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SunGas: Thermochemical Production of Solar-Fuel with Concentrated Solar Energy

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Abstract

Energy plays a very vital role in every body's life. It is required for industrial applications, for house hold systems agriculture and office systems. The production of energy can boost the economic growth of a country. For all the above said process the energy must be in the form of not only sustainable but also reliable in nature. The energy must be economical and sustainable as well as environment friendly. Harvesting the energy from fossil fuel increases the production of SO_X,NO_X which in turn increases the green house gases. So an alternate source of clean energy becomes sun . Sun is generally regarded as the abundant source of energy . This paper describes about the production of energy in the sun and hot to track the sun energy most efficiently for meeting the global energy demand.

Key Words:- Reactor, tracking systems

1. Introduction:

Sunlight is the most abundant resources of energy on the surface of the earth. Still we are not thinking sunlight as a resource for the solution to any energy crisis or as the fuel of near future which will bring cleaner air to our cities. We cannot even imagine that we are driving into the local petrol pump and filling our cars with sunlight. Therefore it is the reason that this resource does not capture our imagination as the alternative that could help us deal with two most dangerous problems that we will meet head on in the 21st century, namely the impending shortage of crude oil and the environmental pollution. Scientists and engineers around the world are fascinated by an astounding fact that by using only 0.1% of the earth's land space with solar collectors which operate with a collection efficiency of around 20%, we could collect more than enough energy to supply the current energy needs of all the people of the planet annually. Moreover, the solar energy reserve is unlimited and it is also not owned by any particular individual or government, further its utilization is environmentally friendly. Some serious drawbacks of utilizing solar energy are: (i) solar radiation reaching the earth is very less (only about 1 kW/m^2), (ii) intermittent (available only during day-time), and (iii) unevenly distributed over the surface of the earth (mostly between 30° north latitude and 30° south latitude).

The question like "How we can seize solar energy such that it can be stored and transported from earth's sunbelt to world's industrialized and populated centers, where a high demand for energy is going, which in terns motivated the scientists and engineers to search for technique that can conveniently convert sunlight into a fuel that one can use to drive not only our cars but the world economy too. In other words these researchers are looking for a process that can convert intermittent solar radiation into storable chemical energy in form of fuels that can be transported to the populated or demand centers. The method by which sunlight can be used to produce fuels or can be converted from one form to another usable form (for example from solar to chemical), comes under the discipline of thermodynamics. In simpler terms, thermodynamics inform us that the higher the temperature at which we supply solar energy to our process, the more productive we can be with what comes out as a final product. We can trap the sun light in a typical flat-plate solar collector, we get warm water which could be used for taking baths or to supply space heat. Although this type of device will be very useful in local areas where sunlight is of favorable condition, so it will not enable solar energy collected in one particular area to be transported to another deficient area to counter

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energy needs. But if we direct solar energy to a chemical reactor at very high temperatures around 2300 K, we can create possibility for such an option: solar energy collected in one area can heat homes, supply electricity, drive cars etc in another far away location.

Figure-1 demonstrate the basic idea how we can concentrate the diluted sunlight over a small area by the help of parabolic mirrors and then seize that radioactive energy of sunlight with the help of suitable receivers and absorbers, we would be able to obtain heat at high temperatures for making a chemical transformation and producing a storable and transportable fuel. Instead of the property of the fuel, the theoretical maximum efficiency of such an energy-conversion process is limited by the Carnot efficiency of an heat engine. With the sun's surface as a 5800K thermal

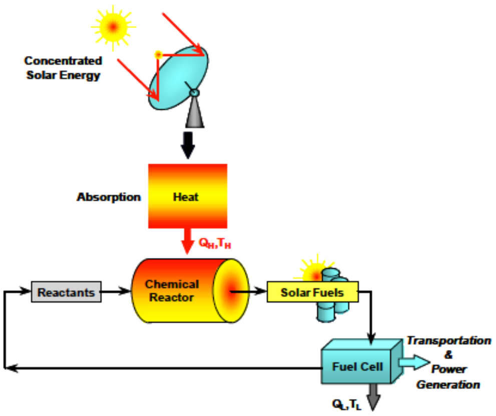

Figure 1. Schematic of solar energy conversion into solar fuels. Concentrated solar radiation is used as the energy source for high-temperature process heat to drive chemical reactions towards the production of storable and transportable fuels.

reservoir where as the earth surface acts as thermal sink, about 95% of the solar energy could, in principle, be converted into the chemical energy of fuels so it is up to the design and development of the technology that approaches this limit.

