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Solar Integrated Energy Efficient Systems for Waste Heat Recovery of Power Generation Industry Using Different Eco-Friendly Energy Materials

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Abstract-

The two major issues are being disused in these days globally, CO_2 concentration in atmosphere on one hand and energy crisis on other hand. All promising savings of reducing CO_2 generation, fossil fuels depletion, control in energy prices increments, achievable by adaptation of eco-friendly energy efficient material based technology. The un-arrested heat discharge from captive power plants, cement production, steel industry, Oil-refineries, like energy intensive industries have tremendous potential for multiple energy generation (heating-power & cooling) for further industrial process with dumped heat recovery. This paper explores eco-friendly material R134a and activated carbon-methanol based organic Rankine model and solar integrated vapor adsorption cooling system for waste heat utilization of condenser unit of steam power plant. The results of proposed model analysis is to explain the environmental parameters of used material, effect of operating parameters and cooling-power output.

Keywords

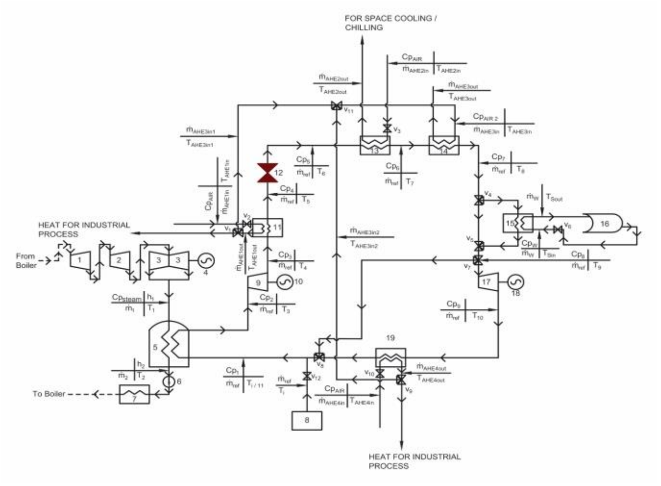
Global Warming Potential, Ozone Déplétion Potential, Solar Integrated Waste Heat Recovery System.

