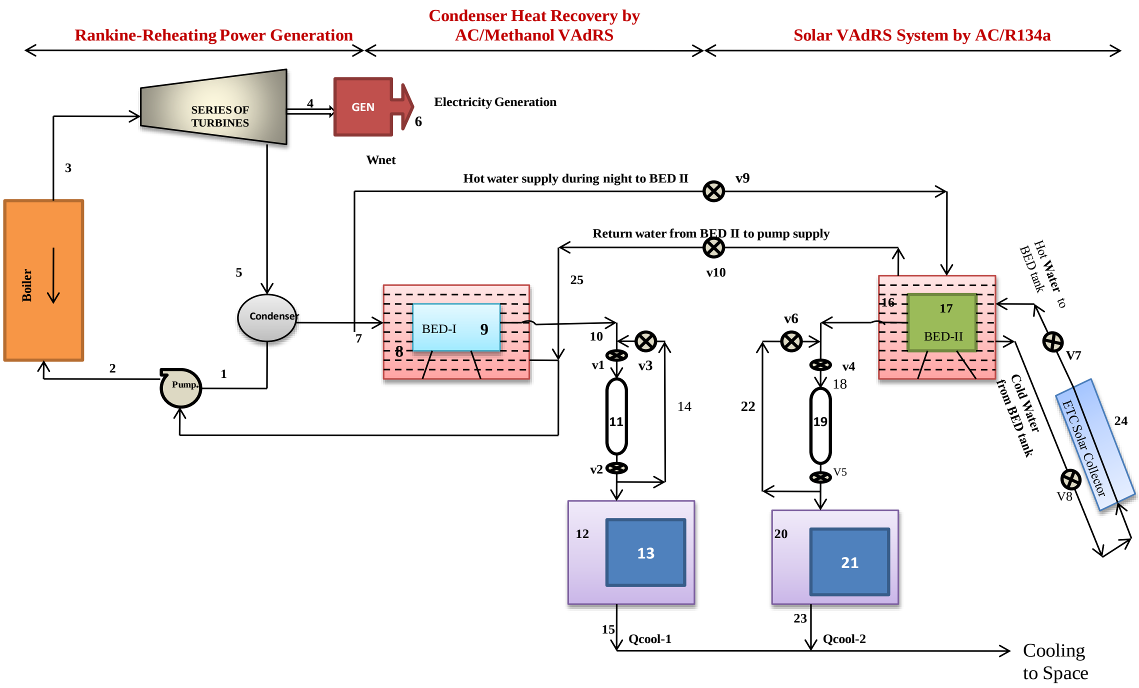

Fig-2: Schematic of combined power and VADRS system

Table-1Unit specification of combined plant

UNIT NO	SPECIFICATION	UNIT NO	SPECIFICATION
1	Condensed steam feed to pump	21	Chiller get to be cooled during evaporation
2	Feed water supply to boiler for steam formation	22	Evaporated refrigerant adsorbed in adsorbent bed
3	Steam from boiler supply to series of turbine	23	Chilled air supply to space where cooling is required through cooling line.
4	Turbine shaft work for electricity generation	24	ETC solar thermal water heater for hot water supply to BED-2.
5	Exhaust steam from turbine supply to condenser unit for condensation process	25	Return cold water from BED-2 and mixed with water line for pumping to boiler.
6	Generator work	v1	Valve 1 open and allow to vaporized

