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Abstract— **To cope with the increasing needs of the energy market in current scenario and protect the environment from getting depleted, there is a necessity for a power production technology to be more efficient, cost-effective and eco-friendly. Hybrid systems may provide the solution to these limitations, by maximizing the energy potential of resources, increasing the process efficiency, providing greater security of supply and reducing overall costs. This paper is a proposal to hybridize Concentrated Solar Power (CSP) stirling power plant with biomass.**

Keywords- stirling engine, biomasss, hybrid systems,CSP

INTRODUCTION

In recent years India has faced acute shortage of power and frequent power cuts. India currently suffers from a major shortage of power, inspite of being world's fifth [1] in power production as of 2010. To encounter this problem more renewable energy sources have to be used rather than fossil fuels. The renewable energy sources include solar and hydropower as its major components. India being tropical country, is bestowed with solar irradiation ranging from 4 to 7 kWhr/m_2 per day across the country [2]. India has a lot of agricultural land. Thus it has a great potential to produce biomass. So, a hybrid system using two abundant sources of energy – solar and biomass could help to overcome the current power crisis.

II. STIRLING ENGINE

A Stirling engine is an external combustion engine developed by Robert Stirling in 1817[9][10]. Here fossil fuel, bio-mass, solar energy can be used to heat the working gases which can be air, hydrogen or helium, filled in the cylinder[11]. The stirling engine has the capacity to give high efficiency with less exhausts in comparison with Internal Combustion(IC) engines [12]. The stirling engine has high fuel efficiency, eco friendliness, quiet operation and versatility in using heat source[2].

A. Thermodynamic analysis of an ideal stirling engine

Stirling cycle is a modified form of carnot cycle to produce higher mean effective pressure than the carnot cycle, While theoretically achieving full carnot efficiency. The theoretical stirling P-V thermodynamic cycle is shown in figure

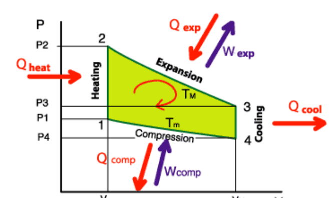


Figure 1- PV diagram of an ideal stirling engine[3]

Process 4 to 1-Isothermal compression
Process 1 to 2-Isochoric heating
Process 2 to 3-Isothermal expansion
Process 3 to4-Isochoric cooling
Where, P is gas pressure in Pa and V is gas volume in m3.
Since the gas compression 4 to 1 is carried out at a lower pressure than the gas expansion 2 to 3 , there is a net work output.

B. Working and mechanical configurations of the stirling engine

The stirling cycle has a constant volume process during the transfer of fluid from hot to cold space of the working cylinder and then heat rejection and addition at constant temperature. A displacer piston shuttles the working fluid back and forth through the heater, regenerator and cooler at constant volume. When the displacer moves to the cold space, it displaces the working fluid from the cold space causing it to flow to the hot

space and vice versa. The common configurations of stirling engine are alpha, beta and gamma. Each configuration has the same thermodynamic cycle but different mechanical design characteristics.
Alpha engines have two separate power pistons in separate cylinders which are connected in series by a heater, a regenerator and a cooler. One is a hot piston and the other one a cold piston. The hot piston cylinder is situated inside the high temperature heat exchanger and the cold piston cylinder is situated inside the low temperature heat exchanger. The generator is illustrated by the chamber containing the hatch lines in figure

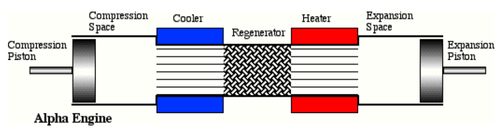


Figure 2 - Alpha stirling engine configuration [4]

Beta engine has both the displacer and piston in an in-line cylinder system. The gamma uses separate cylinders. The purpose of single power piston and displacer is to displace the working gas at a constant volume and shutter it between the expansion and the compression spaces through the series arrangement cooler, regenerator and heater as shown in figure 3.
Gamma type engine is basically a beta stirling engine where the power piston is mounted in a separate cylinder alongside the displacement piston cylinder.(Figure 4)

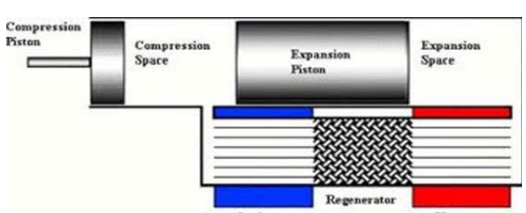


Figure 3 . Beta stirling engine configuration[4]

C. Benefits of stirling engine
The stirling engine has its own advantages and shortcomings like the other engines. The main advantages presented by stirling engines are given below:

- Low NO_x and CO emissions.
- Safe operation and low level noise
- Maintenance cost is very low.
- High efficiency.

