http://www.jctjournals.com
ISSN(ONLINE):2278 – 3814

Volume-13, Issue-12, December 2024
JOURNAL OF COMPUTING TECHNOLOGIES (JCT)
International Journal
Page Number: 01-07

Design, Implementation and Simulation of Solar Thermo Chemical Reactor With Multiple Length and Porosity Using CFD: A Review

Paras Jain[1], Prof. Rana Manoj Mourya [2]
[1,2] M.Tech Scholar, Associate Professor
[1,2] Department of mechanical engineering
[1,2] Oriental College of Technology, Bhopal, India

***Abstract*— Solar thermo chemical processes make use of concentrated solar radiation as the energy source of high-temperature, which drives endothermic reactions aimed at the production of chemical fuels. In this thesis, the main objective is to study the effect of various parameters on the working of thermo chemical reactor. The parameters which are studied here are porosity, velocity and length of the porous material. The results from these parameters concluded that high porosity enhances the working of thermo chemical reactor and velocity must be kept low for the better results. It is also observed that variation in length shows changes in heat transfer rate and temperature of the reactor. In the present study NX11 software is used for CAD modelling. And ANSYS is the software used for modelling as well as for testing the products durability, temperature distribution in product and the movement of fluid under various boundary conditions. For enhancing the working of thermo chemical reactor, seven cases are taken and experiments are performed; the results are concluded in the end of the thesis. Furthermore, overall comparison of heat transfer, temperature and average temperature is also discussed. This comprehensive study enables to study the factors that enhance the working of thermo chemical reactor.**

Keywords*— Solar thermal energy, porosity, thermo chemical fuel, syngas, meshing, boundary condition, renewable energy sources.

I. Introduction

From the studies of Gibbs and Carnot, two famous 19th-century scientists they founded the science of thermodynamics which seems to be the study of how energy can be transferred, for e.g., chemical energy obtained from solar energy, from one phase to another. Thermodynamics shows us, in quite simplistic words, that at higher temperature we transmit energy of solar to our process, more innovative we could be about what gets out like an end product. For instance, when we use sunlight in a traditional flat-plate solar collector, we can produce hot water which could be used to take baths or provide heat for space. While this kind of system will make much sense for some local conditions, this will not allow transportation to Japan of the solar energy produced in Australia. Although at very high temperature if we deliver solar energy to a chemical reactor, we increase the possibility for such a feat: solar energy produced in Australia will heat houses, provide power and can be used for many more.

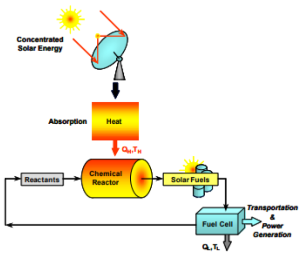

Figure 1.1 Working of the solar thermo-chemical reactor (Steinfeld and Palumbo, 2003)

Figure 1 illustrates the basic idea. Researchers start focusing the diluted sun rays with the help of parabolic mirrors over a limited region and then grab a certain radioactive energy through the help of appropriate receivers, researchers would be able to receive heat at high temperatures to drive a chemical reaction and produce a reusable and moveable fuel. Regardless of the nature of the fuel, the theoretical maximum efficiency of such an energy-conversion process are confined by the Carnot efficiency of an equivalent heat engine. With the sun's surface as a 5800 K thermal reservoir and the earth as the thermal sink, 95% of the solar energy could, in principle, be turned into the chemical energy of fuels. It's up to the user to design and evolve the technology which approaches this limit.

1.2 Thermodynamics of Solar Thermo-chemical conversion

Because thermodynamics is the science that describes the conversion of one form of energy into another form, it is germane to the area of Solar Thermo chemistry. Solar thermo chemical processes convert radiant energy into chemical energy. The two fundamental thermodynamic laws that give practical information with regard to any solar thermo chemical process are the 1st and 2nd laws. Using the 1st law, one establishes the minimum quantity of solar energy needs to produce a particular fuel or chemical species. The 2nd law indicates, among other things, whether or not the chosen path for producing the fuel is physically possible. Both types of information are required for a process designer (Steinfeld and Palumbo, 2003).

