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HEAT TRANSFER IN SOLAR THERMOCHEMICAL REACTOR USING TAGUCHI'S METHOD

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Abstract

Solar-driven thermochemical reaction systems utilising concentrated solar radiation for the synthesis of syngas and hydrogen (primarily CO and H_2) are now widely regarded as a viable alternative to conventional fossil fuels in solving energy and climate change issues. Thermal analysis of a thermochemical reactor system is the subject of this study. During the study, several situations of porosity, fluid medium entry velocity, and solar irradiation intensity are taken into account. In order to discover the optimal configuration for porosity, intake velocity, and solar irradiance for the full reactor system, the Taguchi L27 orthogonal approach was used.

Keywords: Solar energy, hydrogen, Thermochemical reactor, Porous media, Taguchi technique, CFD.

1. Introduction

As nations aim to reduce their dependence on oil, engineers and scientists are searching for new ways to meet their ever-increasing energy demands. It is possible to satisfy these demands using a renewable energy source such as concentrated solar thermochemical technology (CST). Liquid fuels produced by concentrating solar power and thermochemistry may be easily incorporated into the existing energy grid. A solar thermochemical reactor has a capacity to do exactly that; however, such reactors are still in their developmental stage. Because of the cost and time needed to fabricate such reactors, it is of great benefit

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to evaluate and modify reactor designs computationally before a final design is chosen. First though, solar energy engineering is considered from the very beginning of its development.

1.1. Thermochemical Reactor

A wide variety of reactors have been developed over the years, using different concepts and cycles. The common denominator between all these reactors is that they were designed to be solar reactors that produce some kind of fuel by means of thermochemical cycling. It is typical for a research group to design a reactor and develop more reactor prototypes improving upon that design. Most of the reactor models presented here, however, is unrelated and developed by separate research groups. In other words they are not being presented as a design progression. In general, each reactor and its corresponding results, computational modeling, and design development is complex and to go into such detail would go beyond the focus of this section. The purpose here is to lay a basic foundation for the reactors that have been developed.

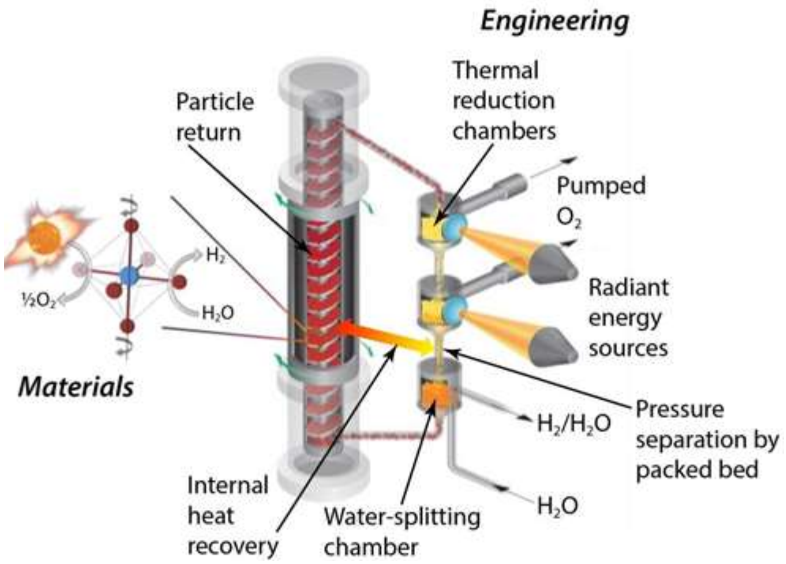


Figure 1: Thermochemical Reactor

Types of Thermochemical reactor

- High Temperature Particle Reactor
- Zinc Oxide Tubular and Windowed Reactors with Carbon reduction
- Honey comb Solar Reactor
- Rotary-type solar reactor
- Two-cavity solar reactor
- Zinc Oxide Particle Reactor
- Gravity-Fed solar-thermochemical reactor
- Counter-Rotating-Ring Receiver/ Reactor/ Recuperate (CR5)

