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Solar Thermochemical Hydrogen Production Plant

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Abstract:- Our main objective of the project was to study all the existing methods of hydrogen production and find most feasible and renewable methods among all. We studied them, compared and analyzed each of the methods that are widely known or used for the production of hydrogen gas and came to a conclusion that steam methane reforming method of hydrogen production is the most widely ysed and most efficient method among the rest. We have introduced the usage of solar energy in the steam methane reforming reaction in the place of utility. However, steam reforming method of methane process is considered as state-of-the-art technology for efficient production of hydrogen regarding the current scientific R&D [2], introducing solar into it might increase some amount of expense but will be a better move while switching to renewable sources on Earth. SRM [3] method of hydrogen production is a highly endothermic process. This requires high potential heat source for the purpose of preheating feedstock, producing steam of high potential and controlling the process. However, the use of concentrated solar energy in this has the potential of avoiding 35-40% of the CO2 - carbon dioxide emissions derived from the conventional SRM process based on fossil fuel. Hence we have made a sustainable project wherein we aim to use renewable energy to generate hydrogen which in itself is considered fuel of the future . Hydrogen produced using solar thermal energy is cost effective , many countries are considering solar energy to produce clean fuel for the future .

***Keywords**:- Hydrogen Production, Water Gas Reaction, Steam Reforming Method, Concentrated Solar Receivers, Production of Hydrogen from solar energy, Hydrogen - a clean fuel , Energy Carrier.*

I. INTRODUCTION

With increasing fuel, diesel and petrol prices and the prices of natural gas, oil and other fossil fuels; hydrogen has come up as a usable and most efficient fuel gas usable in the world. Many countries have already began on making the most of it. Our main objective of the project was to study all the existing methods of hydrogen production and find most feasible and renewable methods among all. We studied them, compared and analyzed each of the methods that are widely known or used for the production of hydrogen gas and came to a conclusion that steam methane reforming method of hydrogen production is the most widely used and most efficient method among the rest. We have introduced the usage of solar energy in the steam methane reforming reaction in the place of utility. To develop a clean fuel to meet the increasing demands of energy over the world has been a latest challenge among us. Hence, many researchers have been thinking of finding alternatives to avoid raising effects of global warming, greenhouse gases and increasing environmental pollution hazards, etc. We have introduced the usage of solar energy in the steam methane reforming reaction in the place of utility. However, steam reforming method of methane process is considered as state-of-the-art technology for efficient production of hydrogen. Various technologies and equipments are used for capturing solar energy and making it a part of the process. Talking about other methods that can be used renewable are wind, tidal, etc. But with increasing usage of solar, we concluded of choosing solar over the other methods would be feasible. The process includes 2 types of reactions, namely, steam methane reforming method and water gas shift reaction. We have simulated a flowsheet on process simulation software, Aspen HYSYS and studied the effects obtained on the parameters. We maintained the temperature 800 degree celsius and pressure upto 30bar.

II. SOLAR THERMOCHEMICAL HYDROGEN PRODUCTION

STCH or Solar Thermochemical Hydrogen Production is a two step process done thermochemically which utilizes metal oxides to convert solar energy into hydrogen gas in which the oxide firstly undergoes reduction reaction via exposure to the generated heat from concentrated solar power. There is a thermochemical water splitting method as well which use high temperature captured from the concentrated solar energy and chemical reactions to produce hydrogen and oxygen from water (H20 gets splits into H_2 & O_2). A number of STCH have been researched, studied, analyzed, discovered and investigated for the production of H_2. Each of these methods are of different number of steps- a 2 step process, a 3 step process, a five step process. Each of them need different set of conditions, challenges, advantages and disadvantages. More than 300 water splitting cycles are found in literature survey. Two examples of thermochemical water splitting cycles, the "direct" two-step cerium oxide thermal cycle and the "hybrid" copper chloride cycle. The direct cycles of the STCH are observed to be less complex and have lesser number of steps. However, they require their operating temperatures to be high if compared to more complicated hybrid cycles. Solar thermal power is one of the significant part in providing a major share of clean renewable energy and solar radiation is the largest known energy that is renewable resource on the planet earth. Approximately 1% of the desert existing in the world if utilized by solar thermal power plants, that would be sufficient enough to generate the whole world's demand of electricity. The concept is mainly based on the principal of using concentrated solar energy by capturing it using different technologies and equipments and using it as a high source temperature process heat in the

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process which will be resulting in driving an endothermic chemical transformation.