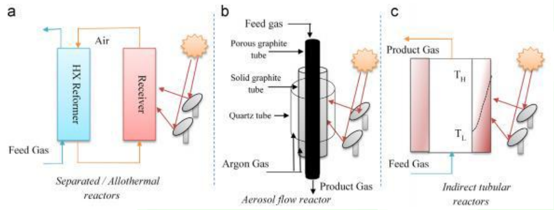

Figure 1.2 Indirectly heated solar reactors

In the directly heated reactors, reactants are directly exposed and heated by incoming solar radiation. Directly illuminated reactors may further classified as volumetric and particle reactors.

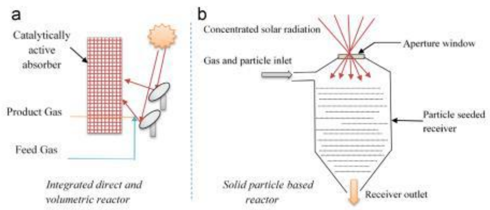

Figure 1.3 Directly illuminated solar reactor

1.3 Principles of Solar Energy Concentration

The conventional method of concentrating solar energy, i.e. collection of solar energy over some large area and delivering it to a smaller one, is by parabolic shaped mirrors. Parabolic centres in its focal point the rays parallel to its axis. Sun rays aren't identical though. For a well approximation it can be assumed that they originate on a disc that subtends the radian angle = 0.0093. When a perfectly specular reflective paraboloid of focal length f and rim angle Φ rim is aligned to the sun, reflection of the rays at the focal plane forms a circular image centered.

1.4 Thermo chemical heat storage material

THS systems often classified as reversible chemical reactions and action processes. in a action process, heat is hold on by disturbing the binding force between the material and also the frappe in the terms of the chemical potential. For the heat energy sorption process, the process is only occurs while the dried materials are uncovered to working sorbent (dried) materials area unit exposed to the operating fluid or material. Thus, in essence, as long because the materials area unit hermitically sealed, and the storage is loss-free.

1.5 Types of Solar energy

It is clear from the stated facts about the sun that there is an enormous energy potential in sunlight. Why is solar energy not being used for the majority of our energy needs? Primarily it is cost and conversion capacity that stands in the way of solar energy. Fossil fuels are much more cost effective because they are rich 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.(Mohammad Bagher, 2016).

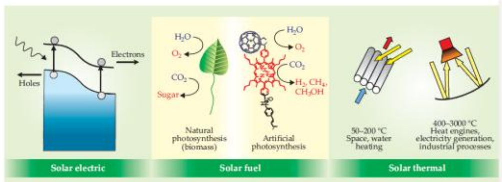

Figure 1.6 Areas of solar energy (Bin, 2002)

1.5.1 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 Photovoltaic energy technology is discovered by a French scientist Edmond Becquerel in year 1839. But the first working photovoltaic cell is successfully made by Charles Fritts in year 1882. This cell is made up of thin sheet of selenium and gold plated. Solar energy is accessible in abundance, but the use of utilizing solar energy by solar panel or other solar energy utilizing technology devices is relatively like new development.(Eldin, Refaey and Farghly, 2015)

Photovoltaic cell technology can be classified according to the material used,

1. Crystalline Silicon
2. Thin Film
3. Concentrated photovoltaic (CPV) and Organic Material (Eldin, Refaey and Farghly, 2015

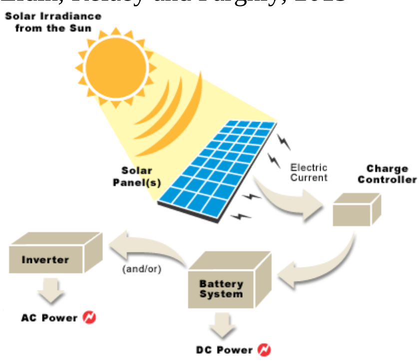

Figure 1.7 Solar Photovoltaic Energy (Image -Sourcehttp://www.ecoplanetenergy.com/all-about-eco-energy/overview/solar/)

