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MODEL OF AN ENVIRONMENT-FRIENDLY AND SUSTAINABLE POWER PLANT

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Abstract: Power plant is one of the major sources of Carbon dioxide gas emission. This gas is leaving an atrocious impact on the environment such as the Greenhouse Effect. This paper proposes a new model that ensures lower Carbon dioxide emission from the power plants. In this model, steps of chemical processes are used in a cycle. The basic principle of the model is represented through 5 chemical reactions. Exclusive reactions like Sabatier Reaction, Hydrogen Production, and Hydrogen Fuel, etc. are used in this cycle in a systematic way. It is observed that the Oxygen to Carbon dioxide ratio in the air can be increased with every completion of this cycle. Also, Methane is re-produced in one step of this cycle which ensures sustainability. It is observed that only 3% of energy is lost to run these extra processes. So, this model can prevent the Earth's environment pollution with a nominal energy loss.
Keywords: Environment, Power Plant, Sustainable Energy, Emission Control, Chemical Process

INTRODUCTION

The major source of air pollution is the emission from combustion that takes place in industries, power generation systems and electrical utilities. The environmental pollution from burning various fossil fuels in thermal power plants poses tremendous health hazard to modern civilization. In addition to causing annoyance to public, air pollution by thermal plants contributes to the cause of property damage, various respiratory diseases and lung cancer.

From burning of fuels (coal, oil and gas) the combustible elements are converted to gaseous products, and non-combustible elements to ash. As a result, thermal power plants continuously emit a massive amount of Carbon dioxide in air. These Carbon dioxide has a molecular structure that triggers the global climate issues by the following mechanism: The internal molecular vibration and rotation of Carbon dioxide causes its molecules to absorb infrared radiation.

When Carbon dioxide gas form part of the atmosphere, they absorb some of the heat that the earth normally radiates into space. So, heat is trapped that would otherwise be lost (Peirce, 1998). This is causing the temperature to increase every year. Hardley Centre for Climate Prediction and Research claims that, "An upward trend can be clearly seen in the annual mean global temperature that initiated from 1920 and continued for the rest of the century." It also shows in a chart that the average temperature increase from 1975 to 2000 was of about 0.5°C/0.7°F (Lawson, 2009). It has been projected that average temperature across the world would climb between 1.4°C and 5.8°C over the next century.

The second of IPCC's impact categories is ecosystem, where it states that, "Approximately 20-30% of plant and animal species assessed so far are at the risk of extinction if increase in global temperature exceed 1.5-2.5°C (Lawson, 2009)."

Scientists have proved that the root cause of global warming is the increase of man-made Carbon dioxide emissions in the free air. Under the light of these certain facts, it is customary that the emission process of Carbon dioxide needs to be modified. But due to economic facts, none of the industry leaders are executing such steps. On the other hand, energy demand is increasing day by day.

According to IEA- key world energy statistics 2015, world final energy consumption of 2014 (109,613 TWh) was more than double of the final energy consumption of 1973 (54,335 TWh) (International Energy Agency, 2015). It also projects 28% increase of energy demand by 2040. Scientists and engineers have demonstrated the necessity of introducing sustainable systems that can ensure fulfilment of the future energy demand.

So, to reduce the Carbon dioxide emissions and ensure future energy demand are the major concerns of the Century. This paper offers a power plant cycle that ensures lower Carbon dioxide emission and reproduction of hydrocarbon that yields sustainability for future use.

This paper proposes a new model where ideas of Artificial Photosynthesis, Hydrogen Fuel and Sabatier Reaction will be used to develop the energy production. Every completed cycle of the system gradually reduces Greenhouse Gas emission and ensures a good amount of Oxygen emission. Which will increase the Oxygen to Carbon Dioxide ratio of the atmospheric air.

The basic principal of the model can be represented by 5 steps of chemical reactions. Various fuels (coal, fuel oil, shale oil, natural gas) are used in thermal power plants. Though the principle of the proposed model is applicable for all the other fuels, only methane (CH_4) is discussed in this paper due to being most widely used.

