Hong Kong Student Science Project Competition 2023

Template of Extended Abstract (Investigation)

(Word Limit: 1,600 words, Pages: 3 pages only)

Team Number: SBBC174

Project Title: AgNPs and Natural dye-sensitized TiO_2NPs-catalyzed photo-oxidation in food waste treatment and its potential application in H_2 production enhanced by Venturi effect (化廢為寶鈦容易)

Project Type: Investigation

***To our best knowledge, there are / ~~are no~~ * similar works in the field*; (if there are,) related research links are as below:**

Lee H.S. ; Vermaas W. F. J. ; Rittmann B.E. ;Biological hydrogen production: prospects and challenges,*Trends in Biotechnology*, 28 (5) **2010**, 262-271, ISSN 0167-7799, https://doi.org/10.1016/j.tibtech.2010.01.007.

The enhancement our project made / the difference with related research are:

Investigating synergistic dyes
Applying Venturi effect
Investigating photocatalyst degradation

I. Background

Hydrogen as an energy source has gained significant public and research attention in recent years. Yet, by reviewing other existing methodologies for hydrogen production, it is not hard to see that they are come with respective disadvantages. One potential method, however, producing renewable hydrogen using a photoelectrochemical pathway, has the potential to offer a promising method to produce green, econoimical, and eco-friendly energy using light energy to reduce protons over a Titanium dioxide (TiO_2) photocatalyst, splitting water into hydrogen and oxygen as a result. The growing human population raises concerns in terms of not only source of energy, but effective food and waste management. In light of this, we hope to help tackle this problem as well by implementing food waste treatment elements onto our project. Today, photocatalysis is frequently applied in a variety of processes, including the production of solar cells, water splitting, and pollutant neutralization, so the method is feasible. 5 chosen dyes that are used to sensitize TiO_2NPs such as chlorophyll have organic origins and so can be extracted sustainably. The implementation of glycerol and other food components means this photocatalytic effect can convert household food waste into useful products, solving a major problem of waste treatment converting waste into treasure. To provide crucial insight regarding TiO_2 photocatalysis under actual environmental conditions, various surface science methods have been used to investigate the photochemical mechanisms and fundamental ideas of photocatalysis, particularly photocatalysis of TiO_2NPs, extensively over the past decade. This is what our project seeks to expand upon.

II. Objectives

The goal of our study is to examine the effectiveness of photocatalytic oxidation by TiO_2NPs in the presence of co-catalysts, as well as its potential uses in the treatment of food waste and the manufacture of clean hydrogen using solar energy.

III. Hypothesis

Surface sensitization of a wide band-gap semiconductor photocatalyst (TiO_2NPs) via chemisorbed or physisorbed dyes can increase the efficiency of the excitation process. The photosensitization process can also expand the wavelength range of excitation for the photocatalyst through the excitation of sensitizers followed by charge transfer to the semiconductor. We sensitized in total 5 dyes including chlorophyll, anthocyanin, β-carotene, betalain and silver nanoparticles (AgNPs) on TiO_2NPs surface. Anthocyanins, carotenes, chlorophyll and betalains, similar to other natural dyes, can be used to absorb lower wavelengths of light to excite the electrons from the valence band to the conduction band. This broadens the absorption of light in the solar spectrum from the original ultraviolet range which make up 4% of natural sunlight. Hence, the hydrogen production can be enhanced. While the AgNPs on the TiO_2NPs surface can increase the hydrogen production by trapping of electrons at the metal sites. We hypothesise that an ideal mixture of titanium dioxide nanoparticles sensitized by the most effective dye, in conjunction with sodium carbonate and glycerol, illuminated with optimal sunlight and in aid of the Venturi effect, can produce the greenest hydrogen whilst resulting in minimal by-products.

IV. Methodology

Parameter

- Loading of Silver nanoparticles (AgNPs)
- Loading of Anthocyanin-sensitized TiO_2NPs
- Loading of Chlorophyll-sensitized TiO_2NPs
- Loading of Anthocyanin-sensitized TiO_2NPs
- Loading of β-carotene-sensitized TiO_2NPs
- Loading of Betalain-sensitized TiO_2NPs
- Loading of Sodium carbonate (Na_2CO_3)
- Loading of Glycerol

Experimental protocol

There are in total three generation of our experimental setups.