2. ENERGY CONCENTRATION PRINCIPLE

The conventional method for concentrating or collecting solar energy over large area and delivering it to load or demand center, is by parabolic-shaped mirrors. A parabola always focuses rays parallel to its axis into its focal point. But, sun rays are not parallel. For a good approximation they can be assumed to originate at a disk which subtends the angle $\boldsymbol{\theta}$=0.0093 radian.

When a perfectly reflective paraboloid of focal length f and the rim angle $\boldsymbol{\Phi rim}$ is aligned to the sun, then the reflection of the rays at the focal plane forms a circular image centered at the focal point as shown in Figure-2. It has the diameter,

$$d = \frac{f \times \theta}{\cos \boldsymbol{\Phi rim}\,(1 + \cos\boldsymbol{\Phi rim})}$$

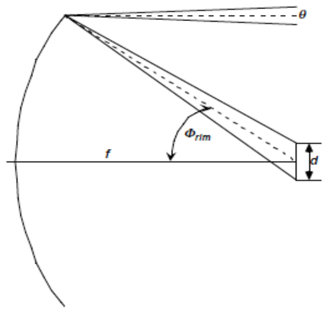

Figure. 2. Concentration of sunlight by a parabolic dish of focal length f and rim angle Φ_{rim}. When the dish is aligned toward the sun, reflection of sun rays at the focal plane forms a circular image centered at the focus of diameter d.

Over this circle, the radiation flux intensity is maximum and uniform in the paraxial solar image that is the hot-spot. For larger diameters (greater than f ×θ) it decreases, such that it forms an elliptical images. According to theory the concentration ratio C at the hot spot is defined as the ratio of the radiation intensity on the hot spot to the normal beam insolation, which is arround

$$C \approx \frac{4}{\theta^2} sin^2 \Phi_{rim}$$

For parabolic-shaped mirrors there are three main optical configurations which are commercially available for large-scale collection and concentration of solar energy. These are the trough, tower, and dish type systems. These systems are shown in Figure-3. Generally the Trough system uses linear, two-dimensional, parabolic mirrors to focus sunlight onto a solar tubular receiver which is positioned along their focal line. The Tower system uses a field of heliostats that are two-axis tracking parabolic mirrors which focus the sun rays onto a solar receiver mounted on the top of a centrally located tower. Whereas a Dish system uses the paraboloidal mirrors to focus sunlight on a solar receiver positioned at their focus. The total power collected by any of these systems is proportional to the projected area of the mirrors. Their arrangement

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mainly depends on the concentrating system selected and on the site latitude.

The solar flux concentration ratio *C* is obtained at the focal plane which varies between 30-100 suns for the trough systems, 500-5,000 suns for the tower systems, and 1000-10,000 for the dish systems. Higher concentration ratios mean lower heat losses from smaller receivers and as a result higher attainable temperatures at the receiver.

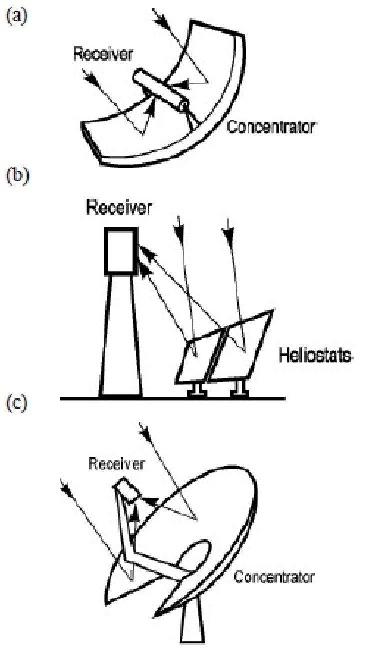


Figure 3. Schematic of the three main optical configurations for large-scale collection and concentration of solar energy: (a) the trough system, (b) the tower system, and (c) the dish system.

3. Thermodynamics of Solar Thermo-chemical Conversion

In solar thermo-chemical process, the concentrated solar radiation is used as the source of energy of high-temperature process heat which drives the endothermic reactions aimed at the production of chemical fuels. Solar reactors for highly concentrated solar systems usually include the use of a cavity-receiver type arrangement i.e. a well insulated enclosure with a small opening or gap to let in the concentrated solar radiation. Due to multiple internal reflections the fraction of the incoming energy absorbed by the cavity exceeds the surface absorption of the inner walls. cavity receiver approaches towards blackbody absorber, if the characteristic length to open diameter increases. . The absorption efficiency of a solar reactor, $\eta_{absorption}$, is defined as the net rate at which energy is being absorbed divided by the solar radiative power coming from the solar concentrator. For a cavity receiver

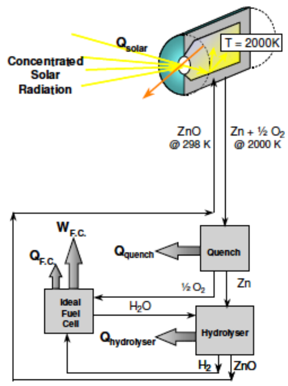
$$C = \frac{Q_{aperture}}{I\,A_{aperture}}$$

where $Q_{solar}$is the solar power coming from the solar concentrator, $Q_{aperture}$is the amount intercepted by the aperture of area $A_{aperture}$. The numerator is denoted by the difference between the power absorbed and reradiated, that should match the enthalpy change of the reaction.. The capability of the solar concentrator system to concentrate solar energy is often expressed in terms of its mean flux concentration ratio *C* over the cavity's aperture, normalized to the incident normal beam insolation.

