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A Review on Various Parameters of Solar Thermochemical Reactor

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ABSTRACT

Solar energy is one of the most abundant, clean, and widespread energy in the world, which has the potential to address the issues of environmental pollution, global warming, and energy crisis, while the intermittent distribution of solar energy in time and space limits its utilization. Among various approaches of solar energy utilization, converting solar energy into chemical fuel (e.g., hydrogen) by thermochemical approach could maintain the steady and high-efficient energy supply and can make use of the full-spectrum solar energy. Initially, an analysis of the environmental problems related to the use of conventional sources of energy is presented and the benefits offered by renewable energy systems are outlined. Thermochemical heat storage is studied in detail with its advantages. Various types of collectors are presented in order to show to the reader the extent of their applicability. These include flate plate collector, compound parabolic collector and parabolic trough collectors. As can be seen solar energy systems can be used for a wide range of applications and provide significant benefits, therefore, they should be used whenever possible.

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I. INTRODUCTION

Thermochemical energy storage is one of the most promising ways for its high energy density, low energy loss and easy transported products. Carbon dioxide reforming of methane is a typical reaction system for thermochemical energy storage and can be used to collect the concentrating solar thermal power. In light of increasing awareness of the role of CO2- emissions in global warming and the dire consequences this may have on human society, the renewable energy sources including wind, tidal, solar, biomass, wave and geothermal are receiving ever-greater attention. These energy sources have the benefits that they have a low environmental impact, are widely available, and produce no or little contamination. However, their widespread adoption is also constrained by geographical location, atmospheric conditions, and both economic and safety considerations. It is increasingly thought that the usage of renewable energy sources, and solar in particular, will be the key factor for continued sustainable human development. (Prasad et al., 2019)

1. Thermochemical Heat Storage

Thermal energy storage (TES) plays a pivotal role in synchronizing energy demand and supply, both on a short- and long term (seasonal) basis. Transformation of our existing building stock towards low energy buildings and nearly zero energy and Plus-energy buildings requires effective integration and full use of the potential yield of renewable energy. Thermal storage is a key priority to make such a step, particularly considering the energy renovation of the existing stock, where compact building level solutions are required.

Among the main parameters that influence the performance of a THS are the TCMs. In selecting the appropriate materials, the key principles include selecting materials which have high energy storage density, low charging or regeneration temperature, high water or sorbate uptake which is measured in (g sorbate/ g sorbent), appropriate heat and mass transfer properties for efficient power output, easy to handle and non-poisonous, low cost price per kWh of energy stored, good thermal stability and suitable with the application. (Jarimi et al., 2019)