1. Introduction

The uncovered heat from power plants and heavy industry is dumped into atmosphere and it causes of severe impact on atmosphere in terms of green house effect. The US Dept of Energy reported that the cement/ captive power plants have, nearly 35% heat is lost, and this corresponds to around 70 to 75 MW of thermal energy. EPA estimated that the 65% of world CO_2 emission is recorded from green house gas emission from fissile fuel burning during intensive industrial process [1,2]. This un-used or waste heat have tremendous potential to generate heating-power and cooling generation for industrial process by using eco-friendly material based novel thermodynamic system like, organic rankine system (ORC), kalina system for cooling-power generation, vapor absorption and adsorption refrigeration techniques. The employment of solar energy will enhance the system performance. All these systems work as waste heat recovery generator (WHRG). For a 6000 ton per day (tpd) capacity of cement plant can be reduced around 70,000 ton/annum of CO_2 by installation of WHRG [1]. The proposed analysis is concern with the condenser heat recovery of reheating-rankine steam power plant by using eco-friendly material based ORC and vapor adsorption cooling system for simultaneously power and cooling generation. Two models have been analyzed in this paper, model 1 (fig-1) integrated with solar ORC and model 2(fig-2) equipped with double bed adsorption refrigeration system. Model2 has two different adsorber beds, bed1 is connected with condenser outlet of reheating-rankine steam plant and AC-Methanol (Activated Carbon)material pair is used and bed2 integrated with solar parabolic collector for condenser water heating that heated water circulating to bed2 for generator purpose. The main objective of this analysis to estimate the multiple thermal effect (heating-power and cooling) from available un-covered heat of power plant by using different novel thermal system. The application of R134a and AC-Methanol type material helps to produce required cooling effect at low grade of thermal availability with environmental safety aspect.The numerous researches have been developed and analyzed eco-friendly material based novel thermodynamic model in environmental concern. The selection of a suitable working material depends on its great influence in the design of the process, application, heat source and the temperature level. The used material must have optimum thermodynamic properties at the lowest possible temperatures and pressures, and also satisfy several criteria such as economical, nontoxic, nonflammable, environmentally friendly. An extensive literature review of R134a was chosen as working fluid. This selection has been done on the basis that R134a: is a nontoxic and nonflammable fluid and its Ozone Depletion Potential (ODP) is zero. R134a has a high molecular mass (chemical formula: CF3CH2F, MM=102kg/kmol). It has a temperature and critical pressure of 101.1ºC and 40.6 bar, respectively, R134a based heat recovery ORC of condenser operates at a higher pressure than atmospheric, and therefore air in-leakages do not occur. [3,4-6] Several researchers have investigated the application and performance of ORC with R134a as a working fluid, the efficiency of the ORC using benzene, ammonia, R134a, R113, R11 and R12 was analyzed [7-9] An analysis of a regenerative ORC based on the parametric optimization, using R12, R123, R134a, and R717 as working fluids superheated at constant pressure was carried out and. results revealed that selection of a regenerative ORC during overheating using R123 as working fluid appears to be a good system for converting low-grade waste heat to power[10]. In a low-temperature solar organic Rankine cycle system was designed and built with R134a as working fluid that works between 35.0ºC and 75.8ºC for reverse osmosis desalination in Greece, the results showed a system efficiency of about 7% and 4%, respectively. Other studies that have analyzed the use of R134a as working fluid in the ORC cycles for reverse osmosis desalination at an experimental level [11-13], and also as a theoretical manner showed a simulation to estimate the increase in the efficiency and the energy available for desalination of an upper ORC coupled with a lower ORC with R134a, obtaining an efficiency for the latter of 4.2%. Other cycles with R134a for applications for geothermal sources are reported also and R134a integrated with internal combustion engine for heat recovery as bottoming cycle [14-23]. The overall screening of all heat recovery fluids R134a was found to be the most suitable in terms of most eco-friendly, non-toxic, high thermal performance for cooling and power generation with optimized system. Another category of energy recovery material for green refrigeration technology is vapor adsorption refrigeration. Activated carbon is a form of carbon that has been processed to make it extremely porous, and it has a large surface area available for adsorption. Methanol and ammonia are the most common refrigerants paired with activated carbon. Activated carbon−methanol is one of the most promising working pairs in practical systems because of its large adsorption quantity and low adsorption heat (about 1800 to 2000 kJ·kg–1[24]. Low adsorption heat is beneficial to the system's performance because the majority of heat consumption in the desorption phase is the adsorption heat. Another advantage of activated carbon−methanol is low desorption temperature (about 100°C), which is within a suitable temperature range for using solar energy as a heat source. Activated carbon−ammonia has almost the same adsorption heat as the activated carbon−methanol working pair.The drawbacks of this working pair are the toxicity and pungent smell of ammonia. Silica gel is a granular, highly porous form of silica made synthetically from sodium silicate. For the silica gel−water working pair, the adsorption heat is about 2500 kJ/kg and the desorption temperature could be as low as 50°C [24-25].

Model-1 -R134a Based Solar Integrated ORC Waste Heat Recovery System.

Model-2-Activated Carbon based Solar Integrated Vapour Adsorption Cooling System For Condenser Waste Heat Recovery.



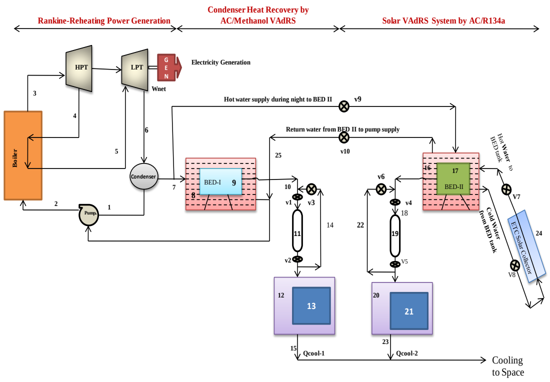
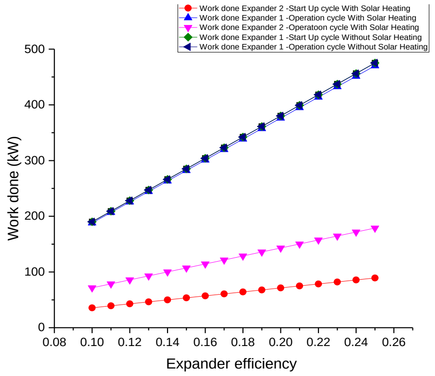


