S−29 Biomass energy for a sustainable future: a new challenge at Tohoku University

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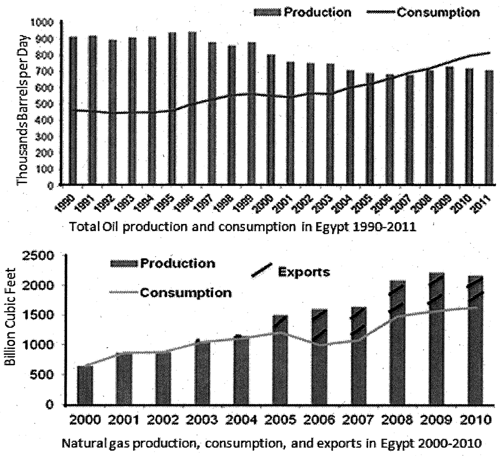
1. Introduction

The research and education in Tohoku University, graduate school of environmental studies, is focused on providing environmental policy solutions through scientific research, collaborative, interdisciplinary internship programs (the environmental leader program). In this program we can strengthen our ability to tackle the source of global environmental problems in the field of energy, resources and water with a practical and international perspective. Water and energy are already becoming critical in some societies and the world will need to find ways to conserve these vital resources. There is probably one fact that we can all agree on: the world's energy reserves are limited. Actually that's not true, there is also a supply of energies coming from the sun and biomass but we are not yet converting it into useful energy on a large scale. Since the Industrial Revolution, mankind has depended on fossil fuels, which are very harmful to the environment because they cause global warming and short term pollution. Globally, August 2012 marks the 4th warmest August since temperature records began in 1880.

Egypt is an important non-OPEC energy producer. It has the sixth largest proved oil reserves in Africa. Approximately 50% of Egypt's oil production comes from the Gulf of Suez, the Western Desert, and Eastern Desert. Major discoveries in the 1990s have given natural gas increasing importance as an energy source. Natural gas is exported by the Arab Gas Pipeline to the Middle east and in the future potentially to Europe. However, Egypt's oil consumption has outpaced production since 2008. As consumption increased, Egypt's imports of both crude oil and refined petroleum products have also increased to make up for decreased oil output (Fig. 1).



Source: U.S. Energy Information Administration, International Energy Statistics

Fig. 1 Energy situation in Egypt, 1990-2011

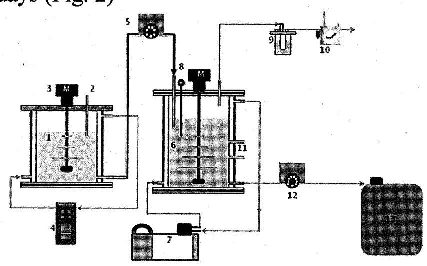
Bio-energy, in its solid, liquid or gas form, can be used to generate power and heat as well as to produce bio-fuels. A big advantage of bio-energy is its storage possibilities. The development and application of bio-energy technologies offer several benefits such as: reduced emissions, less waste and cost savings from reduced energy & resource use during production as well as due to improved systems of recycling and waste management. The Japanese government targets to increase renewable energy sources to account for 25%-35% of its total power output by 2030, compared to 10% in 2010. This is in response to the Great East Earthquake/Tsunami on March 11, 2011 and the subsequent severe accident of Fukushima Nuclear Power Plant.

Hydrogen as a source of energy has been considered for a long time. Chemical and electrolysis processes for hydrogen production are well established, but biological conversion of waste to hydrogen could be a viable alternative method, as current methods require high energy and production cost. Cellulosic materials are the only renewable resources available in large quantities, and could be utilized to help meet our needs for energy, chemicals, food and feed for a long-range solution. The aim of this paper is to highlight and summarize work at Tohoku University on bio-hydrogen energy from cellulose using dark fermentation; also our experience in education in environmental leadership.

2. Our research on bio-hydrogen production

2.1 Research Approach

Compared to other current fuel to energy conversion technologies, the higher efficiency of the conversion of hydrogen to electrical energy due to its high calorific value makes hydrogen a potential substitute for fossil fuels. Besides being energy efficient, it is also carbon-free, non-polluting, and recyclable. Over 95% of the world's hydrogen demand is now being derived from fossil fuels. Biological processes have the potential to generate hydrogen from renewable and/or recyclable feedstock. However, few studies have been dedicated to describing biological hydrogen production using cellulose. Because cellulose is particularly difficult to hydrolyze, its uses have been considered extremely limited. Therefore, the purpose of the research is to generate hydrogen gas continuously from cellulose by dark fermentation, and determine the key parameters of the process. We operated three continuous stirred-tank reactors (CSTR) under different temperatures, 37±2 °C [Mesophilic], 55 ±2 °C [Thermophilic] and 80 ±2 °C [Hyper-thermophilic] with an effective volume of 6 L and operated using a hydraulic retention time [HRT] of 10 days (Fig. 2)



1- Feedstock tank, 2- Feed inlet, 3- Mixer, 4- Recirculation cooler, 5- Sampling pump, 6- Hydrogen reactor, 7- Hot water recirculation, 8-thermometer, 9- Gas-water separation chamber, 10- Wet gas metter,11- Sample port, 12-Effluent pump, 13- Digestion sludge tank.

Fig. 2- Schematic diagram of experimental apparatus

2.2 Research Results

The experimental results show that stable hydrogen production was observed during fermentation of cellulose under mesophilic (37±2°C), thermophilic (55±2°C) and hyper-thermophilic (70±2°C) conditions (Fig. 3). The maximum hydrogen yield was 10.07 mmol H2 / g cellulose (1.94 mol H_2/mol Hexose) in thermophilic conditions. However, 20% of the biogas was methane at mesophilic temperatures. The thermophilic fermentation is expected to have a better economic performance for bioH2 production, especially when going towards feedstock concentrations (Fig. 4).