For better understanding of the new model, operation procedure of a general steam power plant that uses Methane as the fuel is briefly demonstrated below.

TYPICAL OPERATION PROCEDURE OF A STEAM POWER PLANT

Heat required for steam production in a steam power plant is achieved through the combustion of methane. In methane power plants, the following chemical steps take place:

Due to heat and attack by the active elements, methane reacts with methyl radical (CH_3), which then reacts with formaldehyde (HCHO). This formaldehyde reacts with a formal radical (HCO), this forms carbon monoxide (CO).

In these steps, the active elements are used and H_2 and H_2O are formed with the CO.

Principle reaction:

$$CH_4 + O_2 \rightarrow CO + H_2 + H_2O$$

Here, methane gas is converted into two new fuels (CO and H_2) and into one product (H_2O). This process takes place very quickly, within a fraction of millisecond to a few milliseconds, this depends on some parameters such as: pressure, flame temperature, and fuel-air ratio. The process is called Oxidative Pyrolysis.

After oxidative pyrolysis, the H_2 oxidizes, which forms H_2O, which replenishes the active species, and releases heat. This step occurs quickly, usually in less than a millisecond.

$$H_2 + (1/2)\ O_2 \rightarrow H_2O$$

In the final step, the CO is oxidized, forming CO2 and releasing more heat. This step is slower than the other steps, and generally requires up to several milliseconds to occur.

$$CO + (1/2)\ O_2 \rightarrow CO_2$$

The produced heat is used for steam production and the produced Carbon dioxide is released in free air.

PRINCIPLE OF THE PROPOSED MODEL

As mentioned earlier, the proposed model is divided into 5 chemical steps which will take place in different complex compartments (cells). These compartments make up a plant altogether. Products from each compartments will be exchanged with the other. One run of the cycle is completed after each step-wise completion of the model. The steps of the model are as follows:

— **Methane Combustion:**

This is the first step of the model and is the general mechanism used in any thermal power plant. Here, methane is combusted with oxygen and heat is produced. Heat is then used to produce steam. Mechanism of this step is briefly discussed in the previous section of this paper.

Overall reaction:

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

The produced Carbon dioxide (CO_2) shall not be released to air, rather it will be captured and then sent to the next step which is "Artificial Photosynthesis" and the produced H_2O is sent to the third step which is "Hydrogen Production."

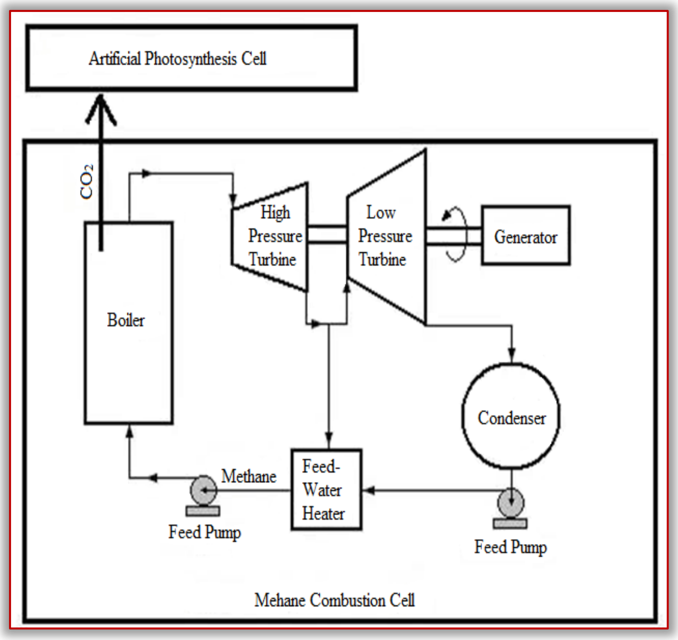

Figure 1: Capture of Carbon dioxide from a typical thermal power plant cycle.

