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Energy and Exergy Analysis of Solar Thermal Energy-based Polygeneration Processes for Applications in Rural India

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Abstract – *The objective of this paper is to analyze the energy and exergy of a solar thermal based polygenearation process used for rural application in India. Linear Fresnel reflector (LFR) is used as solar thermal energy generation source for polygeneration process. The LFR system design is slightly modified to bring down the cost of the solar field. Electric power, cooling and generation of hot water for process applications are various polygeneric applications discussed in this work. The system is modeled to be experimented for application in rural sector of India, where various processes can function in parallel to cater to livelihood enhancements. Such, stand alone units are useful for community based refrigeration units, especially during the season of harvest. Vapour absorption machine (VAM) and adsorption chiller are selected for consideration in cooling applications, while pasteurizing unit is explained as a hot water utilization method. Molten salt-based storage for short time duration is also investigated in the current study. Thermodynamic analysis and solar field optimization are done for the polygeneration process to identify various operating parameters. Key input parameters are varied to identify the changes in outputs of various components. Energy and exergy analysis shows that there is very less loss in most of the components, while LFR and VAM are found to be high exergy loss equipment. There is a scope of scaling up of such systems which can be operated as standalone units for applications in the rural regions.*

Keywords – energy analysis, exergy analysis, linear Fresnel reflector (LFR), polygeneration, solar thermal.

1. INTRODUCTION

In a growing economy like India where energy demand is increasing continuously over the years, the power consumption for process heat applications by industries are significantly large [1]. India has an average monthly global horizontal irradiance (GHI) of 4 to 5.5 kWh/m^2/day [2]. Efficient energy conversion systems have grown of importance for research due to increase in energy demand [3]. There is need for further study and research in using polygenerative systems for decentralised energy supply, nuances in transmission and distribution networks, reliability and reduction of greenhouse gases (GHG) emissions [4]. Newer research has included renewable energy (RE) sources for consideration in polygenerative process applications [5]. Solar thermal energy was used as a RE source for polygeneration application to analyse the advantages of using different processes together than operating individually [6]. Investigations on using solar thermal as a hybrid source for polygenerative applications such as electricity; space cooling and distillation have proved encouraging. The past two decadal developments in this regard have been encouraging and it is expected that in near future polygeneration process can be a competitive process for production of electricity and industrial applications [1]. Earlier research shows that, linear Fresnel reflector (LFR) can be implemented in the same thermodynamic process as a parabolic trough collector (PTC) and the same annual yield can be attained [7]. However, LFR has advantages such as low cost collectors, simplified receiver tubes and direct steam generation applications [8]. Small scale (<500m^2) linear Fresnel collectors are suitable, among concentrating collectors, for cheap industrial process heat applications [9].

Solar heating and cooling (SHC) using absorption and adsorption methods are probably one of the best choices that have application in heat and power generation, especially in standalone applications. Solar refrigeration systems are very optimal, particularly in summer operation mode, when the maximum demand for cooling coincides with the maximum availability of solar radiation [10]. Energy diversification and environmental friendliness make absorption cooling system advantageous than vapour compression systems [11]. The absorption cooling systems are integrated to power generation system to decrease the waste heat and to improve the performance [12]. Research studies were conducted with integration of triple effect absorption refrigeration system for heating, cooling and hot water production [12].

Justification of performing exergetic and energetic analyses together can give a complete depiction of system characteristics. Such a comprehensive analysis is a convenient approach for the performance evaluation and determination of the steps towards improvement [13]-[15]. A number of researchers have performed energy and exergy analysis of absorption refrigeration system. Thermodynamic analysis of a single effect

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vapor absorption system has been analyzed extensively [16]-[19]. Some relative works on double effect vapor absorption refrigeration system considering the analysis of the first law of thermodynamics and the second law of thermodynamics are also available [20]-[21]. Exergy analysis of concentrators has been presented by researchers during previous works [22]. Beside thermal energy analysis, an exergy analysis can lead to understand better the energy conservation potential [23]. Influence of incorporation of solar thermal power generation on a steam power plant has been investigated in Nigeria [24]. Energy and exergy analysis of solar air heaters with double flow corrugated absorber plates has been analyzed [25]. Exergy efficiency analysis was conducted on multigenerational energy system which generates power, water and cooling simultaneously [26].

While lot of work has been focused on combined heating, cooling and power, very less work was found in literature on polygenerative process. Use of solar thermal, particularly LFR system based polygeneration is rarely found in literature.

After reviewing the earlier work done by researchers and considering the importance of standalone solar thermal operated polygeneration system, an attempt is made to integrate multi utility process heat applications for livelihood enhancement at a village level. With this motivation, the objectives of this paper are designed which are as follows:

- To design a renewable energy (solar thermal) based polygenerative system for power, heating and cooling applications at village level.
- To investigate the energy, exergy and entropy analysis of the components of the system described above.
- To conduct sensitivity analysis of the system by varying key input parameters for the system

2. SYSTEM DESCRIPTION

The system is modeled to operate during sunshine hours (0800-1800 h) for the weather conditions for coastal regions of the state of Odisha, India as a standalone unit. LFR being cost effective and with potential to produce direct steam, is considered as the heat source. Slight modifications are done on the LFR to reduce the size of the solar field and for the system to be cost effective. Molten salt is considered as a storage medium to take care of any effect of the passing clouds on the mirrors. The storage mechanism considered in the study is only as a support during the lean hours of sunshine, with a storage capacity for two hours. A single stage LiBr-H_2O vapor absorption machine (VAM), adsorption chiller and a pasteurization unit are considered for application to utilize process heat.