			refrigerant into condenser for condensation
7	Hot water proceeds to BED-1 and only during night to BED-2 for adsorption cooling process.	v2	Valve 2 allow Condensed refrigerant into evaporator and chiller unit.
8	Outer chamber of BED-1 for hot water collection, (need of hot water for adsorption of heat from adsorbate).	v3	Valve 3 open for adsorption of vapor refrigerant into adsorbent bed after evaporation.(v1 & v2 remain closed when adsorption is happening)
9	Inner chamber of bed -1, where Activated carbon-Methanol pair is filled, Its utilize condenser heat.	v4	Valve 4 open and allow to vaporized refrigerant into condenser for condensation
10	Vapor refrigerant (Methanol) supply to condenser of Vader's after desorption process.	v5	Valve 5 allow Condensed refrigerant into evaporator and chiller unit.
11	Refrigerant liquefy by using condenser	v6	Valve 6 open for adsorption of vapor refrigerant into adsorbent bed after evaporation.(v1 & v2 remain closed when adsorption is happening)
12	Liquid refrigerant get evaporation by evaporator	v7	Valve 7 open for hot water supply from ETC to BED-2 for desorption of refrigerant.(V9 & V10 are closed)
13	Chiller get to be cooled during evaporation	v8	Valve 8 open for cold water return in to ETC after desorption. (V9 & V10 are closed)
14	Evaporated refrigerant adsorbed in adsorbent bed	v9	V9 works during night, when ETC does not work. It opens for hot water supply from condenser exhaust to BED-2.
15	Chilled air supply to space where cooling is required through cooling line.	v10	V 10 allows return cold water from BED-2 after adsorption and water mixed with water line for pumping into boiler.
16	Outer chamber of BED-2 for hot water collection, (need of hot water for adsorption of heat from adsorbate).	Turbine	Series of High pressure turbine and low pressure turbine.
17	Inner chamber of bed -2, where Activated carbon-R134a pair is filled, Its utilize condenser heat.	GEN	Generator for electricity generation.
18	Vapor refrigerant (R134a) supply to condenser of V.Adms. After desorption process.	BOILER	Steam formation thermal utilities
19	Refrigerant liquefy by using condenser	CONDENSER	Condensation of exhaust steam and refrigerant vapor condensation process

THERMODYNAMIC ANALYSIS OF COMBINED RANKINE THERMAL AND VAPOR ADSORPTION SYSTEM

The thermodynamic analysis of the Combined Thermal and Vapor Adsorption Plant is consisting in the following parts as mentioned below.

ENERGY AND EXERGY ANALYSIS OF RANKINE CYCLE.

A simplified mathematical model of basic thermodynamic approaches is used in analysis. Mass and energy balance equations has been applied in all thermal utilities. In order to simplify

The analysis, some assumptions are generally made as follows:

A.The process is considering steady flow throughout working of system and thermal utilities also consider as a control volume (CV).

B.The state of the mass at every point within the control volume (CV) does not vary with time.
C.The mass flow rate into and out of the control volume does not vary with time.
D.The efficiencyof both turbines and pump assumed isentropic for analysis.
E.The thermodynamic equilibrium exits in the adsorbent bed at any given time.
F.The refrigerant is adsorbed uniformly in the adsorber and is liquid in the adsorbent,
G.The heat conduction from the adsorber to the condenser and to the evaporator through the metal is neglected.
H.The evaporating temperature is identical to the temperature of the liquid in the evaporator.
I.The specific heat of adsorbed adsorbateis equal to that of bulk liquid of adsorbate.
J.The resistances to the heat and mass transfers in the adsorbent are neglected.

All equations of analysis is fundamental approach of 1st law and 2nd law of thermodynamics, and properties (enthalpy,entropy,specificheat,specificvolume,etc) of steam formation referred from steam property table Data [17]as per steam condition (superheated and saturated) and working refrigerants fluid at different pressure-temperature level. [17]and[18] given energy-exergy equations for power-plant analysis as given below.
The thermal efficiency of plant is expressed by following equation

$\eta_{PLANT} = W_{NET} / Q\_{BOILER}$ ……………………..…...(1)

Where Network done by plant is expressed as

$W_{NET}=W_{TURBINE\_TOTAL}-W_{PUMP}$…………………………………….………...(2)

The Total work done by Turbine is a addition of work one by each turbine as given below

$W_{TURBINETOTAL}=W_{TURBINE\_1}+W_{TURBINE\_2}+W_{TURBINE\_3}$……………………… (3)

$W_{TURBINE\_1}$=m_dot_turbine1_steamflow (h_temp inlet_turbine1-h_temp exit_turbine1)………….……,,,,,……… (4)