Here the waste heat can easily harvested making stirling engines useful for dual output heat (Combined Heat and

Power production system).

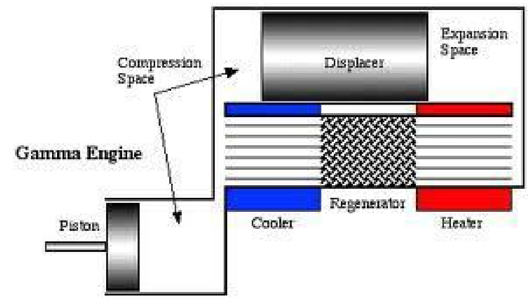


Figure 4 gamma configuration[4]

III. CONCENTRATED SOLAR POWER(CSP)
In CSP plants, moving mirrors track the movement of the sun in order to concentrate the solar radiation onto a point called focus. The usage of CSP technologies are customized depending on the application and difficulties in the power plant. Solar collectors are used to produce heat from solar radiation. The different types of CSP technology are as follows:

- The sun's energy is concentrated by parabolic trough shaped reflectors onto a receiver pipe running along the focal line of the curved surface. This energy heats oil (HTF) through the pipe and the heat energy is then used to generate electricity in a conventional power block. A solar field comprises many troughs in parallel rows aligned on a north-south axis. This configuration enables the single-axis troughs to track the sun from east to west during the day to ensure that the sun is continuously focused to the receiver tubes. Trough designs can incorporate thermal storage allowing for electricity generation several hours into the evening. Troughs can also be hybridized with other fuels such as coal, gas or biomass.
- Power tower systems in which heliostats reflect and concentrate sunlight onto a central tower-mounted receiver where the energy is transferred to a HTF. This energy is then passed either to the storage or to power-conversion systems, which convert the thermal energy into electricity. Heliostat field, the heliostat controls, the receiver, the storage system, and the stirling engine, which drives the generator, are the major components of the system.

- The parabolic dish system uses a parabolic dish shaped mirror or a modular mirror system that approximates a parabola and incorporates two-axis tracking to focus the sunlight onto receivers located at the focal point of the dish, which absorbs the energy and converts it into thermal energy. This can be used directly as heat for thermal application or for power generation[5].

IV. BIOMASS BURNING STIRLING ENGINE

Utilizing biomass as the energy source for stirling engines to produce power would be an excellent option especially in agriculture based countries like India as the dry agricultural wastes could be used for combustion to produce power. The combustion values, ash content and cost are as shown in figure 5 [7]:

Biomass fuels		Lower heating value [kJ/kg]	Water content rate [%]	Ash content rate [%]	Costs [US$/kWh]
Sawdust		7,500	45～60	1～3	0.05
Chip		8,800	30～50	1	0.04
Pellet		16,000	10～15	1～5	0.07
Firewood		12,000	25～50	1～5	0.04
Shredded wood		18,000	13～14	1	0.1

Figure 5

Figure

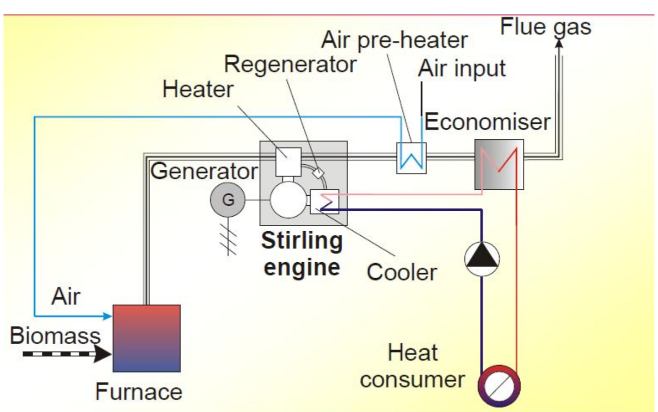


Figure 6 - Illustration of biomass stirling engine plant for power generation [8].