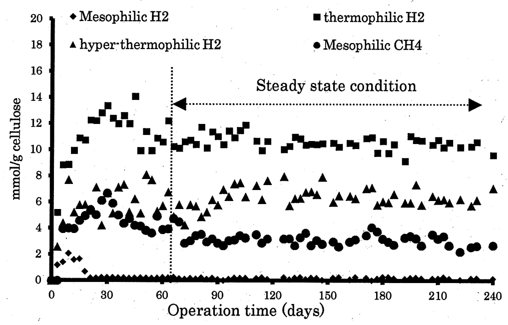


Fig. 3- the time course of hydrogen production yields under different operation temperature.

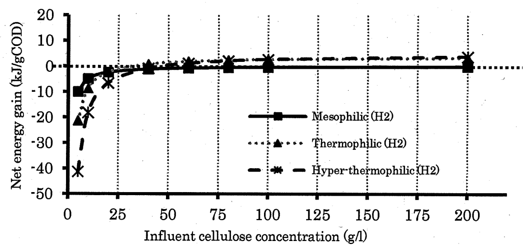


Fig. 4- Prediction the gained net energy at different fermentation temperatures for different influent cellulose concentrations

3. Internship experience

Moving to the theme of environmental education, the Environmental Leaders Program (SERMSS) at Tohoku University helps to hone leadership and communications skills to maximize the impact of research. During this program, studying and participating in internships abroad for more advanced expertise are required. As well as introducing new and updated topics in regular special lectures by different professors from different universities around the world. For example, the osmosis phenomena for water purification and energy generation by Prof. Albert S. Kim from Hawaii University.

As an example of an internship aboard, from 10th July to 8th August 2011, I visited Egypt for an Internship program entitled "The current status of Water Resources in Egypt: Future Challenges and Opportunities". During this period, I made a comparison between what I had learnt from Japanese experience, and the situation in Egypt- particularly experience in wastewater management.

85 million Egyptians live in 222 cities and 4617 villages. More than 95% in urban areas are covered by wastewater treatment plants, but less than 15% in rural areas. This means much wastewater is released to the environment without treatment, causing epidemics and water pollution. Of the collected wastewater (6.5 billion m^3/Yr), 20% receives primary treatment and 80% secondary treatment. Al Gabal El-Asfar Wastewater Treatment Plant (GAWWTP) is one of the most important wastewater treatment plants in Egypt (Fig. 5), and I visited it during my internship. This main project's output is a 500,000 m^3/d with primary and secondary wastewater treatment capacity. In the secondary wastewater treatment, the plant uses mesophilic digestion to produce methane gas. Methane gas can be used for electricity generation and heating the reactors, the generated electricity provides 60% of the plant's needs.

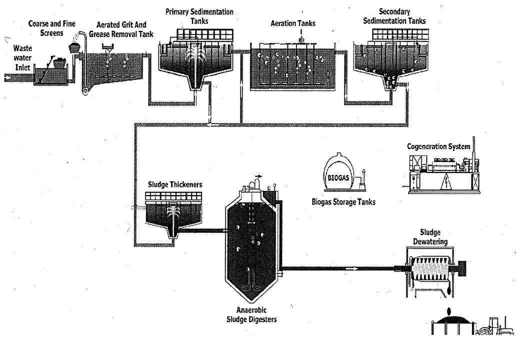


Fig. 5- Water and sludge treatment process flow diagram

By comparison, Sendai municipal sewage treatment plant (which I have visited many times) uses mesophilic and thermophilic digestion. Of course the thermophilic digestion can increase pathogenic destruction and utilize the sludge safely.

As regards renewable energy policies and progress achieved, Egypt has success stories such as wind power generation. Egypt is on top of all African and Middle East countries in grid-connected wind power generation. Since the late 1970s, Egypt started considering the use of renewable energy, and several bilateral and multilateral agreements are underway to explore the potential of renewable energy use. In the biomass energy field, activities have not moved away from the laboratory or pilot scale. Only a few plants have been constructed. One of them was a 170 m^3 digester in EL-Giza Army Camp in 1980.

From my experience, I believe that the Egyptian approach needs to increase awareness about the importance of biomass as a source of clean energy, waste treatment, economic feedback and environmental & social benefits. This may require co-operation between the concerned ministries, authorities, institutions and organizations.

4. The achievements

4.1 Journal publication

S.I. Gadow, Yu-You Li, and Yuyu Liu. Effect of temperature on continuous hydrogen production of cellulose. Int. J. Hydrogen Energy 2012; 37:15465-15472.

4.2 Conferences

- The 7th International Conference on Environmental Anaerobic Technologies and Bioenergy. Tianjin University, Tianjin, China November 12-13, 2011.
- 第 14 回日本水環境学会シンポジウム　2011 年 9 月 10 日　　東北工業大学
- The 46th Annual Conference of Japan Society on Water Environment. Toyo University, March 14th −16th, 2012.
- The Japan-China joint workshop, March 17th, 2012.

4.3 Research Award

Presentation Excellence Awards in The 7th International Conference on Environmental Anaerobic Technologies and Bioenergy Tianjin University, Tianjin, China November 12-13, 2011.

5. Summary

This research suggests that thermophilic operational temperatures are a key factor in sustainable bio-hydrogen production from cellulose and the experience also shows how educational programs can show synergy with research.