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

Research in the field of solar photosynthetic energy aims to produce this natural phenomenon and increase its efficiency. This zone of natural resources, in its research is at a very beginning stage and there are not many notable advances in this area so far that can be mentioned. Nevertheless, it is one of the areas of solar energy that stands in contrast to solar thermal energy, which will be described next.(Thapper et al., 2013).

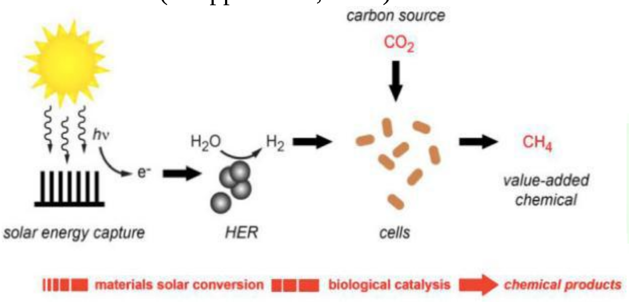

Figure 1.5 Solar Photosynthetic Energy

1.5.3 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.(Kumar, Hasanuzzaman and Rahim, 2019)

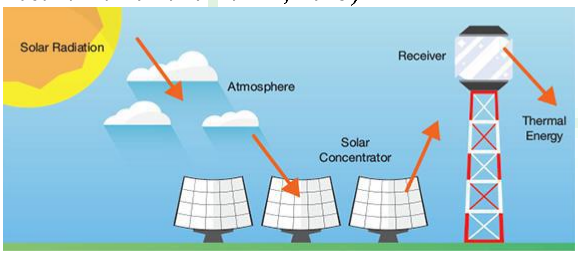

Figure 1.9 Solar Thermal Energy, (Source - https://www.aiche.org/concentrating-solar-thermal)

1.6 Industrial Applications of Solar Thermo-chemical Processes

The previous sections discussed in detail on solar fuel production by improving of carbonaceous feed and from water/carbon dioxide in a thermo-chemical cycle. As discussed earlier, solar thermo-chemical processes also have some direct applications for producing many industrial commodities. This section of research work review on the solar thermo-chemical production of industrial goods.

II. LITERATURE REVIEW

(Zhang *et al.*, 2018) explains that thermal transfer and fluid flow characteristics have important impacts on the performance of hydrogen output as a primary technological parameter for porous media solar thermo-chemical reactor. The implementation of computational fluid dynamics (CFD) could solve these problems more effectively and at a lower cost. Additionally, the option of various models of thermal transport may cause results to vary. In this research, thermal transport and the fluid flow characteristics of solar thermo-chemical reactor with high-temperature porous media were investigated using FLUENT user-defined functions (UDFs) software with different thermo-physical models. The findings suggest that local thermal non-equilibrium model (LTNE) and radiative transfer model have been shown to be invaluable for the thermal efficiency study of a thermo-chemical reaction system with high working temperatures. In comparison, Wu model of momentum source is best suited for simulating energy, while Wu model and Vafai model of heat transfer display no variation in temperature distribution.