1.2. Objectives of the Study

The following objectives are proposed in the present work,

1. The simulation is carried out on the LTNE model of the solar thermochemical reactor.
2. Factor of solar irradiance is considered during analysis.
3. Three different cases of porosity, intensity of solar irradiance and fluid inlet velocity is considered in the analysis.
4. In order to identify the most optimum configuration values of porosity, solar irradiance and fluid inlet velocity; Taguchi L27 optimization technique is used via MINITABS software.
5. Validation of CFD results with existing constraints as per the base paper.

2. Literature Review

Yan et al., 2019 [1] Hydrogen, gas hydrocarbons, as well as liquid biofuels may all be produced using the "solar thermal electrochemical process (STEP)". Methane, n-pentane, and other light hydrocarbons in the gaseous stage were highly congested as a result of the thermal electrolysis process. The chemistry of the STEP is explained in this publication, which shows how the biomass is transformed into biofuels and hydrogen. The presentations of the thermo/electro iatrogenic radical reactions are presented in a simplified form with the help of series manner. To rework the solar biomass towards biofuels as well as hydrogen, the systems are designed from the power of solar also with the chemical reactions as an option of ideal, in the form of green, along with property, as well as reclaimable operation.

Moser, Pecchi and Fend, 2019[2] Analysis and additionally the techno-economic are evaluating the designated path of solar hydrogen production supported thermochemical cycles. The study of solar energy is focused on the concentrated solar power (CSP) solar power is employed so that the two-step thermochemical cycle can run or work easily and supported 2 completely different red-ox materials, particularly "nickel-ferrite and metal oxide (ceria)". The first step was initiated to activate as well as style the system with the enforcement of the versatile mathematical model. There is a temporal delay between the activation of one reactor in parallel and another reactor in a "nickel-ferrite-associated ceria cycle", according to a technical comparison of these cycles.

Jarimi et al., 2019[3] THS systems provide a number of advantages over conventional heat storage systems because of their high energy density and minimal heat loss when they are hermetically sealed. THS is the subject of a number of review publications. THS technology, materials, reactor design and THS thermal batteries are all covered in this paper. There we tend to combine the various reactor styles, coupled with hybrid THS systems, towards the development of improved reactor construction, numerical studies of heat and mass transfer in the style of reactor, and the implementation of thermal batteries. THS technological advancements need further study and development before they can become commercially viable, according to our extensive assessment. Information regarding the numerous studies and gaps in research will be provided by this literature.

Guene Lougou et al., 2018[4] Solar thermochemical reactor was used as an experimental check on the basis of the laboratory-scale. The impact is seen at the time of transfer of heat also with the flow of fluids and the results are bought on the structural parameters that are in the expression of intensity in delicate irradiance, the flow of mass rate, stability rate of heat transfer, emissivity of quartz and inner wall surface, the porosity as well as extinction stability that is investigated on the basis of planned solar cavity receiver. Temperatures dropped significantly as a result of thermal losses via radiation, convection and semi-conductive heat transfer. The comparison between experimental and numerical findings is undertaken for model validation.

Huang et al., 2018 [5] Industrial gas-to-liquid conversion technology relies heavily on the conversion of methane to syngas, a process that requires a significant amount of energy. Here we tend to present an extremely selective and long-lasting iron-based La0.6Sr0.4Fe0.8Al0.2O3-δ. Using a solar-driven thermochemical process, oxygen carriers are employed to produce syngas. During redox cycling, a dynamic structural transition occurs between the perovskite section and a FeO oxides core–shell composite. As a micro-membrane, the compound shell inhibits coke deposition by preventing methane from directly coming into touch with new iron (0). Avoiding direct contact with methane and fresh iron, the micro-membranes of oxides form a micro-membrane.