The advantages of choosing STCH process are the thermochemical process :

- is run intermittently, in which case the high temperature solar energy is used directly in the process.
- can be devised to run in a cyclic manner, consisting of day and night operations. During day operation, the high temperature solar heat is used to produce some intermediate chemicals, which are stored. These stored chemicals are used during night operation.
- is run continuously. Solar energy during high temperature is used directly during hours that have ample amount of sunshine ; however the thermal energy can be stored during night hours or days with less sunshine.

III. SOLAR THERMAL POWER TECHNOLOGIES

Concentrated solar energy is captured by various technologies, all of which are based on four elements :

- Concentrator **-** captures and solar radiation is concentrated here
- Receiver **-** absorbs the concentrated sunlight and transfers the heat energy to workingg fluid
- Transport storage **-** passes the fluid to power conversion system
- Power Conversion **-** cpnversion to power

There are three solar thermal power systems currently being developed all over the world:

- Parabolic Troughs (Fig 1)
- Power Towers / Solar Central Receiver (Fig 2)
- Solar Distribution / Engine System (Fig 3)

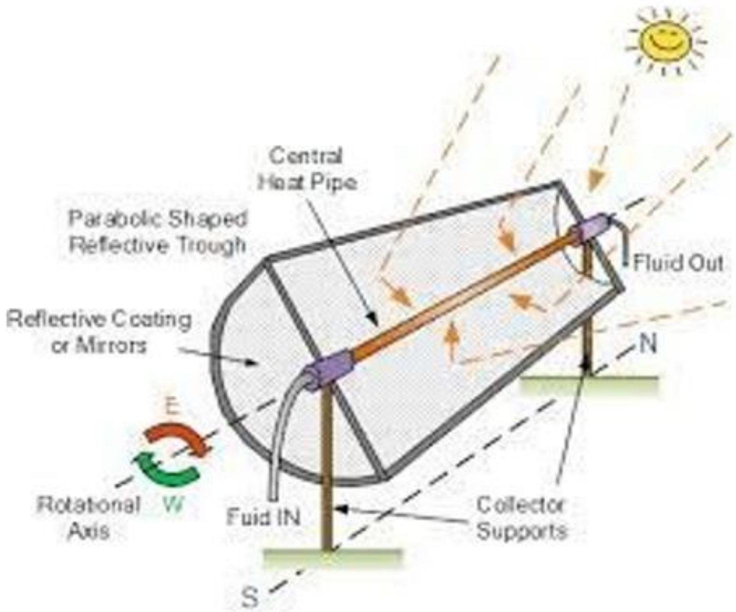


FIG A. PARABOLIC TROUGHS

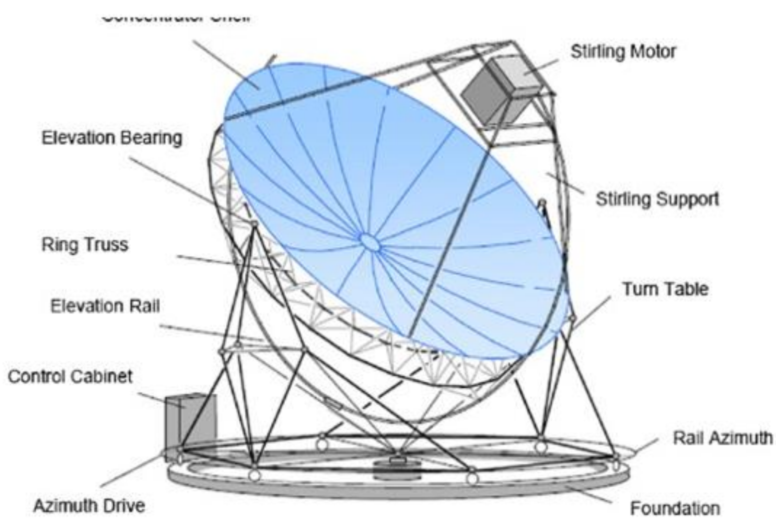


FIG B. SOLAR DISH/ENGINE SYSTEM

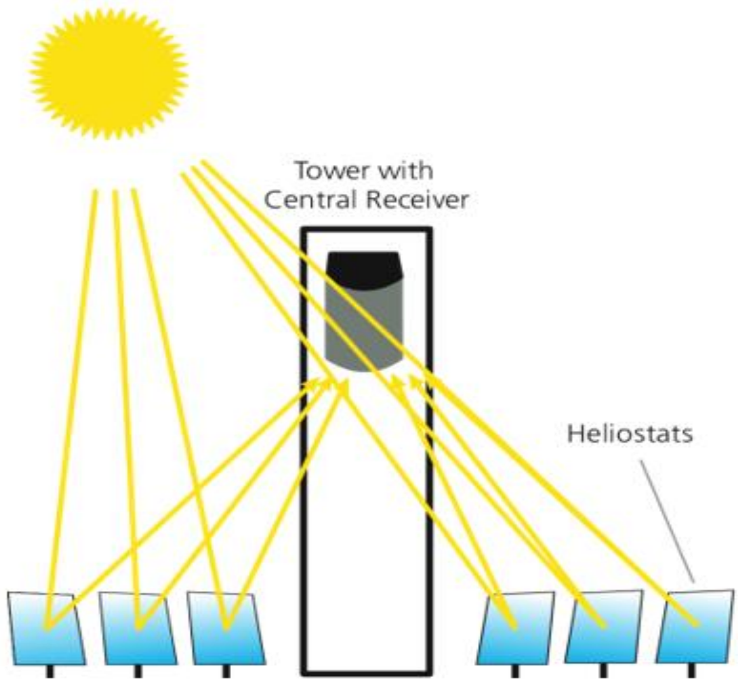


FIG C. SOLAR CENTRAL RECEIVER

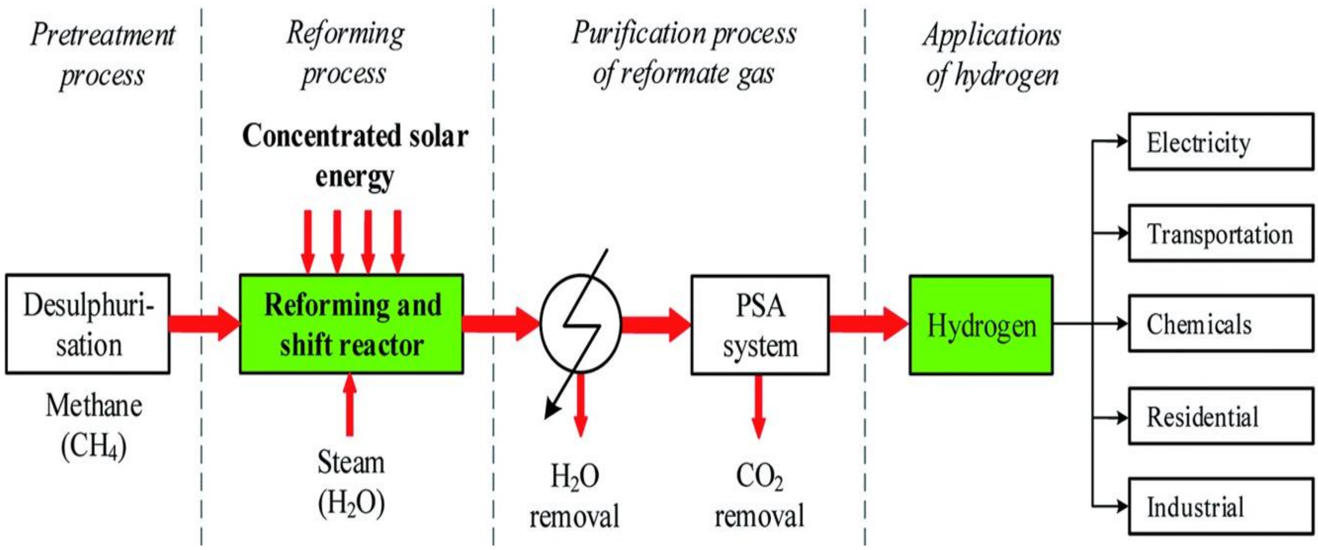
IV. PROCESS DESCRIPTION

Regarding the steam reforming process, methane (natural gas) reacts with steam to produce hydrogen-rich gas using appropriate catalysts at a temperature ranging from 200–1000 °C and operating pressure ranging from 1–30 bar. The steam reforming process is always associated with the water–gas shift (WGS) reaction, which generates a high amount of CO2. Steam methane reforming and WGS reactions are the global reactions for leading to a significant amount of hydrogen production. Considering steam methane reforming reaction, WGS reaction can reduce the concentration of CO in the amount of gaseous product. After the WGS reaction, the concentration of CO in the reformate gas is lower than 1.0%. Water–gas shift reaction is an exothermic type reaction. However, this might lead to excessive CO2 generation in hydrogen-rich gas produced. Steam methane reforming reaction can be typically described by the following equations.