V. HYBRIDIZING SOLAR STIRLING ENGINE WITH BIOMASS COMBUSTION SYSTEM

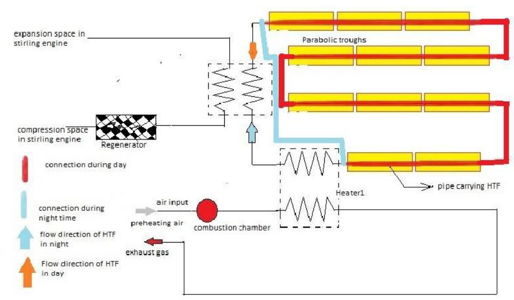
India has diverse climatic conditions and abundance of biomass. The solar stirling power plant is not going to produce the same output everywhere throughout the country. Thus biomass can be coupled with solar in areas with less solar irradiation. On cloudy days the power output gets affected significantly in solar stirling plant. This must not happen and one of the ways to overcome this is hybridization of solar stirling engine with biomass, which can maintain the HTF at constant temperature. In solar power plants power generation is only during the day time and is affected greatly during cloudy days .To overcome these shortcomings, hybridization of solar power plants is necessary. Thus hybridization can help the system to produce maximum output on any given day.

A. Parabolic trough system for biomass hybridized solar stirling plant

Parabolic trough systems are easy to be hybridized with alternate fuels as compared to solar dish stirling system because of its design.

B. Working of biomass hybridized solar stirling power generation system

a. The working of the biomass hybridized solar stirling system (figure 7) is different for day and night times. During the day, biomass acts as an additional source of heat to the HTF, whereas it acts as the only source of heat in the night. Different heat transfer fluids can be heated to its maximum temperature capability depending on their properties and the losses in the system.



Figure

Figure 7 – A schematic diagram biomass hybridized solar stirling system (designed in Microsoft Paint).

During the day operations HTF is preheated using biomass and then by solar parabolic troughs for elevating the temperature. After the preheating of HTF by biomass is over, the HTF enters the trough arrangement and further heated along its path. Thus the exit temperature is made maximum for HTF. During the night operations the parabolic troughs cannot heat the HTF. Now the HTF path way has to be bypassed in such a way that the HTF does not travel the whole distance of the trough array to avoid losses. Valves are used to change the flow direction of HTF.

b. Heating the HTF with trough and then with biomass.

In this configuration (figure 8), the HTF is heated using the trough and then using the biomass. Here, HTF flow direction is same for both day and night but the path of flow get bypassed during nights as shown in figure 8.

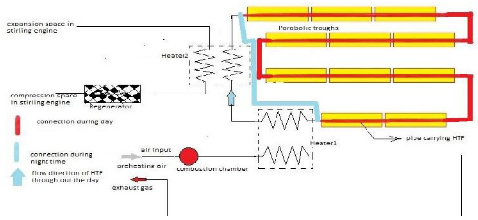


Figure 8

For an hybrid plant in any of the above mentioned configurations, the number of troughs are always constant. Temperature rise of HTF by parabolic troughs depends on the irradiance by sun on that day. To maintain the maximum temperature possible in HTF, biomass should be used. The minimum amount of biomass that should be used depends on the number of troughs and the maximum irradiance possible in the region. The amount of biomass to be used in combustion chamber can be varied by knowing the irradiance value, detected by the sensors. In both configurations shown in figure 7 and 8, the biomass combustion kind of design should have a very efficient dynamic response in order to adapt its working point to the variability of solar irradiation conditions. For this purpose, biomass combustion can be replaced by biogas using biogas gasifiers since it is easy to control its input depending on the irradiance of sun and temperature requirement of the day but setting up biogas gasifier is expensive.