$W_{TURBINE\_2}$=m_dot_turbine2_steam flow(h_tempinlet_turbine2-h_temp exit_turbine2)……………….…,,,,,,……….…..(5)

$W_{TURBINE\_3}$ = m_dot_turbine3_steamflow (h_temp inlet_turbine3- h_{2s})…………………..……..………,,,,,.……....(6)

And Work done by pump=$W_{PUMP}=v\times dP=v\times(P_{BOILERLINE}-P_{CONDENSERLINE})$=m_dot_pump(h4s-hf3)…………………..(7)

From enthalpy and entropy balance equation the isentropic enthalpy at the inlet of condenser (h_{2s}) is expressed as
$h_{2s}=h_{f2}+x_2h_{fg2}$……………………………………………………… (8)
x_2 is steam dryness fraction at condenser
$s1=s_{2s}=s_{f2}+x_2\ s_{fg2}$…………………………….…… (9)

Heat Generated by boiler

Q_{BOILER}=m_dot_boiler_steam_flow (h_boiler temp - h4s)………………………………………………(10)

The energy balance in the condenser is expressed by following equations

$W_{TURBINETOTAL}-W_{PUMP}=Q\_{BOILER} - Q\_{CONDENSER}$………………..…………………...(11)
$\eta_{Boiler}= Q\_{BOILER} / Q\_{FUEL}$…………………….…(12)

WhereQ_{FUEL}=(m_air+m_fuel)×fuelcalorificvalue…...(13)

THERMODYNAMIC MODELLING OF DOUBLE BED VAPOUR ADSORPTION REFRIGERATION SYSTEM

The desorbed of both beds are heated by the waste heat of condenser and solar collector to begin desorbing, and the condensation process occurs firstly in the evaporator because the evaporator temperature is lower than the condenser temperature at that time. Such process will continue until the evaporator temperature rises higher than the condenser temperature. Thereafter, the condenser will be in condensing mode, and the evaporator will be idle. Therefore, in the whole desorption process, the energy equilibrium equations can be described as: The total heat input to the system is estimation of energy liberated during adsorption is called esoteric heating and heat due to desorption [8].

The total energy input to the system is given by

$Q_{heat\_total}=Q_{isosteric}+Q_{desorption}$.............................. (14)

The total heat generated from vapour adsorber bed is given below [16]

$Q_{heat\_total} = \sum m_{ad} [(Cp_{ad} + Cp_r*X_{max})(T_g - T_{ad}) + (Cp_{ad} + \Delta X/2)(T_{des} - T_g) + \Delta X*H_D]_{BED\text{-}1\ \&\ BED\text{-}2}$...........(15)

After condensation of desorbed refrigerant, the liquid refrigerant in the evaporator will absorb the heat of vaporization from liquid to be cooled, this cause the refrigeration effectand the refrigeration amount can be estimate as-

$Q_{Ref} = \sum [(m_{ad} *\Delta X * L_E)]_{BED\text{-}1\ \&\ BED\text{-}2}$.................(16)

The amount of energy used in cooling the evaporated absorb ate when passing through the condenser is given by-

$Q_{Cool}= \sum [(m_{ad} * \Delta X * Cp_r (T_C-T_E)]_{BED\text{-}1\ \&\ BED\text{-}2}$....(17)

The useful cooling of vapor adsorption system can be estimated by

$Q_{cool\ useful} = \sum m_{ad} [(L_E * \Delta X - Cp_r (T_C-T_E)]_{BED\text{-}1\&2}$. (18)

3.3 PERFORMANCE PARAMETERS INVOLVED IN THE DOUBLE BED VAPOUR ADSORPTION REFRIGERATION SYSTEM

The compactness of system is important parameter, Useful cooling per unit mass (specific cooling power) of adsorption system decide the compactness or size of system. Desorption and Adsorption time (second) play key role for cooling effect in the Vader's and its SCP sizing.