Water–gas shift reaction (CO-shift reaction): $CO + H2O \leftrightarrow CO2 + H2; \quad \Delta H298 = -41$ kJ mol−1

Steam methane reforming reaction : $CH4 + H2O \leftrightarrow CO + 3H2; \quad \Delta H298 = 206$ kJ mol−1

Overall reaction : $CH4 + 2H2O \leftrightarrow CO2 + 4H2; \quad \Delta H298 = 165$ kJ



V. SIMULATION & ASPEN HYSYS SIMULATION SOFTWARE

Various chemical plants, processes can be constructed into a flowsheet by applying certain parameters as required to carry out the process on software. Such softwares which allow us to carry out such construction and anaylze the results and take necessary steps over it can be termed as simulating. Various kinds of software are available on the internet as follows : DWSIM, Aspen HYSYS, Pro/II Simulator, etc. Depending on the process, components involved, property packages and desired set of units has to chosed. Basically, molar flow, mass rate, temperature, pressure are the basic parameters needed to be input in the flowsheet. However, energy stream play an significant role in them too. Optimization is one of the most significant thing which can be done on process simulation softwares before carrying out the process in real life. One can build the process on the software applying all the parameters and study and analyze it and make necessary changes by optimizing it.

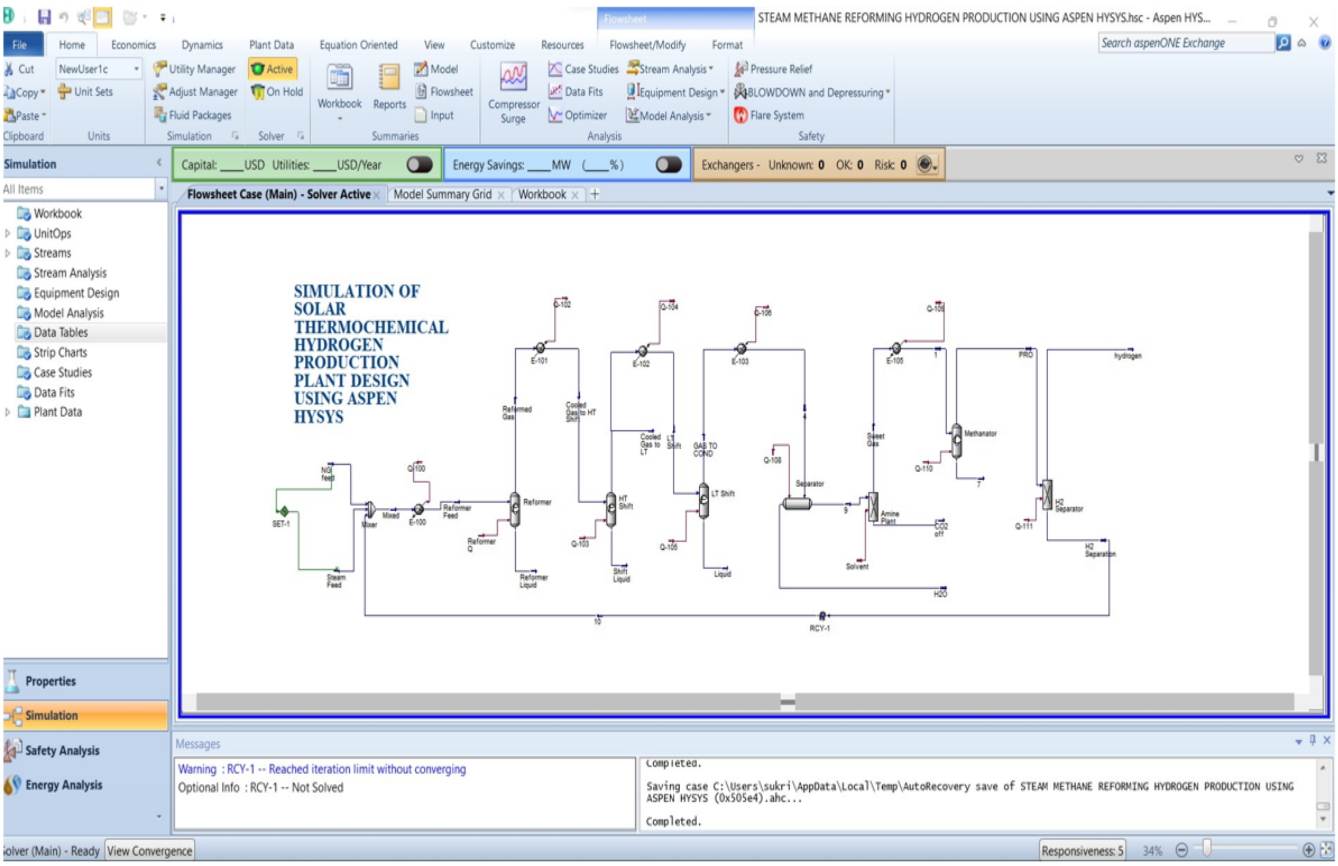
Aspen HYSYS (or simply HYSYS) is a chemical process simulator which is developed by AspenTech used to mathematically model chemical processes, from unit operations to full chemical plants and refineries. HYSYS is able to perform many of the core calculations of chemical engineering including mass balance, energy balance, vapor-liquid equilibrium, heat transfer, mass transfer, chemical kinetics, fractionation, and pressure drop. The software is used widely in industries and in curriculums for both steady state simulation as well as dynamic simulation , modelling , experimenting design and optimization.