1. Generation ONE (Reaction mixture in conical flask under Sunlight exposure)

Experiment procedure:

1. Place the reaction mixture under direct sunlight for 30 min and measure sunlight intensity at 1 min intervals.
2. After 30 min, transfer solutions and sonicate the flask in pulses for 5 min.
3. Measure hydrogen concentration inside each conical flask.

2. Generation TWO (Flow-chemistry setup)

Experiment procedure:

1. The LED lights and water pump are turned on and the solution is illuminated for 1 hour.
2. An additional 20 mL of air is pumped into the full syringe for proper testing
3. A hydrogen detector breaks the aluminium foil seal and measures the hydrogen concentration in the collected mixture of air.

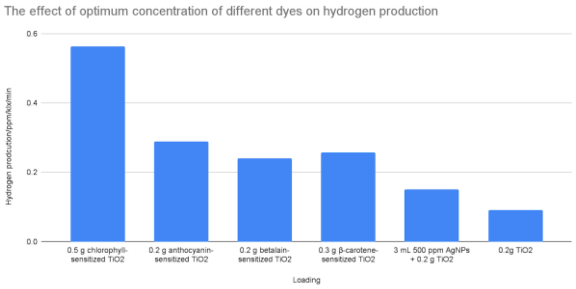
In this new method, the total illuminated surface area of the solution is drastically increased. Experimental time can be shortened as the hydrogen level rises more quickly.

3. Generation THREE (Applying Venturi effect)

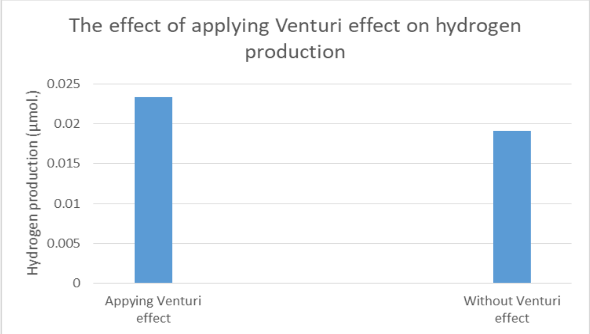
Our final experiments attempted to apply the Venturi effect to flow chemistry by replacing the entire pump reservoir system with a syringe pump.

In this setup, the working fluid is drawn into the syringe pump from the reservoir through the reaction coil, which is a tube wrapped around a light source.

V. Results



According to our research, after comparing the dyes we looked into, we conclude that chlorophyll-sensitized TiO_2NPs has the highest hydrogen production rate, while addition of AgNPs produces hydrogen at the lowest rate. It is suggested that the narrower band gap between the valence band and conduction band of chlorophyll best broadened the solar absorption. The intersystem crossing between the valence bands of chlorophyll and TiO_2NPs lengthened the lifetime of electrons at the valence band for water reduction to generate hydrogen gas. It is also suggested that the low hydrogen production rate of addition of AgNPs is because the AgNPs may block the sunlight that as a result inhibits the photocatalytic water splitting.



From the graph above, the hydrogen production has increased by 21.7% when the Venturi effect is applied under our own proposed design. It is believed that by lowering the pressure of the solutions, the gas solubility of liquid decreases, encouraging dissolved hydrogen and oxygen to escape into their gaseous state to then be collected as hydrogen and oxygen gas, thus increasing yield efficiency. Compared to the various industrial de-gas practices, such as by thermal or pressure degasification, this solution is more cost effective on any scale, small or large.
More data can be found in the report

VI. If your team will compete the Sustainable Development Award, please indicate the specific sustainable development goal the project is related to, and provide justification for competing for this award. *(Word limit: 300 words)*