(Falter and Pitz-Paal, 2018) explained in his paper that the solar thermo-chemical fuel processing pathway is being explored as an appealing alternative for transport sector decarbonisation. Usage of cerium as a reactive material and the new published literature data on inert gases demand and energy need for the vacuum pumping, Analyzes the energy output of the thermo-chemical reactor for vacuum pumping and gas mixture sweeping, and describes the process parameters needed to achieve high efficiency. It is found that thermo-chemical energy conversion efficiencies exceeding 20% can only be reached with a vacuum operated system with reduction temperatures of 1900 K, enhances pump efficiency by 50%, a concentration ratio of 5000 suns, and an energy restoration effectiveness from the gases and the solid phase of 70%. We then analyse the entire fuel processing process from incident sunlight to liquid hydrocarbons by conducting an energy study of a fuel production plant including the recovery of the waste heat. Theoretically, it is observed that now the energy losses could be used to meet the need for electricity and low temperature heat, as well as heating the reactants to the oxidation temperature, Improving the quality of the route from 5.3% to 8.6%. Therefore, the heat recovery from the single process steps in the fuel production route has tremendous potential to increase process efficiency and considerably improve environmental and strategic results. Similarly, waste heat can be use to partly relieve the possibly strict operating conditions of highly powerful thermo chemical reactors, which may have substantial reactor design consequences.

(Huang et al., 2018) introduces a heavily biased and robust iron-based La0.6Sr0.4Fe0.8Al0.2O3-δ oxygen carrier for syngas processing via a thermo chemical process powered by solar energy. It is observed that during redox cycling a complex structural transition occurs between the perovskite layer and a core – shell composite of Fe0@oxides. The layer of oxide, acting as a micro-membrane, avoids direct interaction between methane and fresh iron (0), and inhibits coke deposition. This core – shell intermediate is either regenerated in oxygen or more specifically in oxidant Pure water – Carbon dioxide with parallel production of another source of syngas to the initial perovskite structure. Doping with aluminium oxides decreases the ground oxygen content by reducing free electrons in the perovskite matrix, while preventing overoxidation of methan. As a result, this material exhibits high balance with carbon monoxide selectivity above 95% and yielding an ideal syngas of H2/CO ratio of 2/1.

(Zsembinszki *et al.*, 2018) analysed that to conduct a summary of the state-of-the-art reactors found in the literature that are used for solid gas reactions or thermal decomposition processes around 1000 C, which could be further applied for thermo-chemical energy storage in CSP (concentrated solar power) plants, specifically for SPT (solar power tower) technology. Direct and indirect mechanisms can be applied, and the most studied are direct and closed mechanisms. The most widely used configuration by direct and closed systems is the stacked bed reactor, with the most frequent alternative being the fixed bed reactor. Out of all of the reactors studied, nearly 70% are used for solid-gas chemical reactions. Some data are available regarding solar efficiency in most of the processes, and the available information indicates relatively low values. Chemical change efficiencies show better values , especially for a fluidized bed reactor for chemical reactions of solid gas, and fixed bed and rotary reactors for thermal degradation.

(Kodama *et al.*, 2017) said that by using solar thermal power for the production of high temperature fuel has the potential to significantly reduce the dependence on fossil fuel in our current economy. Over the last two decades, remarkable progress has been made in the development of solar-driven thermo-chemical reactors for hydrogen and syngas production, as they are promising transport energy carriers, domestic and industrial applications.

Compared to conventional thermo-chemical processes, however, there are solar glory-high thermal flux density and common thermal transients due to varying solar output-and traditional industrial thermo-chemical reactors were also normally not dependent on solar powered reactors. To realise efficient solar-driven thermo-chemical processes, solar-specific modifications of the reactor design are therefore necessary. In solar thermo-chemical reactors, the techniques for warming solar particulate solid feedstock at elevated temperatures can also be generally divided as solar reactors that absorb "directly" and "indirectly". Different types of solar directly and indirectly able to absorb particulate reactors have been developed on solar thermo-chemical processes involving reaction of solid particles at high temperatures such as "solar two-step water splitting with metal oxides" and "solar gasification."In this review, recent development of solar particle reactors for the above solar thermochemical processes is described.