Fig-1, Schematic of R134a Based ORC heat recovery Unit (Model-1)

Fig-2: Solar Integrated Vapor Adsorption System for Condenser Heat Recovery (Model-2)

3. Results and Discussion

Increasing the mass flow rate of air in HE2 increases the heat obtained thereby reducing the cooling effect and heating the air more. In operation cycle with solar heater the change in heat obtained and the rise in air temperature for a small increase in mass flow rate of air is much more than that in the operation cycle without solar heater. Fig 3 depicts the efficiency of scroll type expander is in the range of 14% to 25% of model1. The expander in case of cycle without solar integration will do more work. In case of solar integration, more heat for industrial process will be obtained.



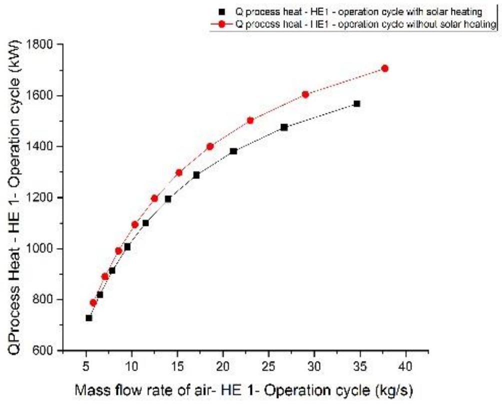


Figure 3: Effect of expander efficiency on work done by expander

Figure 4: Effect of mass flow rate of air flowing through HE 1, on Q process heat in operation cycle and startup cycle

Fig 4 explains that when solar heating is not implemented, the heat for process obtained from HE 1 will be more in both cycles than that obtained when solar heating is implemented. Moreover, the gain in the heat obtained from HE 1, for process, per unit increase of mass flow rate of air passing through the HE 1, in case of operation cycle, is greater when solar heating is not implemented than when solar heating is implemented. All parametric results are concluded in Table 1&2 of both model 1&2.

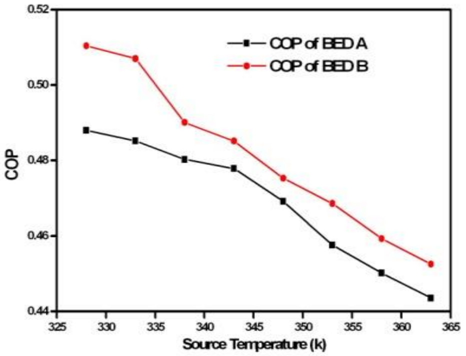


Fig-5 COP Vs Source Temp Of VADRS

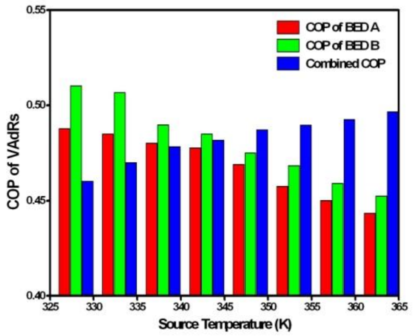


Fig-6-Cpmbined COP Vs Source Temp of VADRS

Table-1-Parametric Results Of ORC Heat Recovery System

Parametric Results	Cycle without solar	Cycle with solar
$\eta_{thermal}$	8-15%	12-27%
$\eta_{expander}$	10-25%	10-25%
Process Heat ($Q_{process\ heat}$)	900-1100 kW	1200-1500 kW
Cooling Effect ($Q_{Cooling}$)	14- 19.25 kW	35- 38.5 kW
Expander work ($W_{expander}$)	200-470 kW	260-650 kW
Solar Heating (Q_{Solar})	N/A	460 kW
Solar Collector Efficiency	N/A	20-25%
Water Temp through solar field	N/A	343.15-363.15 K