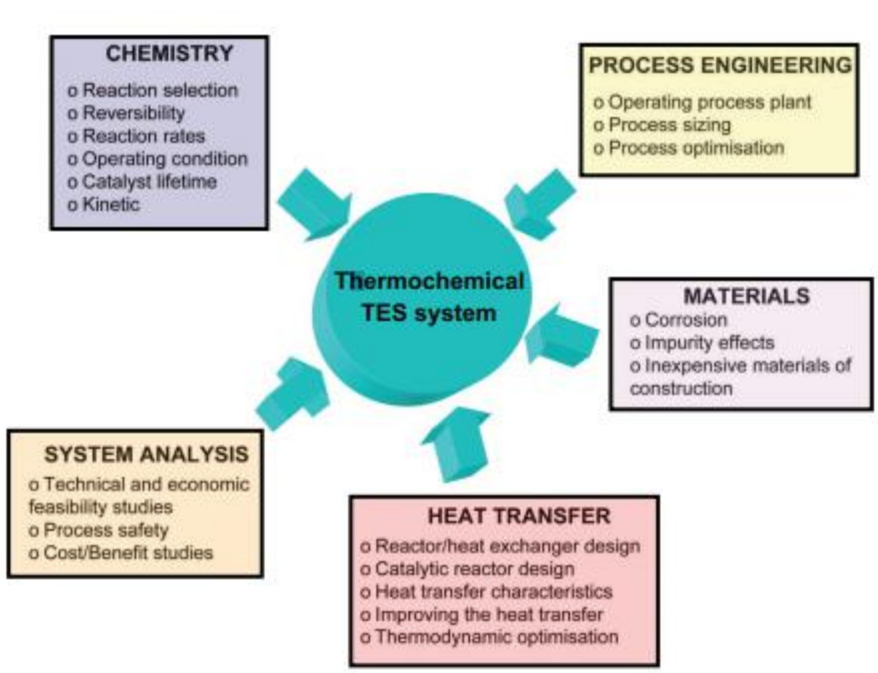

Figure 1 Technical disciplines necessary to the development of a TES system

Advantages of thermochemical heat storage

- Components (A and B) can usually be stored separately at ambient temperature, after cooling to ambient conditions subsequent to their formation. Therefore, there is little or no heat loss during the storing period and, as a consequence, insulation is not needed.
- As a result of the low heat losses, thermochemical TES systems are especially suitable for long-term energy storage (e.g., seasonal storage).
- Thermochemical materials have higher energy densities relative to PCMs and sensible storage media. Because of higher energy density, thermochemical TES systems can provide more

compact energy storage relative to latent and sensible TES. This attribute is particularly beneficial where space for the TES is limited or valuable. (Prasad et al., 2019)

2. Types of Solar Energy

Fossil fuels are much more cost effective because they are highly concentrated sources of energy, but the sunlight is a widely spread resource with a much lower energy density. In other words, the energy is spread over large areas. From an energy efficiency standpoint, this is the ultimate challenge of solar energy technologies. Following are some of the types of solar energy which are in use:

Solar Photovoltaic Energy

Solar Photovoltaic Energy is a technology which uses photovoltaic effect and photovoltaic cells, contain a cells or solar cell which convert sunlight into electricity. Solar energy is available in abundance, but the use of utilizing solar energy by solar panel or other solar energy utilizing technology devices is relatively like new development. (Perret, 2011)

Solar Photosynthetic Energy

Solar Photosynthetic technologies aim to harvest energy from the sun in the same way that biological systems use sunlight. In effect, it is an effort to create a synthetic photosynthesis. In natural photosynthesis, water decomposition and the reduction of carbon dioxide takes to the production of carbohydrates and oxygen as seen in Equation

$$CO2 + O2 + Light \rightarrow CH2O + O2$$

It is one of the areas of solar energy that stands in contrast to solar thermal energy, which will be described next. (Abedin, 2011)

Solar Thermal Energy

From personal experience, we know that when something sits in the sunlight for a while it is warm to the touch. If you have ever stepped out barefoot on the sidewalk on a summer day then you have experienced the thermal power of the sun. Simply put, solar thermal energy is the area of solar energy that uses the heating effect of sunlight to heat something else, for example water which can then be used in traditional power plants to generate electricity. (Falter & Pitz-Paal, 2018)

3. Solar Collector

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days. There are basically two types of solar collectors: non-concentrating or stationary and concentrating. A non-concentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun’s beam radiation to a smaller receiving area, thereby increasing the radiation flux. A large number of solar collectors are available in the market. In this section a review of the various types of collectors currently available will be presented. This includes FPC, ETC, and concentrating collectors. (Bhowmik & Amin, 2017)

4. Types of Solar Collector

Flat plate Collector

FPC is usually permanently fixed in position and requires no tracking of the sun. The collectors should be oriented directly towards the equator, facing south in the northern hemisphere and north in the southern. The optimum tilt angle of the collector is equal to the latitude of the location with angle variations of 10–158 more or less depending on the application. FPC has been built in a wide variety of designs and from many different materials. They have been used to heat fluids such as water, water plus antifreeze additive, or air. Their major purpose is to collect as much solar energy as possible at the lower possible total cost. The collector should also have a long effective life, despite the adverse effects of the sun's ultraviolet radiation, corrosion and clogging because of acidity, alkalinity or hardness of the heat transfer fluid, freezing of water, or deposition of dust or moisture on the glazing, and breakage of the glazing because of thermal expansion, hail, vandalism or other causes. These causes can be minimized by the use of tempered glass.(Camacho et al., 2007)