(Guene Lougou et al., 2017a) in his paper investigated thermal overall performance evaluation of solar thermo-chemical reactor for syngas production. P1 radiation model was once used to observe the reactor thermal performance. It used to be determined that the temperature distribution resulted in the incident radiation depth distribution during the reactor internal cavity. However, the greater temperature used to be attributed to a awesome absorption of incident radiation heat flux intensity. A enormous drop in temperature was once determined round the aperture location and sharply reduced with an amplify in the incident radiation depth from reactor inlet. The reactor at the beginning heating area used to be expanded with an extend in the reactor running temperature from a thousand K to 1600 K. It used to be found that greater the warmness flux was once utilized to the reactor, extra the reactor used to be heating up. The on the spot temperature distribution internal the reactor confirmed the rise in the temperature used to be brought on through the impact of radiation heat transfer. The service fuel go with the flow inlet velocity and the drop in the running stress have significantly affected the reactors thermal performance. High and extra uniform temperature distribution inner the reactor was once received via higher controlling of the reactor running conditions.

(Rao and Dey, 2017) discussed that Solar photochemical potential of splitting water (artificial photosynthesis) to generate hydrogen is rising as a workable process. The photo voltaic thermo-chemical route additionally guarantees to be an attractive capability of accomplishing this objective. These encompass the low-temperature multistep system as nicely as the high-temperature two-step process. It is noteworthy that multistep manner primarily based on the Mn(II)/Mn(III) oxide machine can be carried out at 700 °C or 750 °C. The two-step technique has been finished at 1,300°C/900°C by way of the usage of yttrium-based uncommon earth manganites. It appears viable to render this high temperature method as an isothermal process. Thermodynamics and kinetics of water splitting are mostly managed by using the inherent redox property of the materials. Interestingly, below the conditions of H2O splitting in the high-temperature procedure CO2 can additionally be decomposed to CO, supplying a viable technique for producing the industrially necessary syngas (CO+H2). Although carbonate formation could be addressed as a hurdle at some stage in CO2 splitting, the trouble can be prevented by means of a appropriate preference of experimental conditions. The preference of the photo voltaic reactor holds the key for the commercialization of thermo-chemical gas production.

(Falter and Pitz-Paal, 2017) explained that for non-stoichiometric redox reactions that produce CO and H2 from CO2 and water, heat recuperation from the solid phase is a promising mechanism to improve the cycle efficiency. In solar thermo-chemical reactor principles several various approaches to heat recovery and the gas separation have recently been proposed. To describe many possible degrees of freedom in the reactor design, a generic reactor model is described for two-step redox reactions of solid pieces of reactant moving in counter flow between reduction and oxidation chamber. The reactive substance is expected to be porous ceria, where heat recovery from the solid phase is accomplished by transferring heat from radiation between reduced and oxidised materials going in opposite directions. A separate wall avoids the passage of gas and provides structural protection. The temperature distribution by diffusion at the porous material is based on approximation of the Rosseland diffusion and the three resistor process by conduction. The model can be tailored to a broad variety of principles about the reactor. A analysis of critical design parameters reveals that the heat diffusion in reactive material may have a big effect on heat exchanger efficiency. If the time needed for heat diffusion is substantial in comparison to the overall residence time in the heat exchanger, Material thickness can also be reduced to maximise the proportion of the substance directly engaged in the heat transfer mechanism. In addition, radiation influences the heat exchange within the porous system at the respective temperatures, thereby maximising the total heat exchange by increasing porosity. Duration and residence time of heat exchanger are associated, allowing varying variations of these two variables at constant efficiency of heat exchanger. In general, with an appropriate combination of parameters, efficiencies up to 70 percent are feasible. However, reaching the optimum efficiency of heat exchanger requires a minimum number of the chambers and therefore physical length, for a greater number of the intermediate temperature ranges, as irreversibility's are decreased. The generic model presented provides the definition of the temperature dependence within the foaming agent is a helpful tool for modelling heat exchangers and could be used to define theoretically interesting reactor ideas for achieving high energy conversion efficiencies.