Table-2, Parametric Results of combined double bed vapor adsorption System

Performance Parameter	Resultant Values	Performance Parameter	Resultant Values	Performance Parameter	Resultant Values
Turbine work output (W_{HPT}& W_{LPT})	294.7 & 1072 kJ/kg	Condenser heat exhaust (Q_{OUT})	2133 kJ/kg	COP of combined VAdRS ($COP_{COMBINEDVADRS}$)	0.46 to 0.51 (13-15% increment in overall COP)
Pump Work (W_{PUMP})	16.23 kJ/kg	Plant Efficiency (η_P)	0.388	Sp. Cooling Power ($SCP_{COMBINEDVADRS}$)	70-90 W/kg (10-16% increment in overall SCP)
Boiler Heat Generation (Q_{IN})	3484 kJ/kg	Net Work Output (W_{NET})	1350 kJ/kg	COP gain by Solar energy (COP_{SOLAR})	0.48-0.74 (most effective COP)

4. Conclusions

The selection of a suitable working material depends on its process, application, heat source and the temperature level. The used material must have optimum thermodynamic properties at the lowest possible temperatures and pressures, and also satisfy the several criteria such as being economical, nontoxic, nonflammable, and environmentally friendly. All conventional refrigeration systems consume precious fuel or electricity to attain refrigeration. ORC and Adsorption systems are heat-operated units that need only heat in terms of un-covered heat from the energy intensive sectors, so they can utilize waste heat and generate multiple effects like heating, power and cooling. The major conclusion are drawn from both model analysis-

1. Cycle with solar coupling provides more heat for process. This is nearly two times that of the heat provided for process by the cycle without solar coupling, but the total work achieved in case of solar heating is less than that achieved without solar heating.
2. More power from the expanders is achieved when solar heating is not implemented. This is due to the heat generated by the solar heater is converted into process heat. Therefore, solar integration is recommended, for the purpose of obtaining more process heat, in summer and for the purpose of power generation in winter.
3. Solar integrated thermal circuit in combined power generation system enhances the cooling effect due to more heat addition through solar heating in R134a ORC system. R134a will attain superheating, and produce cooling effect.
4. The parametric table-6 concludes that the performance indicators (thermal efficiency, heating and cooling effect) of proposed system is increased by 30-40% using solar system.
5. Parametric results, which are shown in table-9 of double bed, vapor adsorption refrigeration system for heat recovery of Reheating-Rankine condenser, the overall COP and SCP enhanced by 10-16% shown in figure-6.
6. Solar connected 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 (Qheat-solar) by double rate. The variation of SCP between solar and without solar (bed-1 and bed-2) shown in figure-5.
7. The present combination of adsorbent-adsorbate material is suitable for low-grade heat recovery with solar thermal integration for continuous cooling effect generation and applicable for space cooling purpose. The used material R134a and methanol with activated carbon is most suitable pair under the category of eco-friendly material as per AHRAE guidelines of environmental safety protocol.All ecogriendly material have been shown in appendix tables.
8. The different materials have reviewed in present analysis. The two parameters are very important for environmental aspect, like GWP and ODP values. Minimum value of GWP &OPD shows non-toxic and eco-friendly nature of material for power and cooling generation system.The proposed material also applicable for low-grade heat recovery purpose due to its low boiling and freezing temperature.

Abbreviations-

AC-Activated Carbon
ALT-Atmospheric Life Time
ASHRAE-American Society of Heating-Refrigeration and Air-Conditioning System
COP=Coefficient of Performance
CO2= Carbon Dioxide
ETC=Evacuated Tube Collector
GEN=Generator
GWP=Global warming Potential
HE=Heat exchanger
HPT=High Pressure Turbine
LPT= Low Pressure Turbine
ODP=Ozone depletion potential
ORC=Organic Rankine Cycle
SCP=Specific cooling power

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Appendix-

Table-A Energy recovery and its sources [26]

Heat Categories	Heat Sources	Temperature in ^{0}C	Suggested recovery technology
High Grade (>650^{0}C)	Solid waste	650-1000	Air preheating
	Nickel refining furnace	1370-1650	Steam generation for heating
	Copper reverberator furnace	760-815	Thermoelectric and thermal PV
	Glass melting furnace	1000-1550	Heat exchanger for preheating
	Hydrogen plant	650-1000	Thermal PV
Medium Grade (230-650^{0}C)	Steam boiler exhaust	230-480	Steam rankine cycle
	Gas turbine exhaust	370-540	Organic rankine cycle
	Drying and baking ovens	230-600	Thermal PV
	Catalytic crackers	425-650	Thermal PV
	Reciprocating engine exhaust	315-600	Thermoelectric
Low Grade (>230^{0}C)	Welding and injection molding	32-88	Kalina cycle
	Hot processed liquids and solids	32-233	Organic rankine cycle
	Drying, Baking and Curing ovens	93-230	Absorption and adsorption cooling
	Bearing	32-88	Piezoelectric

.