The solar stirling engine's power output depends on the temperature difference between the temperature at expansion space and compression space. Thus, the maximum achievable output for a given setup is achieved through this process. since the calorific value of biomass is low, amount of biomass used is very high. This makes it difficult to run the plant in the night. This is because the heat is first transferred from biomass combustion chamber to HTF and then to the working fluid by HTF. This increases the losses, as number of heat transfers is higher in this case than in the conventional biomass Stirling plants. As a result the output from the system will be considerably low. From a conceptual standpoint, the key operating conditions of this hybrid plant would involve:

- Whenever possible, the power generation should be based on the CSP cycle, since the fuel (solar irradiation) is free and the operating costs are minimised.
- Biomass combustion will be used during longer periods when solar resource is unavailable, for example during

nights and winter days.

VI. TECHNOLOGY ASSESMENT OF CSP – BIOMASS HYBRID TECHNOLOGY

The first parameter that should to be considered in the design of the power plant is power capacity, as both economy and the energy performance of the plant are sensitive to scale factors. In general terms, larger plants benefit from higher energy efficiencies and take advantage of increasing economies of scale. However, large plants encounter difficulties to ensure a sustainable and stable supply of biomass feedstock.

A. *Solar field power generation*

To determine the power obtained by solar irradiation on HTF, the temperature and volume flow rate of the HTF must be known, of which temperature can be found by thermometers or sensors. The volumetric flow is determined using the following expression[13][14]:

$V_{rate} \square Q_{SF} \square L \square_{loops} \square h_{HTF} \square \square 1$

Where,

V_{rate} - HTF volumetric flow in the solar field.

Q_{SF} - Heat collected in the solar field, based on hourly data.

A - Aperture length of the solar collector.

L - Loop length.

N - Number of loops

□h_{HTF} - HTF Increase of enthalpy.

□(T)- HTF density at the mean logarithmic temperature in the Solar Field.

So, by knowing all the parameters the energy carried by heat transfer fluid in the pipe can be found out by,

$Q_{HTF} = V_{rate} * \square(T) * h_T$ (2)

Where h_T is the value of enthalpy at the temperature T, which can be found out from the data book of purchased heat transfer fluid.

B. *Biomass combustion chamber*

The thermal energy produced in these systems is calculated as the difference between the solar field production and set to meet the power requirements. The biomass fuel required to obtain the energy calculated is given by the equation[13][14] :

η $M_f^{rate} = (Q_{req} - Q_{sf}) / (\eta\, LHV_f)$ (3)

Where,

M_f^{rate} – Mass flow rate of the fuel

Q_{req} - Heat needed for production.

Q^{sf} - Heat collected in the solar field.

η - Performance of biomass combustion system.

LHV_f – Lower heating value of the fuel.

This value is needed to estimate the fuel consumption needed to heat the HTF that cannot be heated in the solar field.

C. *Stirling cycle : output*

For an air-standard Stirling cycle, the amounts of heat added and rejected per unit mass of working fluid are as follows [6]:

Q added = xc_{v}*(T_H - T_C) – (RT_H * ln ($v1$ / $v2$)) (4)

Q rejected = xc_v*(T_H - T_C) – (RT_C * ln($v2$ / $v1$)) (5)

where x is the fractional deviation from ideal regeneration (i.e. x =1 for no regeneration and x =0 for ideal regeneration), c_V the specific heat capacity at constant volume in J/(kg K), T_H is the source temperature in the Stirling cycle in K, T_C is the sink temperature in K, R the gas constant in J/(kg K), v_1 and v_2 are specific volumes of the constant-volume regeneration processes of the cycle in m3/kg, and v_2/v_1 is the volume compression ratio. The Stirling cycle efficiency can be expressed as [15]:

□$_s$= 1- (̃1□̃1C_s(1-1/□)) (6)

Where □=T_H/T_C (7)

$C_s=XC_v/(Rln(V_1/V_2)$. (8)

VII. CONCLUSION

Bioenergy and solar energy based technologies for power production are increasingly important, which have internationally caught extensive attention due to concerns about security of energy supplies and threats of climatic changes. Considerable developments of technologies are steadily taking place in recent years and today, the power production from solar and biomass can be considered a mature option. We conclude that this "**waste to energy"** conversion can help us meet the demand for electricity, at the same time decreasing the consumption of fossil fuel for power generation and production cost.

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