(Villafán-Vidales et al., 2017) said in his paper that Hydrogen is an exciting means of transport, household, and industrial energy carrier. Nowadays the chemical industry basically consumes hydrogen, but its demand is expected to grow significantly in the long term due to emerging market. Hence hydrogen production with sustainable method is a relevant issue. This research provides a description of the different thermo-chemical processes aided by CSP for the production of hydrogen and syngas. Some relevant prototypes of solar proven reactor are characterised for each process. Also developed solar furnaces for thermo-chemical process investigation are discussed in a second part. Moreover, relevant research on the production of hydrogen or syngas in solar turrets installations is presented. Finally the current challenges of the technology and the process for its future commercialization are also analysed.

(Xing et al., 2017) also told that Hydrogen energy can help us in solving the problem of greenhouse gases emissions which results in reduced global warming and stress on the fossil fuel supply and price, provided that hydrogen is produced by clean processes involving renewable energy. Appealing technique is the production of solar hydrogen via a two-step thermo-chemical cycle. This article attempts to present an aspect review to redox pairs in the production of solar thermochemical hydrogen, reactor design technology, general evaluation etc. Some novel reactors have been designed for different redox pair in recent decade years. We give a comparison between different hydrogen technologies and summarize the problems that exist in the cycle. Although solar thermo-chemical hydrogen production methodology is a successful and capability reacted for solving the problem of energy crisis, it still has many problem to solve in the future.

III. METHODOLOGY AND ANALYSIS

3.1 Steps of working

1. Design and modeling of porous media solar thermo-chemical reactor in NX 11 according to the selected base paper.
2. Further converting the NX 11 File in .STEP format for importing it in ANSYS Fluent work bench.
3. Assigning the name selection to the different parts of thermo chemical reactor model.
4. Meshing of thermo chemical reactor model for performing the simulation process.
5. Providing the suitable boundary condition according to the selected base paper.
6. Assigning the material properties to the model.
7. Setting the proper setup for CFD analysis procedure.
8. Evaluating the results after the finish of simulation work.

3.2 Case design

To increase the length of porous media in a chemical reactor, seven cases are taken which are shown in table below. In first three cases, the porosity will increase gradually while the velocity and length of porous media will remain constant. The best result from three cases will be taken for case 4 and 5, in this velocity will be changed. After that the best resulted porosity and best result of velocity will be taken for the next two cases; case 6 and 7. The results of last two cases will show the changes in length of porous media.

IV. CONCLUSION AND FUTURE SCOPE

4.1 Conclusion

Thermodynamics shows us, in quite simplistic words, that at higher temperature we transmit solar energy to our process, more innovative we could be about what gets out like an end product. The same experiment was performed in the above case. To increase the length of porous media in a chemical reactor, seven cases were taken. The conclusions obtained from these cases are discussed below:

- From the table 4.1, case 1 to 3 is considered first. While increasing the porosity, the temperature decreases and Case 3 will be ideal for the chemical reactor as its temperature is lowest when the length is increased. The porosity of 0.9 shows the best results and other parameters remained constant.

From the table 4.2, case 4 and 5 are considered then. While varying the velocity in two cases, it can be concluded that less velocity gives better results.

From the table 4.4, case 6 and 7 are considered last. Here the length of the material varied and as a result it was observed that when length of the material is increased, the temperature decreased. The temperature decrease is different in both the cases. The maximum temperature decrease is observed in Case 7.

The overall comparison of heat transfer, temperature and average temperature are also calculated. Case 7 shows the highest Heat Transfer Rate i.e. 4901.343W, Case 3 shows the least value of temperature when the length increased i.e. 900K; Case 1 and Case 4 are showing the maximum average temperature i.e. 1327.64K.

4.2 Future scope

In the above experiment Silicon Carbide (SiC) is used for enhancing the working of the reactor. In future, other materials like zinc oxide can be used.

This experiment is performed on software NX11 and ANSYS; experimental analysis can be further performed.

Parameters like heat transfer rate, pressure, velocity and temperature are observed in it. Efficiency, heat flux and many other parameters can be considered in further studies.