— **Artificial Photosynthesis:**

In this step, the captured Carbon dioxide from Methane combustion is split into Carbon monoxide and Oxygen. Simple changes are needed to be made to capture this Carbon dioxide from the discharge manifold (Shimizu, 1999). The aim of this step is to produce Carbon monoxide that can be used in the following step which increases energy output. Also, a small amount of the produced Oxygen from this step is sent to the fuel cell and the rest is released in the air. So, this step shall help to increase the amount of oxygen ratio in air.

Artificial Photosynthesis can be done through various mechanisms. But, in this paper it is demonstrated through energy storage reaction (Chen, 2012).

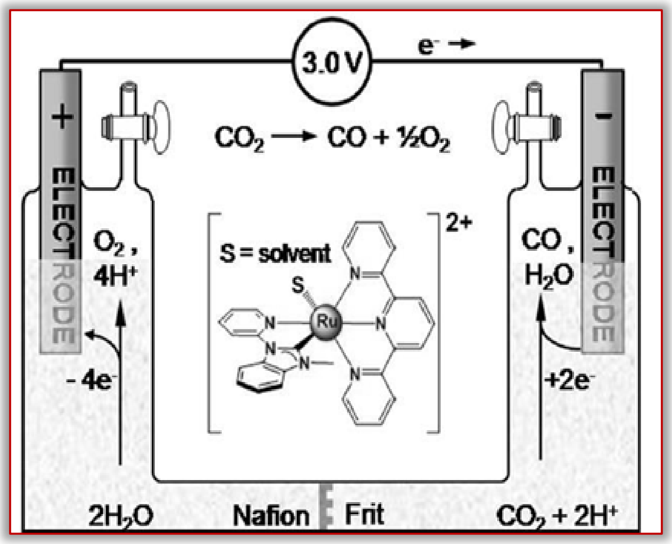

Figure 2: Two compartment cell for Artificial Photosynthesis

This energy storage reaction is split into the following half reactions:

$$O_2 + 4H+ + 4e^+ \rightarrow 2H_2O \text{ (E° 1.23V vs. NHE)}$$

$$CO_2 + 2H+ + 2e^- \rightarrow CO + H_2O$$
$$\text{(E° -0.12V vs. NHE)}$$

The final reaction stands,

$$CO_2 \rightarrow CO + (1/2)O_2$$

The process is designed using a two compartment electrochemical cell which is reactive electro-catalyst for water oxidation to Oxygen and Carbon dioxide reduction to Carbon monoxide

— **Hydrogen Production:**

Hydrogen is required to run the fuel cell in step 4 and Sabatier reaction in step 5. Though Hydrogen can be extracted naturally, but it is not in large enough quantities to be produced economically. Therefore it needs to be separated from other elements. Methods of Hydrogen production includes electrolysis, thermolysis and steam refining from hydrocarbon. Due to the fact that natural gas is cheap and easily available, the steam refining from hydrocarbon method is most widely used. The chemical process for Hydrogen Production is an exothermic, lower-temperature, water gas shift reaction: (performed at about 360°C)

$$CO + H_2O \rightarrow CO_2 + H_2$$

This is called the Water-Gas Shift Reaction which is the second step of steam refining from hydrocarbon method. Here, Hydrogen is produced and Carbon monoxide is eliminated by passing it through a catalytic reactor, called shift reactor. Where carbon monoxide reacts with steam and forms carbon dioxide and hydrogen. As this step is exothermic, according to Le Chatelier's principle the reaction must be done at a low temperature. This reaction is conducted in both high temperature shift and then low temperature shift to get maximum output. The H_2O to CO_2 ratio should be as high as possible to avoid any side reaction (Braga, 2017).

— **Fuel Cell:**

A fuel cell is a device that generates electricity by a chemical reaction. This is an important step of the model. Because it supplies not only renewable source of electricity, but also heat energy that can be used in other purposes (Michael, 2008).