$\mathbf{SCP_{VADRS}} = Q_{cool\ useful} / m_{ad}$...............................(19)

Or coefficient of performance of Vader's (is a ratio of useful cooling and total heat input for adsorption and desorption account the refrigeration capacity) is given by following expression

$\mathbf{COP_{VADRS}} = Q_{cool\ useful} / Q_{heat\_total}$..................... (20)

Similarly the solar thermal system COP is a ratio of refrigeration effect of solar vapor adsorption refrigeration system to the solar heat generation.

$\mathbf{COP_{SOLAR}}= Q_{cool\ useful} / Q_G$ ….........................(21)

Where $Q_G = I * Ac$

3.4. EXERGY ANALYSIS OF COMBINED THERMAL AND VAPOR ADSORPTION PLANT

Exergy flow rate of inlet steam-

$€_{f\_1n}$ = m_dot_steam × cp_boiler steam × to $[\frac{Tboiler}{To} - 1 - ln\frac{Tboiler}{TO}]$……………………… (22)

Exergy flow rate of exhaust steam-

$€_{f\_out}$ = m_dot_steam × cp_boiler steam × to $[\frac{Tboiler}{To} - 1 - ln\frac{Tboiler}{TO}]$……………………… (23)

Rate of exergy increase of steam = Exergyutilization rate= $€_{f\_Usefull}$

$€_{f\_Usefull}$ = m_dot_steam [h1-h4s-To (s1-s4s)]…………………………………………… (24)

Exergy Destruction in boiler=$€_{Des\_boiler}$ = Rate of exergy increase of steam - Rate of exergy decrease
Exergy flow rate of wet steam to condenser

$€_{wetsteam\ to\ condenser}$ = $m_{\_\ wet\ steam\ to\ condenser}$ [h2s-hf3-To (s_2-sf_3)]…………………………..………...…….(25)

Irreversibility estimation of each components-

I_{RR}= ToΣΔS = To (ΔS_{boiler}+ $\Delta S_{turbine}$+ $\Delta S_{condenser}$+ΔS_{pump}+$\Delta S_{Bed\text{-}1}$+$\Delta S_{Bed\text{-}2}$+ΔS_{solar})…….(26)

And $\Delta S = cp\ln(\frac{Tout}{Tin})$……………………………..(27)

(cp will vary with temperature and pressure condition of working fluid, putting all value of cp and Tout&Tin of components)

Now EDRratio = $\frac{To\Sigma\Delta S}{Qboiler}$…………………..…….(28)

Exergetic efficiency = η_{EX} = 1- EDR_{ratio}……..…(29)

Exergy Destruction Rate = $\frac{To\Sigma\Delta S}{Wnet}$……………… (30)

Rate of exergy loss in boiler= $\frac{€f\_out}{€f\ in}$……………. (31)

RESULTS AND DISCUSSIONS

The operational data of thermal power plant is provided in table-2(a) & (b), all data measured in February month2015 in daily basis, but for analysis average data is taken. (plant data referred from Adani Thermal Power Plant, Gujarat, India)

Table-2(a)-Plant Operational data (average data on daily basis)

Time	CW FLOW	Temperature		Ambient Conditions			Condenser		
		CW - IN	CW - OUT	DBT	RH%	WBT	Vacuum	Temp	Flow
	(m3/hr)	(ºC)	(ºC)	(ºC)	(%)	(ºC)	(Kg/cm2 g)	(ºC)	(TPH)
All day	**2376.22**	**28.67**	**39.89**	**28.00**	**50.00**	**20.30**	**-0.94**	**43.54**	**13.66**