REFERENCES

[1.] Abdiwe, R. A. and Haider, M. (2016) ‘A mathematical model for ammonia solar and synthesis reactors’, *Renewables: Wind, Water, and Solar*. Springer Singapore, 3(1), p. 12. doi: 10.1186/s40807-016-0034-4.

[2.] Agrafiotis, C. *et al.* (2014) ‘Solar thermal reforming of methane feedstocks for hydrogen and syngas production - A review’, *Renewable and Sustainable Energy Reviews*, 29, pp. 656–682. doi: 10.1016/j.rser.2013.08.050.

[3.] Bellan, S. *et al.* (2014) ‘Numerical modeling of solar thermochemical reactor for kinetic analysis’, *Energy Procedia*. Elsevier B.V., 49, pp. 735–742. doi: 10.1016/j.egypro.2014.03.079.

[4.] Bin, L. (2002) ‘Doctor of Philosophy 扫描隧道显微镜成像机制中 若干问题的理论研究’, (December).

[5.] Eldin, A. H., Refaey, M. and Farghly, A. (2015) ‘A Review on Photovoltaic Solar Energy Technology and its Efficiency’, *A Review on Photovaltaic Solar Energy Technology and its Efficiency*, (December), pp. 1–9.

[6.] Ermanoski, I. and Siegel, N. (2013) ‘Annual average efficiency of a solar-thermochemical reactor’, *Energy Procedia*, 49, pp. 1932–1939. doi: 10.1016/j.egypro.2014.03.205.

[7.] Ermanoski, I., Siegel, N. P. and Stechel, E. B. (2013) ‘A new reactor concept for efficient solar-thermochemical fuel production’, *Journal of Solar Energy Engineering, Transactions of the ASME*, 135(3), pp. 1–10. doi: 10.1115/1.4023356.

[8.] Falter, C. P. and Pitz-Paal, R. (2017) ‘A generic solar-thermochemical reactor model with internal heat diffusion for counter-flow solid heat exchange’, *Solar Energy*. The Author(s), 144, pp. 569–579. doi: 10.1016/j.solener.2017.01.063.

[9.] Falter, C. and Pitz-Paal, R. (2018) ‘Energy analysis of solar thermochemical fuel production pathway with a focus on waste heat recuperation and vacuum generation’, *Solar Energy*. Elsevier, 176(September), pp. 230–240. doi: 10.1016/j.solener.2018.10.042.

[10.] Guene Lougou, B. *et al.* (2017a) ‘Analysis of radiation heat transfer and temperature distributions of solar thermochemical reactor for syngas production’, *Frontiers in Energy*, 11(4), pp. 480–492. doi: 10.1007/s11708-017-0506-2.

[11.] Guene Lougou, B. et al. (2017b) ‘Analysis of radiation heat transfer and temperature distributions of solar thermochemical reactor for syngas production’, Frontiers in Energy, 11(4), pp. 480–492. doi: 10.1007/s11708-017-0506-2.

[12.] Huang, C. et al. (2018) ‘In situ encapsulation of iron(0) for solar thermochemical syngas production over iron-based perovskite material’, Communications Chemistry, 1(1), p. 55. doi: 10.1038/s42004-018-0050-y.

[13.] Jarimi, H. et al. (2019) ‘Review on the recent progress of thermochemical materials and processes for solar thermal energy storage and industrial waste heat recovery’, International Journal of Low-Carbon Technologies, 14(1), pp. 44–69. doi: 10.1093/ijlct/cty052.

[14.] Kodama, T. et al. (2017) ‘Particle reactors for solar thermochemical processes’, Solar Energy. Elsevier Ltd, 156, pp. 113–132. doi: 10.1016/j.solener.2017.05.084.

[15.] Kumar, L., Hasanuzzaman, M. and Rahim, N. A. (2019) ‘Global advancement of solar thermal energy technologies for industrial process heat and its future prospects : A review’, Energy Conversion and Management. Elsevier, 195(February), pp. 885–908. doi: 10.1016/j.enconman.2019.05.081.