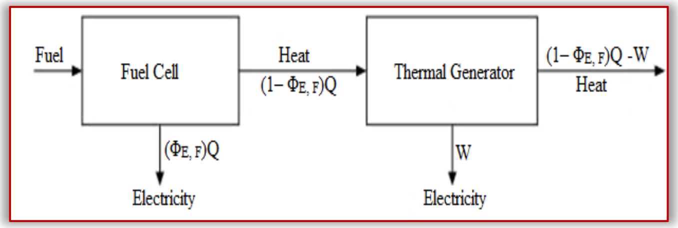

Figure 3: Energy production from a fuel cell

There are many types of fuel cells and any of them can be implemented in the model. Alkaline fuel cell is preferable for its high efficiency, fast start and simple design.

Here, hydrogen is sent to the anode where a catalyst splits hydrogen's negatively charged electrons from positively charged protons (H^+). At the cathode, protons combine with oxygen resulting in water.

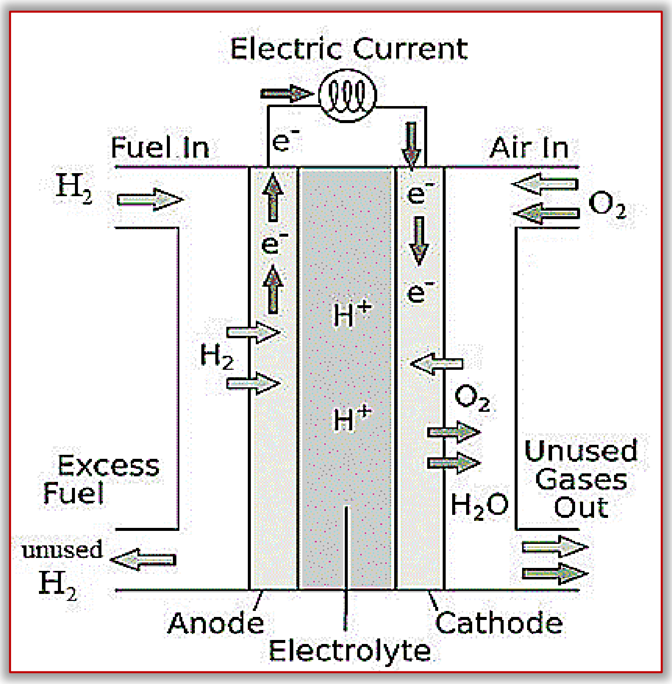

Figure 4: Principle of a Fuel Cell. (Source: Dept. of Energy)

This chemical reactions occur in an alkaline fuel cell:

- Cathode: $(½)O_2 + H_2O + 2e^- \rightarrow 2OH$
- Anode: $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$

Hence, electricity is produced due to the flow of electrons.

— **Sabatier Reaction:**

It involves the reaction of hydrogen with carbon dioxide at elevated temperatures (optimally 300-400 °C) and pressures in the presence of a nickel catalyst to produce methane and water. It is described by the following exothermic reaction:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

Optionally, ruthenium or alumina (aluminum oxide) makes a more efficient catalyst (Brooks, 2007).

To avoid the energy crisis in near future, we must employ sustainable systems. This step reproduces methane which can be re-used hence, it contributes to a more efficient usage of non-renewable energy.

SUMMARY OF THE MODEL

At first, the Carbon dioxide and steam produced from the combustion of methane will be captured. Then it will be sent to the Artificial Photosynthesis compartment and split into Carbon monoxide and Oxygen. This Carbon monoxide will be sent to Hydrogen Production compartment where reaction with steam (from Methane Combustion) will take place. Then the produced Hydrogen from Hydrogen Production compartment will be sent to both the Fuel Cell compartment and Sabatier Reaction compartment. In this case, only 25% of Hydrogen will be sent to Fuel Cell and the rest to Sabatier Reaction compartment. This will balance for maximum conversion of Carbon dioxide in Sabatier Reaction, energy production in Fuel Cell and release of oxygen from the system. Since Hydrogen is more efficient for producing energy compared to Methane, the distribution of Hydrogen must be optimal.