For example if we consider a solar thermo-chemical process in which splitting of H2O occurs using ZnO/Zn redox reaction, comprising of following two steps: (1) the solar endothermic dissociation of ZnO(s) into its elements; and (2) the non-solar exothermic steam-hydrolysis of Zn into H2 and ZnO(s), and represented by the following equations

1st step solar ZnO − decomposition: $ZnO \rightarrow Zn + 0.5O_2$

2nd step non − solar Zn − hydrolysis: $Zn + H_2O \rightarrow ZnO + H_2$

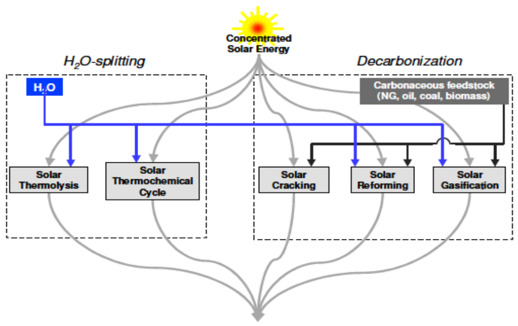


Schematic of an ideal cyclic process for calculating the maximum solar-to-fuel energy conversion efficiency of the 2-step water-splitting cycle using ZnO/Zn redox reactions

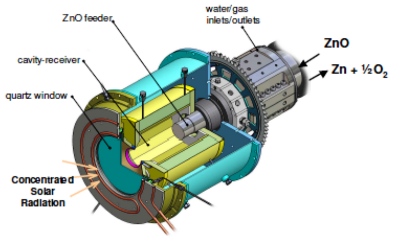
A model of the proposed two-step solar thermo-chemical cycle is shown in the Figure. It comprises of a reactor, hydrolyser reactor and quenching device, and a H_2/O_2 fuel cell. All materials are recycled. A constant pressure of 1 bar is maintained throughout the process. Pumps are also used to maintain the pressure whenever pressure at any point of time drops below required level.

4. Solar Thermo-chemical Processes and Reactors

There are five thermo-chemical routes for solar fuels production which are shown in the Figure. Indicated is the chemical feedstock: H_2O and/or carbonaceous feedstock (e.g. natural gas, oil, coal, biomass). All these routes comprised of highly endothermic processes which occurs at very high temperatures and uses concentrated solar radiation as the source of energy for process heat. The single-step thermal dissociation of water known as hydro-thermolysis, although conceptually simple, has been impeded by the need of a high-temperature heat source at above 2500 K for achieving a reasonable degree of dissociation. Water-splitting thermo-chemical cycles bypass the H_2/O_2 separation problem and further allow operating at relatively moderate upper temperatures. These cycles required multiple steps (>2) and were suffering from inherent inefficiencies associated with heat transfer and product separation at each step. A lot of steps have been taken in order to achieve a concentration ratio up to 5000 suns. Such high solar radiation fluxes allow the conversion of solar energy to thermal reservoirs at 1500 K and above which are needed for the more efficient two-step thermo-chemical cycles using metal oxide redux reactions.



Five thermochemical routes for solar fuels production using concentrated solar radiation as the energy source of high-temperature process heat



Scheme of the solar reactor configuration for the thermal dissociation of ZnO, as part of a 2-step water-splitting thermochemical cycle based on ZnO/Zn redox reactions. It consists of a windowed rotating cavity-receiver lined with ZnO particles. With this arrangement, ZnO is directly exposed to high-flux solar irradiation and serves simultaneously the functions of radiant absorber, thermal insulator, and chemical reactant

5. Conclusion

What ever the sun light that the earth receives about 30% of them is get reflected back in the outer region of the atmosphere. Nearly 20% is again reflected by the earth atmosphere. So we are able to receive only nearly about 40-50%. However if we cover the entire earth surface with solar PV then the entire earth energy demand of the earth would be eliminated for some fewer days. The efficiency of the solar cell is nearly about 25-30%. With this little amount of efficiency it is too difficult to maintain the global energy demand. Some technical analysis must be carried out so as to develop more & more efficient solar cell.

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