[16.] Lipiński, W. et al. (2013) ‘Review of heat transfer research for solar thermochemical applications’, Journal of Thermal Science and Engineering Applications, 5(2), pp. 1–14. doi: 10.1115/1.4024088.

[17.] Maatallah, T. et al. (2018) ‘A novel solar concentrating system based on a fixed cylindrical reflector and tracking receiver’, Renewable Energy. Elsevier Ltd, 117(February 2018), pp. 85–107. doi: 10.1016/j.renene.2017.10.040.

[18.] Mohammad Bagher, A. (2016) ‘Types of Solar Cells and Application’, American Journal of Optics and Photonics, 3(5), p. 94. doi: 10.11648/j.ajop.20150305.17.

[19.] Rao, C. N. R. and Dey, S. (2017) ‘Solar thermochemical splitting of water to generate hydrogen’, Proceedings of the National Academy of Sciences, 2017, p. 201700104. doi: 10.1073/pnas.1700104114.

[20.] Reich, L. et al. (2014) ‘Towards solar thermochemical carbon dioxide capture via calcium oxide looping: A review’, Aerosol and Air Quality

Research, 14(2), pp. 500–514. doi: 10.4209/aaqr.2013.05.0169. 21. Steinfeld, A. (2014) 'Solar thermochemical production of hydrogen', Handbook of Hydrogen Energy, (June), pp. 421–444. doi: 10.1201/b17226.

[21.] Steinfeld, A. and Palumbo, R. (2003) 'Solar Thermochemical Process Technology', Encyclopedia of Physical Science and Technology, 15, pp. 237–256. doi: 10.1016/b0-12-227410-5/00698-0.

[22.] Thapper, A. et al. (2013) 'Artificial Photosynthesis for Solar Fuels – an Evolving Research Field within AMPEA, a Joint Programme of the European Energy Research Alliance', Green, 3(1), pp. 43–57. doi: 10.1515/green-2013-0007.

[23.] Villafán-Vidales, H. I. et al. (2011) 'Heat transfer simulation in a thermochemical solar reactor based on a volumetric porous receiver', Applied Thermal Engineering. Elsevier Ltd, 31(16), pp. 3377–3386. doi: 10.1016/j.applthermaleng.2011.06.022.

[24.] Villafán-Vidales, H. I. et al. (2017) 'An overview of the solar thermochemical processes for hydrogen and syngas production: Reactors, and facilities', Renewable and Sustainable Energy Reviews. Elsevier, 75(November), pp. 894–908. doi: 10.1016/j.rser.2016.11.070.

[25.] Wang, F. et al. (2014) 'Thermal and chemical reaction performance analyses of steam methane reforming in porous media solar thermochemical reactor', International Journal of Hydrogen Energy. Elsevier Ltd, 39(2), pp. 718–730. doi: 10.1016/j.ijhydene.2013.10.132.

[26.] Xing, H. et al. (2017) 'Solar thermochemical hydrogen production using metallic oxides', Energy Sources, Part A: Recovery, Utilization and Environmental Effects. Taylor & Francis, 39(3), pp. 257–263. doi: 10.1080/15567036.2013.878769.

[27.] Yadav, D. and Banerjee, R. (2016) 'A review of solar thermochemical processes', Renewable and Sustainable Energy Reviews. Elsevier, 54, pp. 497–532. doi: 10.1016/j.rser.2015.10.026.

[28.] Zhang, H. et al. (2018) 'Analysis of thermal transport and fluid flow in high-temperature porous media solar thermochemical reactor', Solar Energy. Elsevier, 173(July), pp. 814–824. doi: 10.1016/j.solener.2018.08.015.

[29.] Zsembinszki, G. et al. (2018) 'Review of reactors with potential use in thermochemical energy storage in concentrated solar power plants', Energies, 11(9). doi: 10.3390/en11092358.