The schematic layout of the system considered for the investigation is as shown in Figure 1 which is divided into four major sub systems.

- Solar energy steam generation
- Thermal energy storage
- Power generation
- Process application

The major components present in the solar-based polygeneration system are as follows:

- Solar collector field (Modified LFR)
- Steam drum
- Thermal energy storage
- Steam turbine
- Single effect lithium bromide – water (LiBr-H_2O) Vapour absorption unit
- Closed loop cooling tower for removing heat from VAM
- Pasteurization unit
- Vapour adsorption chiller
- Closed loop cooling tower to remove heat from adsorption chiller
- Process heater

The description of major components are mentioned below.

2.1 Linear Fresnel Reflector (LFR) Solar Energy Collector

In order to reduce the cost of existing LFR system some modifications in the system design has been introduced. The height of the LFR receiver is brought down from a typical value of about 10 m (commonly used) to about 5m above the plane of the mirrors. Two blocks of LFR system with six numbers of mirrors, each with length and a width of 48 m and 1.05 m respectively are considered to obtain the required mirror area. The distance between nearby mirrors is chosen as 0.4m so as to minimize the shadowing effect. One block of LFR is incorporated with multiple tube receivers while the other block is given a single tube receiver. Ray tracing of the proposed LFR system were done with coding. The block having multiple tubular cavities is shown in Figure 2 along with the ray tracing of the system at zero degree sun incidence. This novel LFR block results in reduced concentration but, it is sufficient to produce process steam necessary for the turbine input. The reduced height of receiver tubes makes them accessible from the ground for easy cleaning and maintenance.

Steam (wet) at designed pressure and temperature leave LFR at point 1, which enters the steam drum. Pure steam is taken at point 2 for storage and turbine after separation in steam drum. Saturated water along with feed water streams return to LFR system at point 5.

2.2 Thermal Storage System

Phase changing material (PCM) storage containing KNO_3 and $NaNO_3$ are considered as the storage medium. The storage capacity is sized for providing 2 hours of thermal storage along with a steam accumulator used to provide smooth steam flow during solar intermittency, *i.e.* during no sun periods and for early starts for the day. The objective of low sizing is to reduce the cost and optimize to the climatic conditions. Table 1 represents the properties of the storage system used.

Part of dry steam from steam drum enters thermal storage at point 4 and after giving up heat to PCM materials at point 21.

2.3 Steam Turbine

Steam at 30 bar and 234°C enters to the turbine and is expanded to 2 bar pressure to produce 18 kW of electric power. Power production capacity is based on the auxiliary consumption of all power equipment required for the system to operate. Steam leaving at 2 bar is used for process heating applications. Isentropic efficiency is assumed as 60% for turbine energy calculations.

Pure steam from LFR enters the turbine to produce electricity at point 3. Fluid exiting from turbine enters process applications.

2.4 Process Heat Applications

The outlet steam from turbine drives a 15 TR single effect vapor absorption machine (VAM). Li-Br+H_2O is used for the present case. The chilled water from VAM is circulated in air handling unit to provide refrigeration effect for the agro-perishables. At point 9, hot water enters VAM and chilled water leave at point 7. Heat released in condenser is taken by condensate fluid to cooling tower and after cooling, cold fluid enters VAM condenser at point 10 for heat extraction. The proposed VAM is typically sized to cool 7000 sq. ft space, which is ideal for storing perishables from harvest from a typical village community (Typical farm products being tomatoes, potatoes and onions). The return hot water at point 11 from VAM at 100°C is used for the heat needed for pasteurizing milk produced by the local farming community. The fluid exits from pasteurization unit at point 12. The temperature requirement for pasteurising milk is from the range of 62.8°C to 71.7°C. Hot water after pasteurization is available at 80°C which enters to this chiller at point 14. A 9 TR adsorption chiller is used for cooling application, points 17 and 15 being the inlet and the outlet of the chiller unit. After releasing heat to generator of chiller unit, the fluid exits at 19 which enter to process heater. The heat available at this point can be used for other process heat applications including industrial laundry and distillation. The warm water leaves at point 20 and mixes with fresh intake in feed water tank.

Table 1. Properties of molten salt considered for storage system.

Type of the Molten Salt	KNO_3 and $NaNO_3$
Density	2100 kg/m^3
Specific heat	1822J/kgK
Melting temperature	223°C
Latent heat	106 kJ/kg