Table-2(b)-Plant Operational data (average data on daily basis

Time	Inlet Steam			Extraction 1 & 2			Extraction 3			Generation
	Pressure	Temp	Flow	Pressure	Temp	Flow	Pressure	Temp	Flow	
	(Kg/cm2 g)	(ºC)	(TPH)	(Kg/cm2 g)	(ºC)	(TPH)	(Kg/cm2 g)	(ºC)	(TPH)	(MW)
All Day	**61.87**	**473.90**	**68.80**	**14.14**	**323.19**	**15.76**	**2.52**	**182.61**	**40.17**	**9.41**

h1=h_temp inlet_turbine3 = 2827.18 KJ/Kg….temp at 180 ^{0}C (inlet temp of turbine3)

s1=s2 = 7.353 kJ/kg-K from steam properties at condenser line pressure of 0.098 bar (absolute)

h3=hf3=hf2=184 kJ/kg from steam properties
s4=s3=sf2=0.629 kJ/kg-K
hfg2= 2397.95 kJ/kg

sfg2= 7.591 kJ/kg-
Sp Volume of saturated steam at condenser line v=0.001009 m3/kg
Put all values of entropy and get x2=0.91 and estimate h2s from eq. no7
h2s=2376KJ/kg
Now total turbine work (mass flow rate of steam for different turbine provide in plant data table-1 (a)&(b),providing all values of enthalpy as per inlet temperatures Values of turbines)
$W_{TURBINE\ TOTAL}$ = 960 kJ/kg or 8.5 MW (flow rate of steam varying daily with time)
h4s = 184.06 kJ/kg
W_{PUMP}=184 kJ/kg or 437KW at 8.5TPH of water flow through pump
W_{NET} = 8.2-0.43 = 7.77 OR 7.8MW
(Steam flow through boiler is 65TPH from data table)
Q_{BOILER} = 3196 kJ/Kg or 58627 KW
η_{PLANT} = 24.12%
(4620 kcal/kg as per data)
η_{Boiler} = 11%

(13 TPH of coal feeding with 97 TPH of air)
[Solar Irradiations (I) is taken 800-900 W/m^2 as per site, and aperture area of ETC is 6m^2 as per design]
(Steam generation inlet temperature is 485±5^{0}C, 75TPH and specific heat of steam 2.21 kJ/kg-k, atmospheric temp To is 298K)
$€_{f\_1n}$ = 387 kJ/Kg or 7715KW

(Steam temperature exhaust is 320 ^{0}C, 75TPH and specific heat of steam 2.21 kJ/kg-k, atmospheric temp To is 298K)
$€_{f\_out}$= 260 KJ/Kg or 5240KW

Rate of exergy decrease- $€_{f\_1n}$ - $€_{f\_out}$= 127 KJ/Kg or 2475 KW
Rate of exergy loss in boiler = $\frac{€f\_out}{€f\_in}$ = 0.47

$€_{f\_Usefull}$= 1172.10 KJ/Kg or 23547.5KW
$€_{Des\_boiler}$=1045.1 KJ/Kg or 21072.5 KW
(26THP of wet steam passing through condenser)
$€_{wet\ steam\ to\ condenser}$ = 188.25 KJ/Kg or 1350.44 KW
I_{RR_Boiler}= To(ΔS)$\_{boiler}$ = 1086 KJ/Kg
$I_{RR\_turbine}$= To(ΔS)$\_{turbine}$ = 419 KJ/Kg
$I_{RR\_condenser}$= To(ΔS)$\_{cond}$ = 124 KJ/Kg
I_{RR_pump}= To(ΔS)$\_{pump}$ = 61.17 KJ/Kg
I_{RR_Bed-1}= To(ΔS)$\_{Bed1}$ = 59.57KJ/Kg
I_{RR_Bed2}= To(ΔS)$\_{Bed2}$ = 59.31KJ/Kg
I_{RR_Solar}= To(ΔS)$\_{solar}$ = 364.77 KJ/Kg
EDR ratio = 0.63

η_{EX} = 1- EDR_{ratio}= 0.37

Exergy Destruction Rate = 2.8

The performance parameters of combined thermal power plant and VADRs are given in the tables 3(a), 3(b) and table no4.It is observed that COP of bed-2 is more than bed-1, because solar generator provides more temperature comparison to condenser, but maximum exergy destruction found in solar generator in exergy analysis of plant.