Falter and Pitz-Paal, 2018 [6] It is investigated that, the fuel production by a solar thermochemical process is a good choice for de-carbonization of the transport sector. victimization ceria because of the material that is reactive in nature and hence, the latest data reveals that the demand of inert gas as well as the demand of energy for "vacuum pumping from the fiction", there is a balance in the energy of thermo-setup is analyzed for "vacuum pumping and inert gas sweeping", and therefore the required method parameters for reaching high efficiencies are mentioned. As the temperature drops below 1900 K, the thermochemical energy conversion efficiency increases by 20%, the pump efficiency is increased by 50%, the volume-quantity relation increases by 5000 solar units, and the energy recovery efficiency from the gases and therefore the solid component increases by 70%.

3. METHODOLOGY

3.1. Steps of working

1. A solar thermochemical reactor with porous media was designed and modelled in CATIA V5 using the specified base paper.
2. Import the CATIA V5 file into the ANSYS Fluent workbench by converting it to .STEP format.
3. Allocating names to the thermo - chemical reactors model's many components.
4. Thermochemical reactor model meshing for simulation purposes.
5. Assisting in the selection of appropriate boundary conditions for the chosen base paper.
6. Assigning the model's material characteristics.
7. Configuring your computer so that CFD analysis may be performed properly.

8. After completing the simulation, it's time to evaluate the findings.
9. Using the Taguchi L27 approach, the most optimal results may be achieved.

3.2. Design of Experiment

Experimental design tactics have been intensively explored by statisticians since the early twentieth century, but they were difficult for practitioners to implement. By making it easy for users with little statistical data, Taguchi's technique of experimentation has been widely accepted in the engineering and scientific communities. Taguchi is fond of the following three items:

- "Larger the better (for example, agricultural yield)";
- "Smaller the better (for example, carbon dioxide emissions)"; and
- "On-target, minimum-variation (for example, a mating part in an assembly)".

Table 3.1 Level selection

Level	**1**	**2**	**3**
Porosity	0.6	0.7	0.9
Radiation	1400	1500	1700
Velocity	0.003	0.004	0.006

4. RESULT AND DISCUSSION

4.1. Results

After geometry definition and mesh generation model analyzed by the FLUENT software based on the above assumptions.