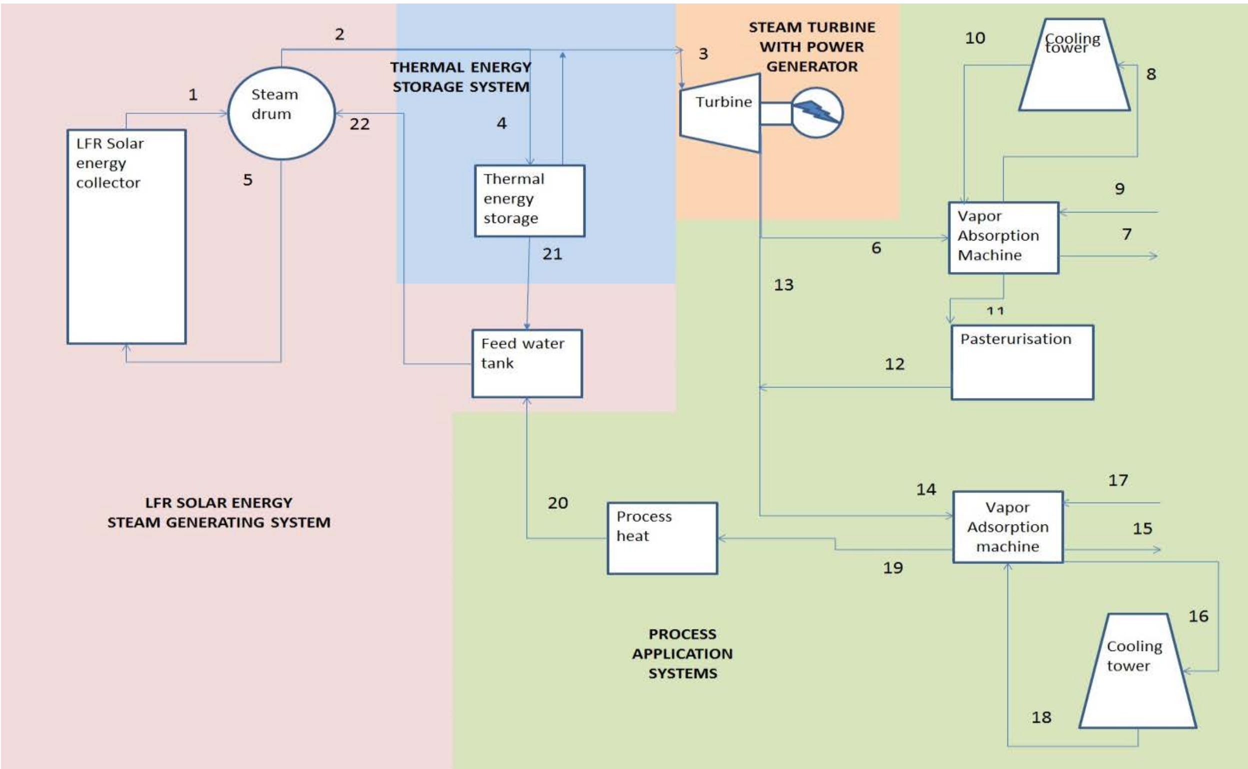

Fig. 1. Schematic layout of the considered system.

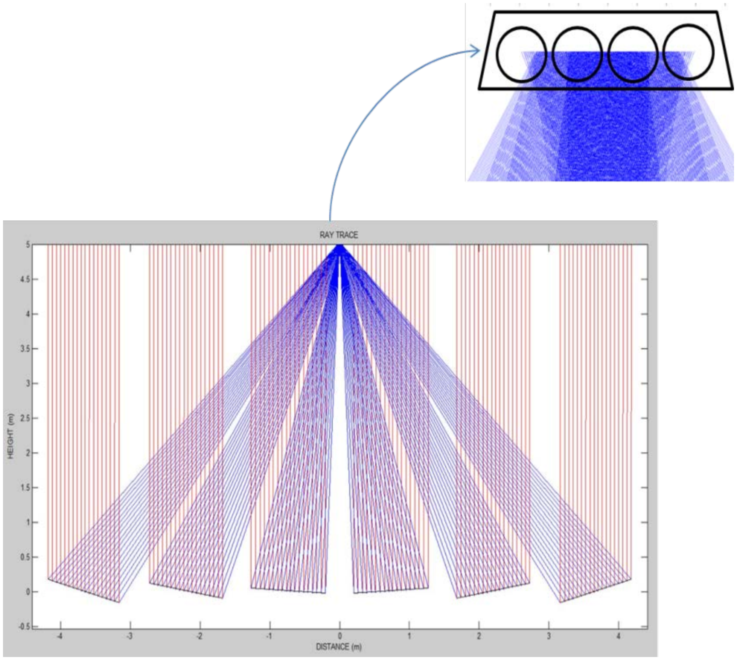

Fig. 2. Ray tracing of LFR system.

3. MODELLING AND ANALYSIS

Energy and exergy analysis for the major components of the polygeneration system are presented in this section. Data considered for the analysis are mentioned in Table 2. To calculate the properties of working fluids, in-house code was used for calculation at each state points. The relevant energy balances are mentioned in the following sections.

3.1 Energy Analysis

Assuming steady flow with negligible potential and kinetic energy, energy equations can be written as follows:

$$\sum \dot{m}_i h_i + \dot{Q} = \sum \dot{m}_o h_o + \dot{W}_{net} \quad (1)$$

Where $\dot{m}$ is mass flow rate, h is the specific enthalpy. $\dot{Q}$ and $\dot{W}_{net}$ are heat and net work transfer rate respectively. Subscripts i and o are inlet and outlet of steady flow apparatuses used.

Energy balance equations of major components of the system considered are presented in Table 3. The Hottel–Whillier [27] equation for the actual useful heat gain (Qu) of a concentrating solar collector system like LFR system may be used as following,

$$Q_u = F_R A_A \left[C\left(\rho_R \alpha_A\right)\right] I_S - U_L\left(T - T_a\right) - \varepsilon\sigma\left(T^4 - T_a^4\right) \quad (2)$$

Where A_A is the area of the absorber surface, UL is the overall heat loss coefficient, C is the concentration ratio, σ is the Stefan-Boltzmann constant and ρR, αA, ε and FR are the reflectivity, absorptivity, emissivity and heat removal factor of the collector respectively. Is the solar intensity, T is the temperature of the collector and Ta is the ambient temperature. The heat removal factor FR is defined as [27].

$$F_R = \frac{mC_p}{A_A U_L}\left[1 - e^{\frac{A_A U_L F'}{mC_p}}\right] \quad (3)$$

Where m and F' are mass flow rate and heat removal coefficient. Overall heat loss coefficient, UL for LFR system is dependent on many factors such as cavity geometry, number of tubes, emissivity of tubes and glass cover, wind velocity induced convective heat transfer coefficient. The approach to get UL in this paper is adopted as described in [28], [29].