Table-3(a), Performance of Adsorption bed-1

COP_{TH}	Q_{COOL}(kJ)	Q_{HEAT}(kJ)	Q_{REF}(kJ)	SCP(kW/kg)	T_{GEN} (K)
0.488	854.6	33543	17222	23.32	328
0.4852	1688	58643	30139	40.53	333
0.4803	2687	84050	43056	57.51	338
0.4749	3850	109765	55973	74.25	343
0.4692	5179	135787	68890	90.76	348

Table-3(b), Performance of Adsorption bed-2

COP_{SOLAR}	COP_{TH}	I_G (W/m^2)	Q_{COOL}(kJ)	Q_{HEAT}(kJ)	Q_{REF} (kJ)	SCP (kW/kg)	T_{GEN}(K)
0.4811	0.507	750	1570	19858	11638	38.18	333
0.5529	0.482	775	1865	24804	13820	45.34	340.5
0.6202	0.4593	800	2159	30136	16002	52.49	348
0.6834	0.4387	825	2454	35855	18184	59.65	355.5
0.7429	0.4199	850	2748	41961	20366	66.81	363

Table-4, Parametric Results of VA pour adsorption Refrigeration system combined with Rankin Thermal power plant

Thermodynamics Parameters	Computed Results
Net Out Put (Wnet)	**7.8MW**
Total Turbine Out Put (Wturbine)	**8.5 MW**
Boiler Heat Generation (Qboiler)	**3196KJ/KG**
Plant Efficiency (η_{PLANT})	**24.12%**
Boiler Efficiency (η_{BOILER})	**11%**
Plant Exergy Destruction Rate	**2.8**
Plant Exergetic Efficiency (η_{EXERGY})	**37%**
COP of VAdRS ($COP_{COMBINEDVADRS}$)	**0.46 to 0.51 (13-15% increment in overall COP)**
Sp.Cooling Power ($SCP_{COMBINEDVADRS}$)	**70-90 W/kg (10-16% increment in overall SCP)**
COP gain by Solar energy (COP_{SOLAR})	**0.48-0.74 (most effective COP)**
Maximum Exergy Destruction of plant	**47% (during steam generation)**

The performance of proposed combined solar integrated vapor adsorption refrigeration system for condenser heat recovery is estimated using basic fundamental of thermodynamic. Parametric results of double bed vapor adsorption refrigeration system for heat recovery of Rankine condenser, the overall COP and SCP enhanced by 10-16% shown in figure 3(a) & (b). Solar based vapor adsorption bed gives more COP individually as compare to condenser connected vapor adsorption bed. The specific cooling power (SCP) of solar vapor adsorption bed is increasing but increasing of evaporation temperature will decrease the SCP of solar vapor adsorption bed due to conversion of solar gain into heating ($Q_{heat-solar}$) by double rate. The variation of SCP between solar and without solar (bed-1 and bed-2) shown in figure no4.