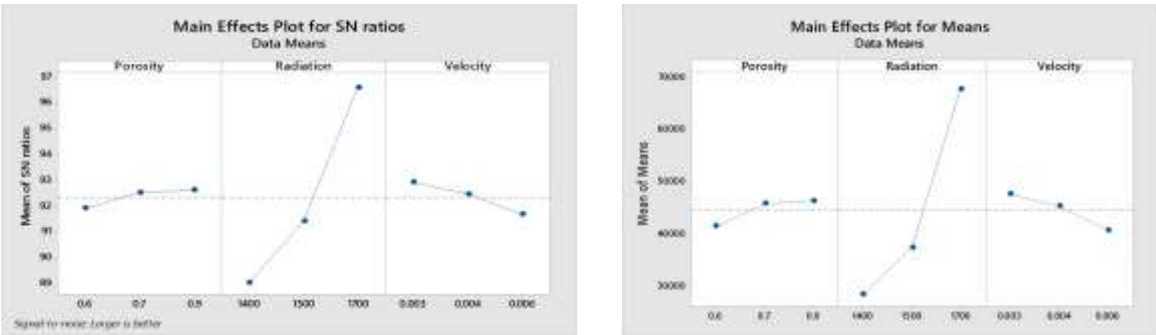


Figure 2: (a) Plots for SN Ratio; (b) Main affect Plot for Mean Ratio

Table 4.1 S/N Ratio and mean calculation

Porosity	Radiation	Velocity	Total Heat Transfer	S/N Ratio
0.6	1400	0.003	28916.33	89.22286
0.6	1400	0.004	31057.98	89.84346
0.6	1400	0.005	27493.87	88.78472
0.6	1500	0.003	36373.45	91.21569
0.6	1500	0.004	35167.88	90.92292
0.6	1500	0.006	35396.1	90.97911
0.6	1700	0.003	70885.86	97.01119
0.6	1700	0.004	67227.43	96.55093
0.6	1700	0.006	60006.48	95.56396
0.7	1400	0.003	31003.54	89.82823
0.7	1400	0.004	29582.7	89.42076
0.7	1400	0.006	26915.8	88.60015
0.7	1500	0.003	41578.54	92.37738
0.7	1500	0.004	39531	91.93876
0.7	1500	0.006	35316.64	90.95959
0.7	1700	0.003	70890.29	97.01174
0.7	1700	0.004	67209.11	96.54856
0.7	1700	0.006	60373.05	95.61686
0.9	1400	0.003	31003.54	89.82823
0.9	1400	0.004	29582.7	89.42076
0.9	1400	0.006	26915.8	88.60015
0.9	1500	0.003	41578.54	92.37738
0.9	1500	0.004	39531	91.93876
0.9	1500	0.006	35316.64	90.95959
0.9	1700	0.003	70890.29	97.01174
0.9	1700	0.004	67209.11	96.54856
0.9	1700	0.006	60373.05	95.61686

Table 4.2 Response Table for Signal to Noise Ratios

Level	Porosity	Radiation	Velocity
1	91.90	89.04	92.91
2	92.52	91.41	92.45
3	92.61	96.59	91.67
Delta	0.71	7.55	1.25
Rank	3	1	2

Table 4.3 Response Table for Means

Level	Porosity	Radiation	Velocity
1	41364	28341	47515
2	45713	37291	45226
3	46280	67725	40616
Delta	4917	39383	6899
Rank	3	1	2

4.2. ANOVA

It is possible to use an applied math approach called ANOVA to see whether two or more groups' methods are significantly different from each other. Using a variety of samples, an analysis of variance examines the influence of one or more variables.

Table 4.4 ANOVA Contribution table of parameters

Source	DF	Seq. SS	Contribution	Adj. SS	Adj. MS	F-Value	P-Value
Porosity	2	0.488	0.19%	0.488	0.244	2.42	0.155
Radiation	2	242.303	96.29%	242.303	121.151	1200.50	0.000
Velocity	2	6.820	2.71%	6.820	3.410	33.79	0.000
Error	20	2.018	0.80%	2.018	0.101		
Total	26	251.629	100%				

4.3. Result Validation

"When porosity is 0.9 radiation is 1700 K and velocity is 0.003 m/s"