3.2 Exergy Analysis

Exergy balance equations can be written in many ways. In this paper, entropy balance and exergy balance [30] which are related to each other are mentioned as below

$$\sum \dot{m}_i s_i + S_{gen} = \sum \dot{m}_o s_o \quad (4)$$

$$\sum \dot{m}_i \psi_i + \psi_Q = \sum \dot{m}_o \psi_o + \psi_{Wnet} + T_a S_{gen} \quad (5)$$

Where s and ψ are entropy and exergy respectively. S_{gen} is entropy generation in sub system and $T_\alpha S_{gen}$ is exergy loss or destruction energy.

ψ_Q is the exergy rate due to heat transfer across the control volume at temperature, T and is written as

$$\psi_Q = \left(1 - T_a / T\right)\dot{Q} \quad (6)$$

Similarly, ψ_{Wnet} is exergy rate due to shaft work and can be written as

$$\psi_{Wnet} = \dot{W}_{net} \tag{7}$$

The entropy balance and exergy balance equations are written in Table 4 and Table 5 using the above mentioned procedures.

3.3 Energy and Exergy Efficiency

Energy and exergy efficiency are otherwise called as 1st law and 2nd law efficiency [30], respectively.

$$\eta_{II} = \eta_I / \eta_{rev} \tag{8}$$

$$COP_{II} = COP_I / COP_{rev} \tag{9}$$

4. RESULTS AND DISCUSSION

For obtaining results, certain fixed data were assumed which are listed in Table 2. The salient point data obtained using Equations mentioned earlier are listed Table 6.

Figure 3 shows the mass flow rate of steam generated from LFR system with respect to DNI and solar collector area.

Two parameters such as direct solar radiation and collector areas are varied between 4-6 kWh/m^2 and 400-800m^2 for the analysis of the system. The data varied are considered based on the solar data available across India so that the system can be scaled and replicated elsewhere.

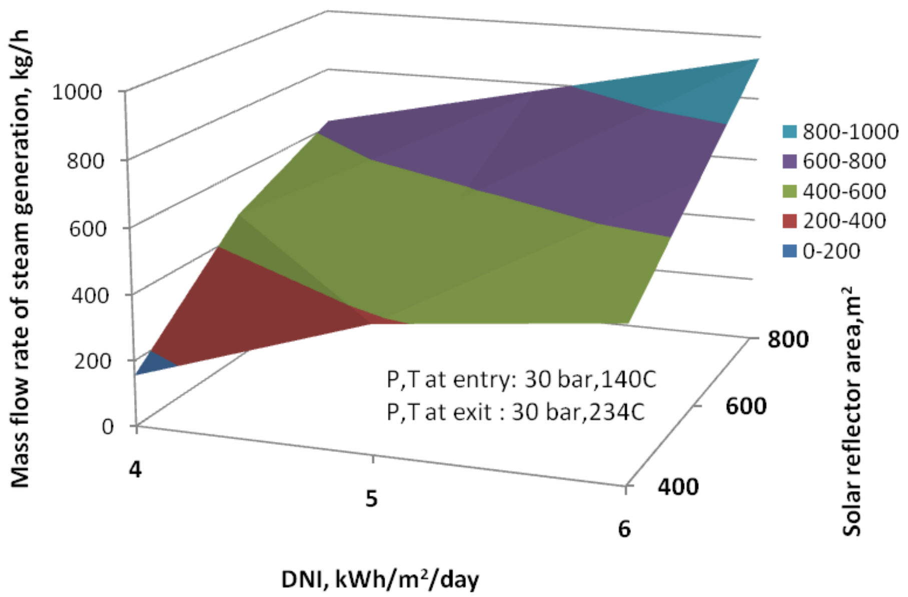

Fig. 3. Mass flow rate generated with variation in DNI and solar reflector area.

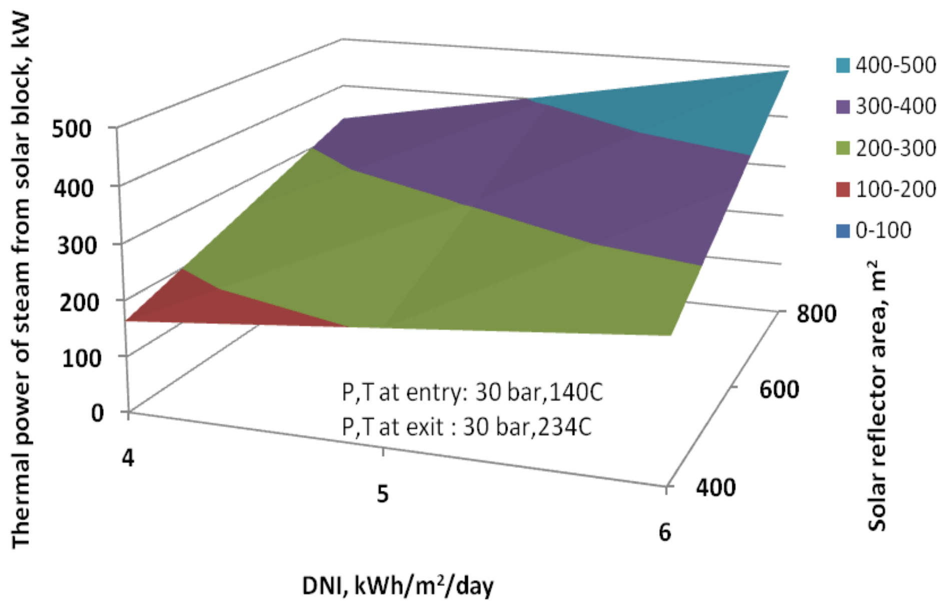

Fig. 4. Thermal power content of steam generated with variation in DNI and solar reflector area.