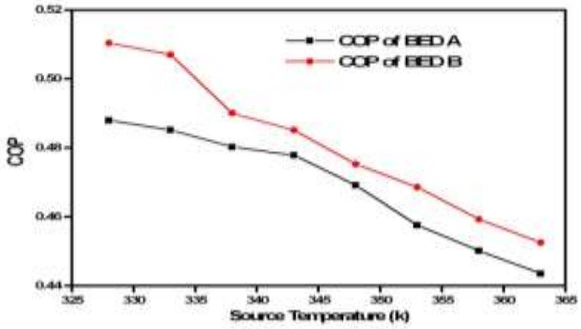

Fig-3(a), COP Vs. Source Temperature

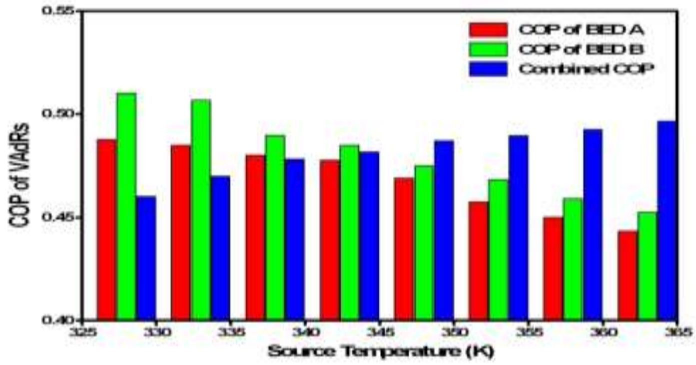

Fig-3(b), COP Vs. Source Temperature

A) **Chaperon diagram- Basic Adsorption cycle [6]**

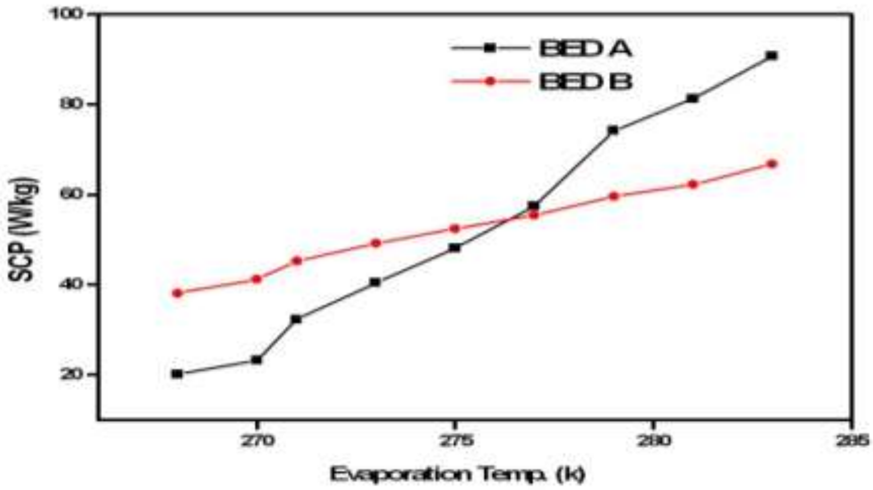

Fig-4, SCP and Evaporation Temperature

CONCLUSION

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. Increasing the attention on waste heat recovery through adsorption system. The 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, and the forced convection cycle. Research has shown that solid-adsorption technology has a promising potential but still limited for commercialization and a under laboratory testing stages.

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. The maximum irreversibility found in boiler in thermal power plant and solar generator of adsorption machine, whereas overall cooling effect from adsorption system is increasing by 15% in double bed combination. Some results have been found in present analysis.

1. The maximum energy destruction (irreversibility) found in boiler as 47% in thermal power plant and 12% estimated in solar generator of cooling plant...
2. Exergy Destruction is found to be 2.8 (which is the based on output analysis) and o.63 based on input.
3. The thermal power plant efficiency is 24.12%
4. The second law efficiency is 37%.
5. COP and specific cooling power is increased by 13-15% overall of combined bed system of adsorption machine.

The result of present analysis gives minimum energy wastage into environment with more power generation and cooing effect as outcome. These novel concepts helped to low grade waste heat recovery with eco-friendly solar refrigeration opportunities to mini and micro scale of power generating industry.

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NOMENCLATURES

ETC-Evacuated Tube Collector
WEC-World Energy Council
COP-Coefficient of Performance
AC-Activated Charcoal
ORC-Organic Rankine Cycle
CFCs-Chlorofluorocarbons
HFCs-Hydrofluorocarbons
GWP-Global Warming Potential
CV-Control Volume
I=Solar Irradiation
EES-Engineering Equation Solver
VADRS-Vapour Adsorption Refrigeration System
BTU-British Thermal Unit
SCP-Specific Cooling Power
GHG-Green House Gas
HVAC-Heating Ventilation & Air-Conditioning
HCFCs–Hydro chlorofluorocarbons
ODP-Ozone Depletion Potential
HRSG-Heat Recovery Steam Generator
VCRS-VA pour Compression Refrigeration System
Ac=Aperture area of ETC

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