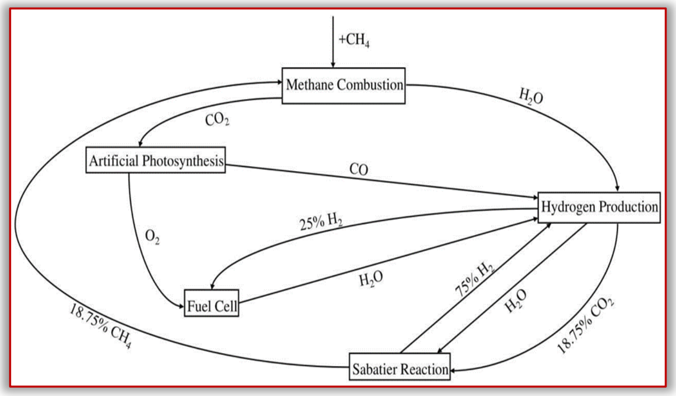

Fig. 5: Flow diagram of the proposed power plant model

The basic principle of the model can be represented by these 5 steps of chemical reactions: (100 moles of Methane is considered to demonstrate the product distributions.)

$$\text{Step 1: } 100CH_4 + 200O_2 \rightarrow 100CO_2 + 200H_2O + 88200 \text{ KJ}$$

$$\text{Step 2: } 100CO_2 \rightarrow 100CO + 50O_2 - 17050 \text{ KJ}$$

$$\text{Step 3: } 100H_2O + 100CO \rightarrow 100CO_2 + 100H_2 + 4100 \text{ KJ}$$

$$\text{Step 4: } 25H_2 + 12.5O_2 \rightarrow 25H_2O + 7150 \text{ KJ}$$

$$\text{Step 5: } 75H_2 + 18.75CO_2 \rightarrow 18.75CH_4 + 37.5H_2O + 3093.75 \text{ KJ}$$

This model releases 75% of the produced oxygen to air and re-uses 18.75% carbon dioxide for the next cycle. So, every next cycle produces more energy, hence more Oxygen and less Carbon dioxide is released to the environment compared to the conventional power plants. Thus increases the oxygen to Carbon dioxide ratio of the environment and eradicates global warming.

VIABILITY & SIGNIFICANCE

Net energy production from this model was determined by adding the produced energy values of each step given in Process Summary.

So, the net energy of the model: 85493.75 KJ.

Which is 97% of the conventional process (Methane Combustion: 88200 KJ).

Hence, the energy loss of the model is only 3%.

A field assessment was conducted on Ashuganj Power Station Company Ltd. in Bangladesh. System losses were neglected for the ease of calculation.

For the maximum capacity of 146 MW of the Power plant, it was determined that 11.7 X 10^9 liters of Carbon dioxide is released to the air per year. For 18.75% conversion of this Carbon dioxide by Sabatier reaction at step 5, this emission was reduced by 2.19 X 10^9 Liters.

Which means emission reduction of 15000000 liters/MW in a year.

As suggested by Osama T Akoubeh in a model, methane could be simply re-produced using Sabatier reaction (Akoubeh, 2015). In that case, the Carbon dioxide collected from Methane combustion will be directly sent for Sabatier reaction. Which means, a model where only the step 1 and 5 is applied. But in that case, the system produces zero net energy. So, the model fails to provide any means of benefit. Additionally, this model is unique for the future energy demand, sustainability. Hence, reduction of carbon dioxide emission can be enacted through the model proposed in this paper with a minimal energy loss (3%).

CONCLUSIONS

The proposed model releases 18.75% less Carbon dioxide in air compared to the conventional power plant system. This is possible due to Sabatier Reaction (Step 5) where this Carbon dioxide is converted to

Methane (CH_4). In this model, 4 out of the 5 steps are exothermic. And renewable energy is used in Fuel Cell (step 4). Due to higher heating value (BTU/lb) hydrogen is more efficient fuel compared to methane. So, Fuel Cell provides efficient and clean energy. On the other hand, reproduced methane can be used that yields sustainability. So, this model can help to improve the future energy scenario.

Energy produced in the model, such as from Fuel Cell can be used to run the power plant itself. On the other hand, this model offers the most economical solution for environment pollution without any kind of extra processing, carbon sequestration storage (CSS), or transportation.

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