Table 2. Data considered for system analysis.

Items	Value	Units
Solar area	600	m^2
DNI	5	kWh / m^2 /day
Efficiency	57%	
VAM capacity	15	TR
ADC Capacity	9	TR
Steam input pressure	30	bar
Steam input temperature	234	°C
Feed water temperature	40	°C
Operating hours	8	hours
Mass flow rate from solar steam generator	291	kg / h
Mass flow rate to thermal energy storage system	58	kg / h
Mass flow rate to steam turbine	233	kg / h
Inlet enthalpy to turbine	2803	kJ / kg
Outlet steam pressure from turbine	2	bar
Isentropic enthalpy	2336	kJ / kg
Isentropic efficiency	60%	
Actual enthalpy change	278	kJ / kg
Turbine power output	18	kWe
Actual enthalpy at the outlet of turbine	2525	kJ / kg
Temperature at the outlet of turbine	120	°C
COP of VAM	0.65	
Temperature at the outlet of VAM	100	°C
Mass flow rate of steam required for VAM	139	kg / h
Temperature at the outlet of pasteurization	80	°C
Thermal power for VAM	81	kW
Thermal power output for pasteurization	3	kWe
COP of ADC	0.611	
Mass flow rate available for ADC from steam turbine outlet	94	kg / h
Temperature at the outlet of ADC	100	°C
Enthalpy at the inlet of ADC	1219	kJ / kg
Mass flow rate for ADC	233	kg / h
Thermal power required for ADC	52	kW
Temperature at the outlet of ADC	99.6	°C
Thermal power available for process steam	16	kW

Table 3. Energy balance equations of sub-systems of integrated systems

LFR	$m_5 h_5 + Q_u = m_1 h_1$
Steam drum	$m_1 h_1 + m_{22} h_{22} = m_2 h_2 + m_5 h_5$
Steam turbine	$m_3 h_3 = m_6 h_6 + m_{13} h_{13} + W$
VAM	$m_6 h_6 + m_9 h_9 + m_{10} h_{10} = m_7 h_7 + m_8 h_8 + m_{11} h_{11}$
Pasteurisation unit	$m_{11} h_{11} - Q_{pstrztn} = m_{12} h_{12}$
Adsorption chiller	$m_{14} h_{14} + m_{17} h_{17} + m_{18} h_{18} = m_{15} h_{15} + m_{16} h_{16} + m_{19} h_{19}$
Process heater	$m_{19} h_{19} - Q_{process} = m_{20} h_{20}$

Table 4. Entropy balance equations of sub-systems of integrated systems.

LFR	$m_5 s_5 + \int_{T_5}^{T_1} \frac{\delta Q_{LFR}}{T} + S_{gen,LFR} = m_1 h_1$
Steam drum	$m_1 s_1 + m_{22} s_{22} + S_{gen,s\_drum} = m_2 s_2 + m_5 s_5$
Steam turbine	$m_3 s_3 + S_{gen;turbine} = m_6 s_6 + m_{13} s_{13}$
VAM	$m_6 s_6 + m_9 s_9 + m_{10} s_{10} + S_{gen;vam} = m_7 s_7 + m_8 s_8 + m_{11} s_{11}$
Pasteurisation unit	$m_{11} s_{11} + \int_{T_{11}}^{T_{12}} \frac{\delta Q_{pn}}{T} + S_{gen,pn} = m_{12} s_{12}$
Adsorption chiller	$m_{14} s_{14} + m_{17} s_{17} + m_{18} s_{18} + S_{gen;chiller} = m_{15} s_{15} + m_{16} s_{16} + m_{19} s_{19}$
Process heater	$m_{19} s_{19} + \int_{T_{19}}^{T_{20}} \frac{\delta Q_{process}}{T} + S_{gen,process} = m_{20} s_{20}$

Table 5. Exergy balance equations of sub-systems of integrated systems.

LFR	$m_5 \psi_5 + Q_u \left(1 - \frac{T_a}{T}\right) = m_1 \psi_1 + T_a S_{gen,LFR}$
Steam drum	$m_1 \psi_1 + m_{22} \psi_{22} = m_2 \psi_2 + m_5 \psi_5 + T_a S_{gen,s\_drum}$
Steam turbine	$m_3 \psi_3 = m_6 \psi_6 + m_{13} \psi_{13} + W + T_a S_{gen,turbine}$
VAM	$m_6 \psi_6 + m_9 \psi_9 + m_{10} \psi_{10} = m_7 \psi_7 + m_8 \psi_8 + m_{11} \psi_{11} + T_a S_{gen;vam}$
Pasteurisation unit	$m_{11} \psi_{11} - Q_{pn} \left(1 - \frac{T_a}{T_{cv}}\right) = m_{12} \psi_{12} + T_a S_{gen,pn}$
Adsorption chiller	$m_{14} \psi_{14} + m_{17} \psi_{17} + m_{18} \psi_{18} = m_{15} \psi_{15} + m_{16} \psi_{16} + m_{19} \psi_{19} + T_a S_{gen,chiller}$
Process heater	$m_{19} \psi_{19} - Q_{process} (1 - \frac{T_a}{T_{cv}}) = m_{20} \psi_{20} + T_a S_{gen,process}$

Table 6. Properties at each state point in the current system.