Table 4.5 Predicted Values

Porosity	Radiation	Velocity
0.9	1700	0.003

And the predicted values of SN curve and mean ratio are,

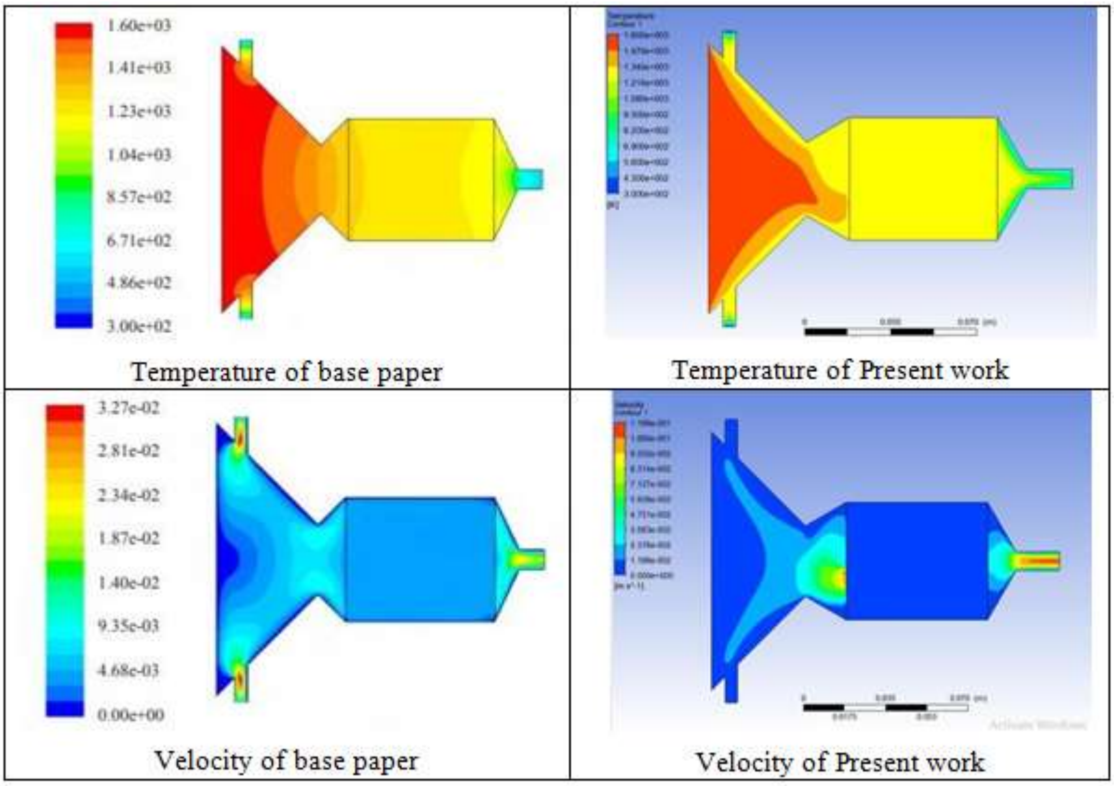
Table 4.6 Predicted value of S/N Ratio

SN Ratio
97.17546

4.4. Comparison result of base paper

Table 4.7 Comparison result base paper and present work

Base Paper	Present Work
The base paper is focus to determine the temperature, velocity and pressure distribution by using CFD analysis.	In present work the study is focus to optimize the temperature, velocity, pressure and heat transfer rate using TAGUCHI'S method to after that determine the temperature, velocity and pressure distribution by using CFD analysis.
In base paper single model is simulate in 0.8 porosity limit.	In present work porosity is vary at the value 0.6, 0.7 and 0.9 porosity limit is used and compare the performance of solar thermochemical reactor.
In base paper the value of velocity is used to flowing fluid is 0.005 m/s, and inlet air temperature is used 600K and solar radiation temperature is 1600K.	In present work three different velocity is consider which are 0.003, 0.004 and 0.006 m/s, and three different solar radiation temperature 1400, 1500, 1700 K.



All the base paper condition is considered in present thesis work, the work is including to determine better heat exchange between inlet to outlet by determining Maximum heat transfer rate. After performing analysis, it is seen that every condition which is used in analysis (Inlet Velocity, Inlet temperature porosity and solar radiation temperature) are play major role which affect the heat transfer rate. The most optimize value is determine by using Taguchi and ANOVA method which is not used base paper.

5. CONCLUSION

There are a various type of reactors available. And many researches are on-going on the development of reactors efficiency, improved solar irradiance, heat transfer rate etc. These all parameters can be improved by changing design, material, velocity etc. In this research study, 3D model of solar thermochemical reactor is designed in CATIA and the simulations are performed with varying various parameters in Ansys. Following are the conclusion from the above study is obtained:

- When the porosity is 0.9, the greatest results are shown for overall heat transfer rate.
- The resulting sun irradiance is 1700 K.
- Moreover, the inlet velocity is 0.003 m/s.
- A total heat transfer rate is computed when the Taguchi technique is used to verify new input parameters in ANSYS for CFD analysis.
- Porosity of 0.9, sun intensity of 1700 K, and intake velocity of 0.003 m/s were used to calculate the maximum heat transfer rate of 72239.19 W.

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