Compound Parabolic Collector

CPC are non-imaging concentrators. These have the capability of reflecting to the absorber all of the incident radiation within wide limits. Their potential as collectors of solar energy was pointed out by Winston. Compound parabolic concentrators can accept incoming radiation over a relatively wide range of angles. By using multiple internal reflections, any radiation that is entering the aperture, within the collector acceptance angle, finds its way to the absorber surface located at the bottom of the collector. The absorber can take a variety of configurations. . CPCs are usually covered with glass to avoid dust and other materials from entering the collector and thus reducing the reflectivity of its walls. (Menni et al., 2018)

Parabolic trough collectors

In order to deliver high temperatures with good efficiency a high performance solar collector is required. Systems with light structures and low cost technology for process heat applications up to 400 8C could be obtained with parabolic through collectors (PTCs). PTCs can effectively produce heat at temperatures between 50 and 400 8C. Parabolic trough technology is the most advanced of the solar thermal technologies because of considerable experience with the systems and the development of a small commercial industry to produce and market these systems. PTCs are built in modules that are supported from the ground by simple pedestals at either end. In order to achieve cost effectiveness in mass production, not only the collector structure must feature a high stiffness to weight ratio so as to keep the material content to a minimum, but also the collector structure must be amenable to low labour manufacturing processes. (Bhowmik & Amin, 2017)

II. LITERATURE REVIEW

(Zsembinszki et al., 2018) The aim of this study is to perform a review of the state-of-the-art of the reactors available in the literature, which are used for solid-gas reactions or thermal decomposition processes around 1000◦C that could be further implemented for thermochemical energy storage in CSP (concentrated solar power) plants, specifically for SPT (solar power tower) technology. Both direct and indirect systems can be implemented, with direct and closed systems being the most studied ones. Among direct and closed systems, the most used configuration is the stacked bed reactor, with the fixed bed reactor being the most frequent option. Out of all of the reactors studied, almost 70% are used for solid-gas chemical reactions. Few data are available regarding solar efficiency in most of the processes, and the available information indicates relatively low values. Chemical reaction efficiencies show better values, especially in the case of a fluidized bed reactor for solid-gas chemical reactions, and fixed bed and rotary reactors for thermal decompositions.

(Jarimi et al., 2019) presents a literature survey and a review that add insights into the current state-of-the-art THS technologies, covering: the THS materials, THS reactor design and THS as thermal batteries. Emphasis is placed on THS for solar thermal energy storage and also for industrial waste heat recovery. At the materials level, in addition to a review on THS material sorbents, emphasis is placed on innovative composite THS materials with salt mixtures and metal-organic frameworks materials. Reactor design is one of the major fields of THS system development. In this paper, we also review several types of innovative reactor designs, including hybrid THS systems, towards obtaining advanced reactor concept, numerical studies in THS studies mainly covering the heat and mass transfer in the reactor designs, and also the implementation of THS systems as thermal batteries.

(Zsembinszki et al., 2018) performs a review of the state-of-the-art of the reactors available in the literature, which are used for solid–gas reactions or thermal decomposition processes around 1000 ◦C that could be further implemented for thermochemical energy storage in CSP (concentrated solar power) plants, specifically for SPT (solar power tower) technology. Both direct and indirect systems can be implemented, with direct and closed systems being the most studied ones. Among direct and closed systems, the most used configuration is the stacked bed reactor, with the fixed bed reactor being the most frequent option. Out of all of the reactors studied, almost 70% are used for solid–gas chemical reactions. Few data are available regarding solar efficiency in most of the processes, and the available information indicates relatively low values. Chemical reaction efficiencies show better values, especially in the case of a fluidized bed reactor for solid–gas chemical reactions, and fixed bed and rotary reactors for thermal decompositions.