Salient points	Pressure (bar)	Temperature (C)	Mass flow rate (kg/h)	Enthalpy (kJ/kg)	Entropy (kJ/kgK)	Thermal Power (kW)
1	30	234	582	1905.818	4.415	308
2	30	234	291	2803.264	6.185	227
3	30	234	233	2803.264	6.185	181
4	30	234	58	2803.264	6.185	45
5	30	140	582	589.281	1.732	95
6	2	120	139	2525.153	6.666	97
7	1	7	9018	29.523	0.106	74
8	1	41	12906	171.801	0.585	616
9	2	12	9018	50.602	0.180	127
10	3	32	12906	134.373	0.464	482
11	1	100	139	417.436	1.302	16
12	1	80	139	334.990	1.075	13
13	2	120	94	2525.153	6.666	66
14	2	120	233	1218.567	3.344	79
15	1	7	5411	29.523	0.106	44
16	1	41	8034	171.801	0.585	383
17	2	12	5411	50.602	0.180	76
18	3	32	8034	134.373	0.464	300
19	1	99.6	233	417.436	1.302	27
20	1	40	233	167.623	0.572	11
21	1	40	58	167.623	0.572	-
22	30	40	291	170.191	0.571	14

It is seen that mass flow rate of steam generated is more for high DNI and high solar reflector area. The data sets are generated for 30 bar, 140°C inlet to the solar field and 30 bar, 234°C inlet to the turbine. Similarly, Figure 4 depicts the thermal power output of steam from solar block with variation in DNI and solar reflector area. It is seen that the power content (thermal) is more for high DNI and high reflector area. It means that with increase in demand, the area of LFR is to be increased so as to increase the mass flow rate and thermal power output. Higher DNI at selected locations will be useful as DNI is a factor for better output.

Figure 5 shows the mass flow rate of steam available for heating storage medium with variation in DNI. It is seen that with high mass flow rate resulted in high thermal power stored in storage medium. Although the system has been designed for 2 hour back up time during no sun period but due to high mass flow rate circulated, thermal power storage increases as well which may lead to more back up time. Sensitivity analysis shows that late afternoon cloud cover for periods of more than 45 minutes have largely affected storage efficiency and early morning start operations.

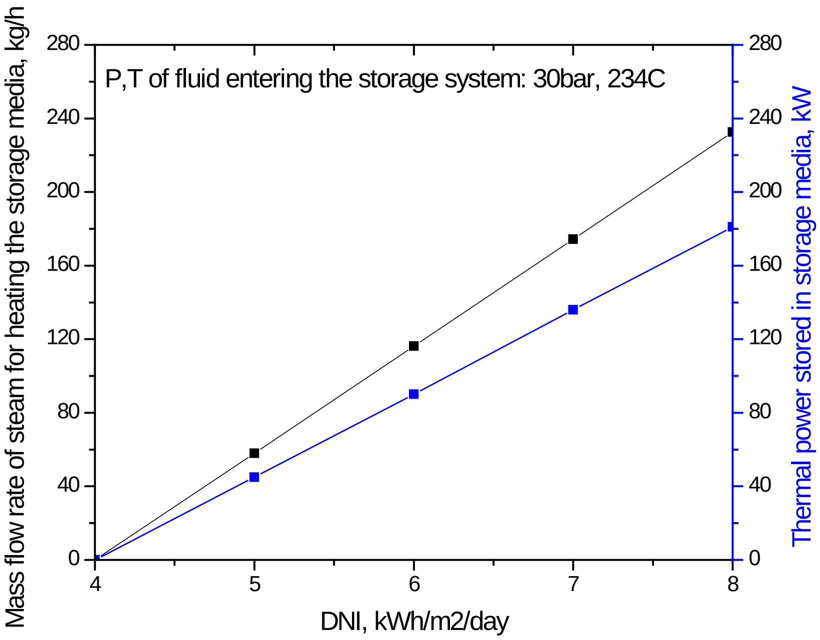

Fig. 5. Mass flow rate of steam sent for heating the storage media and thermal power stored with respect to DNI.

As expected, the turbine power output from turbine and thermal power at the end of turbine increases with increase in mass flow rate as shown in Figure 6. The conditions of pressure and temperature at inlet of the turbine are maintained at 30 bar and 234°C. The exit pressure has been fixed at 2 bar as the fluid at this pressure will be required for heat requirement to VAM machine and adsorption chiller.

Analysis show that COP of the VAM is decreasing with increase in mass flow rate to generator of the VAM while the thermal power increases with the mass flow rate, which is depicted in Figure 7. The evaporator section is undisturbed as it absorbs same heat irrespective of heat supplied to generator. The COP of the adsorption chiller is also decreasing with increase in mass flow rate to generator while the thermal power increases. The same is shown in Figure 8.

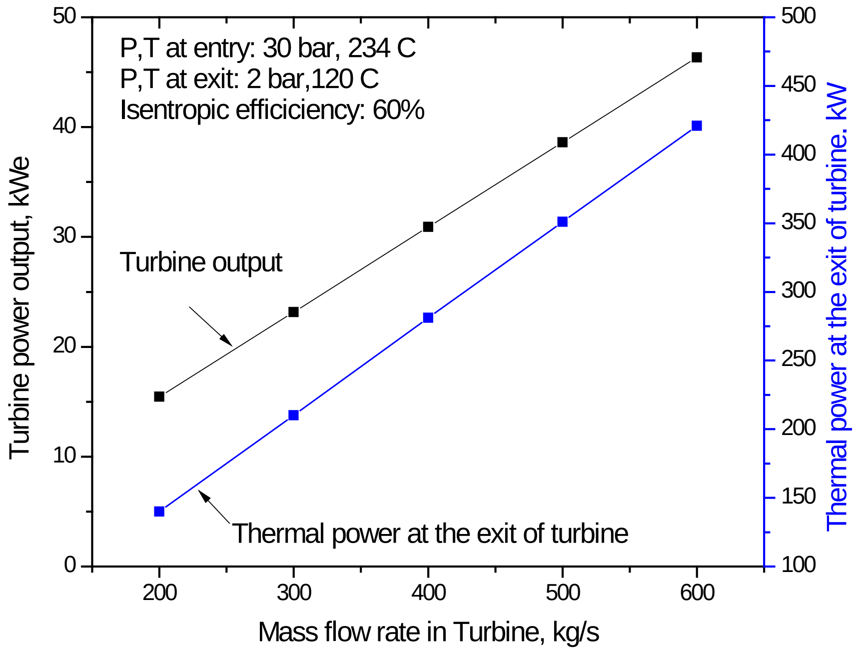

Fig. 6. Turbine power output and thermal power at the exit of the turbine with respect to mass flow rate.