VI. MODEL DEVELOPMENT AND DATA

Steam Methane Reforming using solar energy simulated flowsheet was performed on Aspen HYSYS. According to previous studies, the steam methane reforming and water gas shift reactions were modeled based on the method of equilibrium constants. However, the thermodynamic equilibrium in the method can be calculated by either minimizing the Gibbs free energy or using equilibrium constants.

Methane and water are feed streams firstly mixed in a mixer standard model. The inlet and outlet streams are monitored by the gas analyzer intalled. Once entered into the reactor, the feeding stream is transformed into a drain stream involving different chemical composition due to the effect of concentrating solar energy. Besides, the energy balance is formulated using the total thermodynamic enthalpies of all streams including their possible loadings.

VII. SIMULATION & ASPEN HYSYS SIMULATION SOFTWARE



Flowsheet On Solar Thermochemical Hydrogen Production Plant - Steam Methane Reforming Method On Process Simulation Software Aspen Hysys

VIII. RESULTS

The whole process consists of two distinct reactions, namely, water gas shift reaction and steam methane reforming reaction. The SRM reasction is an example of endothermic reaction and absorbs energy as it proceeds. Four moles of hydrogen is generated for each mole of methane. The process chosen is most efficient process as compared to other processes in market.

A temperature is kept maintained below 800 degree celsius and pressure range between 1.02-30bar. The mass ratio of steam to methane is maintained between 1.0 and 4.0. The increase in the concentration of carbon dioxide along with that of hydrogen could be attributed to the reverse WGS (water gas shift) reaction leading to significant water and carbon monoxide conversion into carbon dioxide and hydrogen.

IX. CONCLUSION

The project report "Solar Thermochemical Hydrogen Production Plant" presented the simulated results of the solar SRM process for producing low-carbon hydrogen using concentrated solar energy. The software used was Aspen HSYSY for process modelling. The simulation flowsheet consists of water gas reaction and steam methane reforming process. Of all the technologies for capturing solar energy, the solar concentrating sytem with the centralized tower is the best technology for using high range temperature and applications that are large scaled. The temperature needed to be maintained between 200- 900 degree celsius and pressure between 1 bar and 30bar. The effects of different operating conditions on the process were investigated with an purpose of finding preliminarily optimized and validated results for solar SRM process. The increase in the concentration of carbon dioxide along with that of hydrogen could be attributed to the reverse WGS (water gas shift) reaction leading to significant water and carbon monoxide conversion into carbon dioxide and hydrogen.

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- Aspen HYSYS - Hyprotech and Systems , a simulation software used by chemical engineers for creating flowsheets and optimization
- R&D - Research & Development
- SRM - Steam Reforming of Methane
- CSP - Central Solar Receiver / Concentrated Solar Receiver
- WGS - Water Gas Reaction

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