(Falter & Pitz-Paal, 2018) studied that the solar thermochemical fuel production pathway as an attractive option for the decarbonization of the transportation sector. Using ceria as the reactive material and the latest published data on inert gas demand and energy demand for vacuum pumping from the literature, the energy balance of the thermochemical reactor is analyzed for vacuum pumping and inert gas sweeping, and the required process parameters for reaching high efficiencies are discussed. It is found that the energy losses theoretically can be used to cover the demand for electricity and low temperature heat, as well as the heating of the reactants to the oxidation temperature, enhancing the pathway efficiency from 5.3% to 8.6%. The heat recovery from the single process steps along the fuel production pathway therefore has a large potential to increase the efficiency of the process, improving the economic and ecological performance significantly. Likewise, waste heat may be used to partially relax the likely stringent operating conditions of highly efficient thermochemical reactors, which could have important implications for reactor design.

(Guene Lougou et al., 2017) This paper investigated radiation heat transfer and temperature distributions of solar thermochemical reactor for syngas production using the finite volume discrete ordinate method (fvDOM) and P1 approximation for radiation heat transfer. Different parameters including absorptivity, emissivity, and reflection based radiation scattering, and carrier gas flow inlet velocity that would greatly affect the reactor thermal performance were sufficiently investigated. The fvDOM approximation was used to obtain the radiation intensity distribution along the reactor. The drop in the temperature resulted from the radiation scattering was further investigated using the P1 approximation. The results indicated that the reactor temperature difference between the P1 approximation and the fvDOM radiation model was very close under different operating conditions. However, a big temperature difference which increased with an increase in the radiation emissivity due to the thermal non-equilibrium was observed in the radiation inlet region. It was found that the incident radiation flux distribution had a strong impact on the temperature distribution throughout the reactor. This paper revealed that the temperature drop caused by the boundary radiation heat loss should not be neglected for the thermal performance analysis of solar thermochemical reactor.

(Ermanoski & Siegel, 2014) report on results regarding the annual average efficiency of a recuperating packed particle bed reactor for solar-thermochemical hydrogen production via a two-step metal oxide cycle, using detailed numerical models. The key findings are that reactor efficiency is substantially flat as a function of direct normal irradiance, leading to an annual average efficiency almost equal to the design-point efficiency, and that ample high quality waste heat is available to make standalone operation feasible, including feedstock water production.

(Lipiński *et al.*, 2013) reported outlines of the advances, obstacles and possibilities in heat transfer research as applied to thermochemical high-temperature systems using high-flow solar irradiation as the source of process heat. Listed related fields such as radioactive spectroscopy and the heat and mass characterization of heterogeneous media dependent on tomography, High-temperature kinetics Heterogeneous reactions, heat and mass transfer simulation of solar thermochemical processes, and thermal measurements in high-temperature processes are discussed, with brief description of their methods and descriptions of the effects of selected applications.

(Camacho et al., 2007) A historical introduction into the uses of solar energy is attempted followed by a description of the various types of collectors including flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish and heliostat field collectors. This is followed by an optical, thermal and thermodynamic analysis of the collectors and a description of the methods used to evaluate their performance. Typical applications of the various types of collectors are presented in order to show to the reader the extent of their applicability. These include solar water heating, which comprise thermo syphon, integrated collector storage, direct and indirect systems and air systems, space heating and cooling, which comprise, space heating and service hot water, air and water systems and heat pumps, refrigeration, industrial process heat, which comprise air and water systems and steam generation systems, desalination, thermal power systems, which comprise the parabolic trough, power tower and dish systems, solar furnaces, and chemistry applications.

III. CONCLUSION

Solar thermochemical processes make use of concentrated solar radiation for driving chemical reactions. The processes are classified into those for production of solar fuels and chemical commodities. Several of the most common types of solar collectors are presented in this paper. The various types of collectors described include flat-plate, compound parabolic, evacuated tube and parabolic trough. It should be noted that the applications of solar energy collectors are not limited to the above areas. There are many other applications which are not described here either because they are not fully developed or are not matured yet. As an overall, THS presents an important opportunity to reduce future fossil fuel usage and CO2 emissions. The application areas described in this paper show that solar energy collectors can be used in a wide variety of systems, could provide significant environmental and financial benefits, and should be used whenever possible. In further studies, its parameters can be studied to increase the efficiency of Solar Thermochemical Reactor.

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