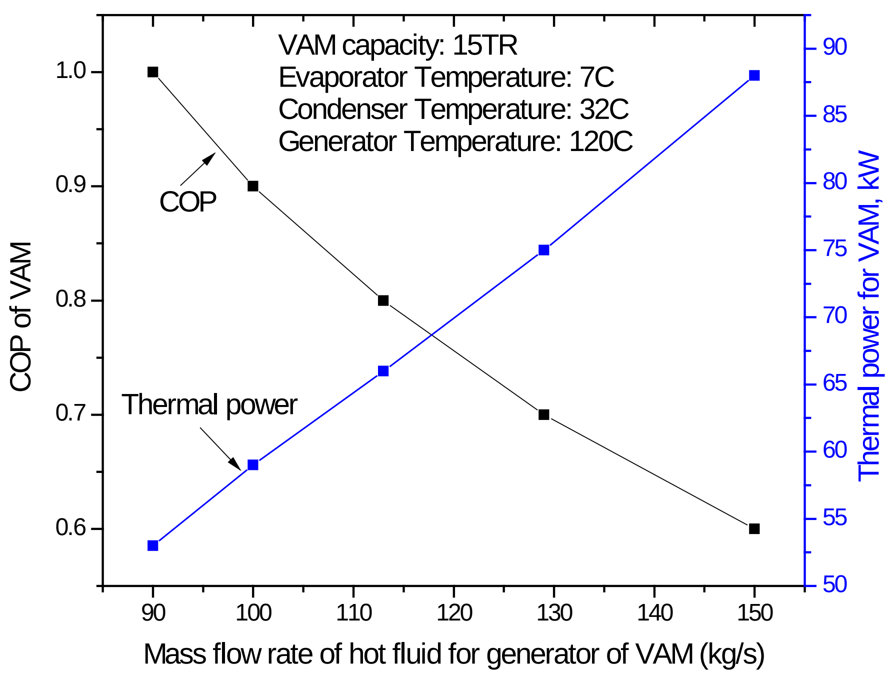

Fig. 7. COP of VAM and thermal power with respect to mass flow rate of hot fluid for generator.

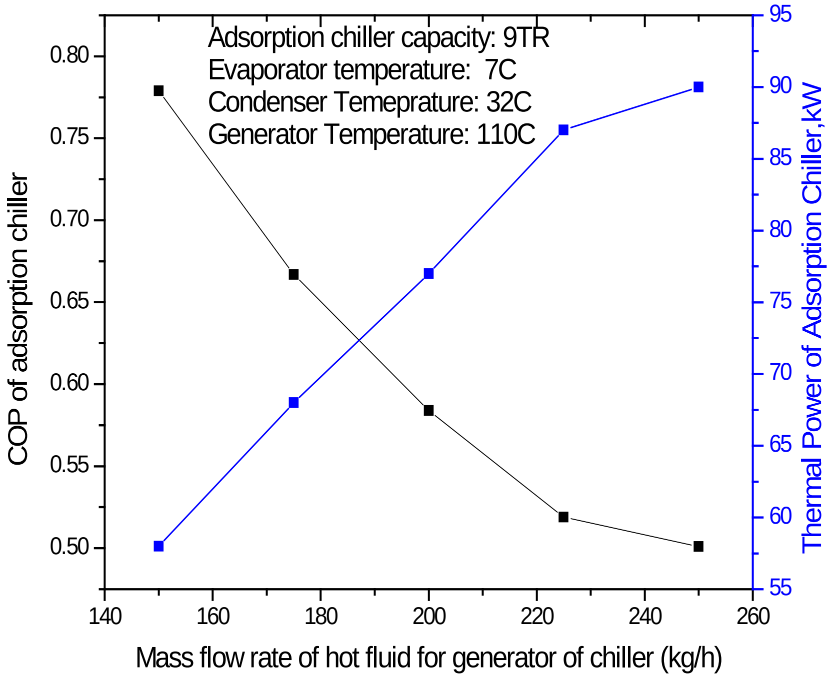

Fig. 8. COP of adsorption chiller and thermal power with respect to mass flow rate of hot fluid for generator.

Irreversibility of all components is shown in Figure 9. The majority of the components have less exergy losses. This benefits the system because there is less heat losses in these parts. It is seen that LFR and VAM experiences much irreversibility compared to other and hence these components need to be focused more during operation.

Energetic and exergetic efficiency values are mentioned in Figure 10. It is seen that Exegetic efficiency of the turbine is more compared to energetic efficiency. Similarly the energetic COP of chiller and VAM are found to be more than exergetic COP.