Due to the exponential development in both the human population and industrial activities, humanity's need for energy has significantly increased in recent decades. Furthermore, it has been discovered that conventional energy production methods based on fossil fuels are the biggest producers of greenhouse gases and, as a result, the main causes of climate change. It is easy to understand through literature review that other currently used methods for producing hydrogen suffer from flaws. Our investigation covers different parameters, including raw mixture, dye-sensitized TiO_2NPs, or both in varying ratios, since TiO_2NPs is sensitive to ultraviolet light, which consists of only 4% of the solar spectrum, we sensitize TiO_2NPs with natural or synthetic dyes to broaden the solar spectrum absorption of the catalyst to increase energy conversion efficiency. Therefore, we believe that our investigation provides valuable insight of sustainable method on producing "affordable and clean energy'. In addition, we also implemented glycerol into our mixture, and the addition of glycerol has successfully enhanced the hydrogen production for 89.4%. The implementation of glycerol and other food components means this setup can convert household food waste into useful products, solving a major issue of food waste and converting waste into treasure. It will complete a circular flow of resource where all waste are responsibly collected and completes the loop by becoming energy for use once again. Hence, we believe that our system is also a better way on handling leftovers that will be beneficial to all life on Earth.
To conclude, we investigated the sustainability of hydrogen gas generation by exploiting the ever-increasing supply of food waste and naturally occurring materials with the use of nanoparticles as catalysts in photocatalytic water

splitting. We believe that in the near future, improved versions of our project might be used to produce hydrogen and power humanity sustainably.

VII. If your team will compete the Social Innovation Award, please list the target group or social issue the project focuses on, and provide justification for competing for this award. *(Word limit: 300 words)*

A similar setup to the Generation THREE in our proposal can be easily upscaled while retaining a similar or perhaps larger surface area for photocatalytic reaction. Our research shows that exposing the setup under natural sunlight is not only feasible but is highly promising. When applied industrially under regions on Earth with intense, prolonged sunlight periods paired with a large reaction surface, the production efficiency could be even higher. Lipids and other organic components of common food waste could be added offering increased efficiency and waste treatment capacity. A Venturi tubing system similar to our design (Generation THREE) could be implemented to decrease the gas solubility of solutions and promise higher yields while remaining cost-effective. After all, we believe our project can pave the way as a sustainable method of generating hydrogen, improving the livelihood of bi given that there are still a few challenges to overcome including industrial mass-application. However, from our perspective, technological advances ensure that it would not be a significant barrier to overcome. Imagine rooftops, open areas of bright sunlight covered with such a system, eliminating organic wastes from nearby residents while providing continuous hydrogen to power humanity for centuries to come, the possibilities exhibited are endless.

VIII. Conclusion

We discovered that the amount of hydrogen produced varied depending on the co-catalysis, and that excessive co-catalysis could inhibit hydrogen generation, which performed better in sensitive setups. Among the three dyes that we have investigated, chlorophyll-sensitized TiO_2NPs has the highest production rate, able to enhance the hydrogen production rate by 516.0%. When AgNPs act as a dye, they can raise hydrogen production by 65.2%. When anthocyanin acts as a dye, hydrogen production has increased by 216.5%. When betalain acts as a dye, hydrogen production has increased by 161.9%. When β-carotene acts as a dye, hydrogen production has increased by 181.2%. By adding sufficient sodium carbonate as an electron-hole pair recombination inhibitor increases production by 189.2%. Using an alkaline medium further increases yield. It has also been found that while an acidic medium produces roughly the same hydrogen as a neutral solution, an alkaline medium performs exceptionally well, achieving a 195.8% improvement over other chlorophyll-based setups.

As we still do not fully understand how all Co-Catalysis affect one another, the synergy of more Co-Catalysis might be investigated more. We have already examined the effect of AgNPs and chlorophyll in conjunction in water splitting. Our experiments show that the usage of both synthetic and natural dyes shows little to no interference effect, perhaps even slight synergistic effects. Then again, the detailed effect of various dyes working together should be further investigated in the future. It is possible to examine potential natural dyes or additions, such as anthraquinone[13] combined with chlorophyll, for their role in promoting photolysis by transferring untapped wavelengths into energy which is transferred through Förster resonance energy transfer to TiO_2NPs.

After all, we believe our project can pave the way as a sustainable method of generating hydrogen, given that there are still a few challenges to overcome including industrial mass-application. However, from our perspective, technological advances ensure that it would not be a significant barrier to overcome. Imagine rooftops, open areas of bright sunlight covered with such a system, eliminating organic wastes from nearby residents while providing continuous hydrogen to power humanity for centuries to come, the possibilities exhibited are endless.

To conclude, we investigated the sustainability of hydrogen gas generation by exploiting the ever-increasing supply of waste and naturally occurring materials with the use of nanoparticles as catalysts in photocatalytic water splitting. We believe that in the near future, improved versions of our project might be used to produce hydrogen and power humanity sustainably.

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