Table-B: Summary of Commercialized Working fluids [27-29]

S. No	Working Fluids	Physical Data				Safety Data	Environmental Data		
		Molecular Mass (Kg/K mol)	**Normal Boiling Point Temp (T_{bp}) in ^{0}C**	**Critical Temp (T_{criti}) in ^{0}C**	**Critical Pressure (P_{criti}) in MPa**	**ASHRAE Group**	**Atmospheric Life Time (ALT) in years**	**Ozone Depletion potential (ODP)**	**Global Warming Potential (GWP) of 100 years**
1	RC118	200.03	-6.0	115.2	2.778	A1	3200	0	10225
2	R600a	58.12	-11.7	135	3.647	A3	0.017	0	˜˜20
3	R114	170.92	3.6	145.7	3.289	A1	300	1.00	10040
4	R600	58.12	-0.5	152	3.796	A3	0.018	0	˜˜20
5	R601	72.15	36.1	196.5	3.364	NA	0.01	0	˜˜20
6	R113	187.38	47.6	214.1	3.439	A1	85	1.000	6130
7	Cyclohexane`	84.16	80.7	280.5	4.075	A3	NA	NA	NA
8	R290	44.10	-42.1	96.68	4.247	A3	0.041	0	~20
9	R407C	86.20	-43.6	86.79	4.597	A1	NA	0	1800
10	R32	52.02	-51.7	78.11	5.784	A2	4.9	0	675
11	R500	99.30	-33.0	105.5	4.455	A1	NA	0.738	8100
12	R152a	66.05	-24.0	113.3	4.520	A2	1.40	0	124
13	R717 (Ammonia)	17.03	-33.3	132.3	11.333	B2	0.1	0	<1
14	Ethanol	46.07	78.4	240.8	6.148	NA	NA	NA	NA

15	Methanol	32.04	64.4	240.2	8.104	NA	NA	NA	NA
16	R718 (Water)	10.2	100	374	22.064	A1	NA	0	<1
17	R134a	102.03	-26.1	101	4.059	A1	14.0	0	1430
18	R12	120.91	-29.8	112	4.114	A1	100	1.000	10890
19	R123	152.93	27.8	183.7	3.668	B1	1.3	0.02	77
20	R141b	116.95	32.0	204.2	4.249	NA	9.3	0.120	725
21	R245fa	134.05	15.3	154.1	3.64	B1	8.8	0	820
22	R236fa	152.0	-1.5	124.0	3.20	-	209	0	6300
23	R227ea	170.0	-17.5	102.0	2.95	-	36.5	0	2900
24	R1234yf	114.02	-29.45	94.7	3.382	A1	NA	~0	4

Table-C- Energy Recovery Materials for Adsorption Refrigeration Techniques of Heat Recovery [24]

Material	**Heat Source**	**Performance Index (COP)**	**Application**
AC-Methanol	20 MJ/m2 per Day	0.12	Ice Making
	18 to 19.2 MJ/m2 per Day	0.12 to 0.14	
	17 to 20 MJ/m2 per Day	0.13 to 0.15	
	<120 degree C	0.18	
AC-NH3	105 degree C	0.10	
Silica Gel-Water	15.4 MJ/m2 per Day	0.16	
AC-Blanked steel-Methanol	20 MJ/m2 per Day	0.18	
AC+CaCl2-NH3	115 degree C	0.39	
Silica Gel-Water	55 degree C	0.36	Chilled Water
	65 degree C	0.28	
	75-90 MJ/m2 per Day	0.35 to 0.60	
	80 to95 MJ/m2 per Day	0.35 to 0.60	
	80 MJ/m2 per Day	0.33to 0.50	
AC-NH3	232 degree C	0.42 to 1.19	Air Conditioning
	100 degreeC	0.20	
Zeolite-Water	204 degree C	0.60 to 1.60	
	230 degreeC	0.41	
	310 degreeC	0.38	
	230 to 300 degreeC	0.20 to 0.21	