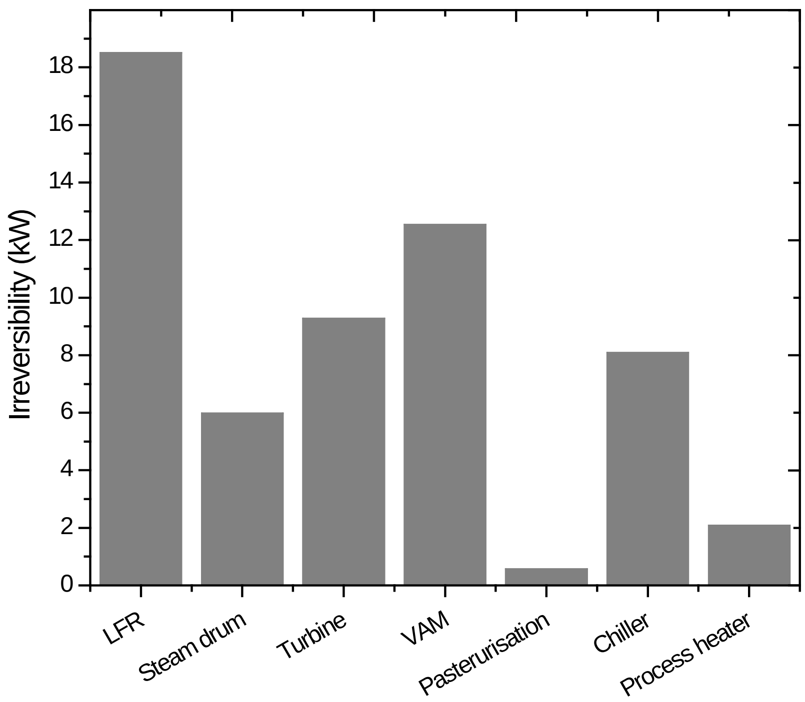

Fig. 9. Irreversibility associated with different components of the considered system.

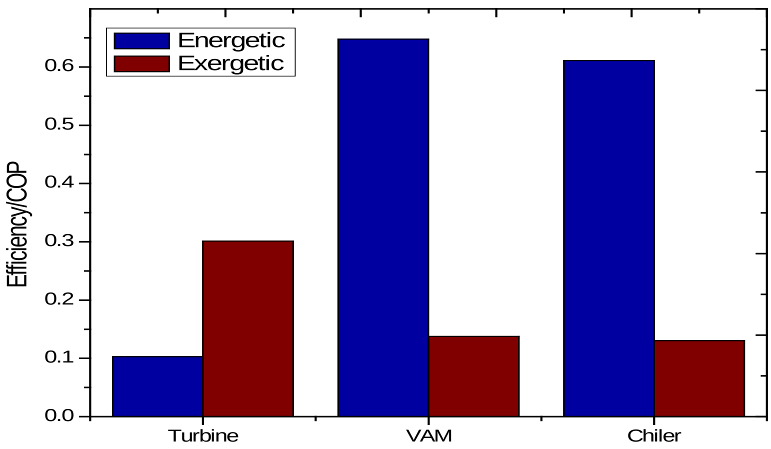

Fig. 10. Energetic and exergetic efficiency and COP of turbine, VAM and chiller.

5. CONCLUSIONS

The purpose of the current study was to analyze and identify the potential of using a standalone solar thermal energy generation unit for power, heating and cooling applications with some modifications in the LFR. Comparisons of adsorption and absorption methods are analyzed in the application of refrigeration. Energy, entropy and exergy analysis are done for the major components in solar thermal based polygeneration system. The thermodynamic parameters at critical points of the system are found. The system is integrated with a thermal energy storage application. Most of the equipment experiences less exergy loss. LFR and VAM are found to be delicate equipment as irreversibility incurred in these are more compared to other and hence these components need to be focused more during operation. The system design is optimized with sensitivity analysis of major parameters with respect to desired output.

Even though the current work focus only on refrigeration and pasteurization as polygenerative applications, a series of other applications including cooking, industrial laundry, desalination, water purification, effluent treatment and drying of fish can be analysed for application by local village communities.

There is further scope in analyzing such systems for commercialization in scaling up or down for specific applications in livelihood enhancements with modifications in the solar field. An addition of a biomass boiler based on locally available agricultural residue with proper scaling down of solar field should also be studied as a cost effective solution for wider integration of solar thermal application.

NOMENCLATURE

A_A	Area of the absorber tube,m^2
C	Concentration ratio
F_R	Heat removal factor
h	Enthalpy, J/Kg-K
I_s	Solar insolation, W/m^2
p	Pressure, bar
$\dot{Q}$	Heat transfer rate
Q_u	Useful heat gain in the absorber tube, W
T	Temperature, K
T_a	Atmospheric temperature
U_L	Overall heat loss coefficient, W/m^{2}K
$\dot{W}_{net}$	Network output from turbine

Subscripts and Superscripts

a	Atmosphere
cv	Control volume
chiller	Chiller
gen	Generation
i	Inlet
L	Loss
net	Net
o	Outlet
process	Process
pn	Pasteurization
rev	Reversible
s_drum	Steam drum
turbine	Turbine
u	Useful
vam	Vapor absorption machine
1-22	State points
I	first
II	Second

Greek Words

$\rho_R\alpha_A$	Reflectivity-absorptivity
σ	Stefan-Boltzmann constant, W/m^{2}K^4
C_p	Specific heat J/kgK
$\dot{m}$	Mass flow rate, kg/s
F’	Heat removal constant

Ψ	Exergy
η	Efficiency

Abbreviations

ADC	Adsorbent Chiller
COP	Coefficient of Performance
CLFR	Compact Linear Fresnel Reflector
DNI	Direct Normal Irradiance
GHI	Global Horizontal Irradiation
LFR	Linear Fresnel Reflector
PCM	Phase Change Material
SHC	Solar Heating and Cooling
VAM	Vapor Absorption Machine

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