

## The Efficiency of Ethanol Distillation Process Using Bubble Pump Technique: A Comparison of LPG and Solar Energy as Energy Source

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**Abstract :** Due to the increasing demand of ethanol production for renewable energy, the research was compared the efficiency of ethanol distillation process using bubble pump technique with two different energy sources. The two fuel sources of distillation involved liquefied petroleum gas (LPG) and solar energy. In addition, the capital cost of a distillation was also calculated. First, pineapple juice was fermented with yeast (*Saccharomyces cerevisiae*) for ethanol concentration between 8-10% by volume. Then, ethanol solution was distilled using bubble pump technique. For the solar ethanol distillation with bubble pump technique, the solar collector area was 2.2 m<sup>2</sup> with inclined angle of 14 degree. The process operated during November to December 2017 under Nakhon Pathom province, Thailand climate. The average solar radiation was 6.48 kWh/m<sup>2</sup>. The results of solar distillation shown that the ethanol concentration was 54.8 % v/v and efficiency was 43 %. When the LPG was used as energy source; the cold water entered the condenser tower at 27°C at a rate of 10 L/min. The efficiency of bubble pump with LPG was 53 %. The results of LPG distillation shown that the ethanol concentration was 65.7 % v/v and 39.1 % v/v in the first and second state, respectively. Finally, the unit cost for solar energy system was 128.82 THB/L ethanol which was due to 43.68 THB/L ethanol of the LPG unit (LPG cost is 20.29 THB/L).

**Keywords:** Bubble Pump Techniques, Capital Cost, Ethanol, Natural Gas, Solar Distillation

## 1. Introduction

Energy is a fundamental to the quality of our lives. Energy sources are classified into two main groups: nonrenewable and renewable energy. Nonrenewable energy sources come from fossil fuels (coal, crude oil, natural gas) and uranium while renewable energy is energy generated from natural resources such as sunlight, wind, rain, tides, geothermal heat, and various forms of biomass. Fossil fuels are high in carbon, when burned; produce major amounts of carbon dioxide. It causes more greenhouse gases to build up in the atmosphere. The ways to reduce greenhouse gas are increasing used renewable energy and improve energy efficiency. Thailand, the Ministry of Energy has been planning to develop and enhance the use of renewable energy and alternative energy to 25% over 10 year (2013-2023). One of the targeted strategies is the consumption of ethanol, which are sources of agricultural raw materials in the country. Any the improvement of ethanol production process must correspond to the Ministry of Energy's policy. Especially, the transportation industry has been encouraged to use ethanol as a form of alternative energy [1-3].

Ethanol is a grain alcohol that can be blended with gasoline and used in motor vehicles. Ethanol is produced from biomass mostly via a fermentation process using glucose derived from sugar, starch or cellulose as raw materials. However, the important process in producing fuel from ethanol is fractional distillation. To increase the concentration of

ethanol from 9-10 % v/v to 93-95 % v/v, a large amount of heat is required. The distillation process is remained interesting in process industries to separate mixtures with similar boiling points. Anyway, a variety of new technologies have been explored [4-6]. This work is investigated the ethanol distillation with bubble pump technique. This is because of the many advantages of this techniques including smooth continuous flow, simple operation, and low cost of maintenance. The bubble pump is a fluid pump that operates on thermal energy to pump the liquid from the lower level to the upper level. When heat is applied to the pump tube, the ethanol solution turns into two phases, liquid and vapour. Dynamiting the gas creates a pressure that pushes the boiling ethanol to a higher elevation. There are many parameters of the bubble pump which can be optimised its pumping action. These parameters involve: the diameter of the lift tube, the work fluid, the level of pressure, and the heat input. The source of heat energy in the production and distillation of ethanol are many such as fossil fuels and solar radiation. Propane or liquefied petroleum gas (LPG), which can be used as a source of heat, releases fewer toxic and smog-forming air pollutants, is less expensive than gasoline. Nonetheless, solar radiation can be used instead of fossil fuels in the ethanol distillation process. The advantage of using solar ethanol distillation include the production of ethanol concentration in batch operation is significantly higher than that of a normal process.

## 2. Objectives

This research was aimed to study (1) the efficiency of ethanol distillation with bubble pump technique and (2) to calculate the capital cost per unit distilled when solar energy was used compared with LPG consumption. The ethanol was produced from fermentation pineapple. The initial concentration of ethanol in this experiment was 10% by volume.

## 3. Literature reviews

There are many previous research improve the efficiency of solar ethanol distillation [7-12]. For example, Jareanjit and Naemsai [13] reported the performance of solar ethanol distillation using ultrasonic waves. They found that the amount of pure ethanol product from each distilled batch was larger than the amount of product obtained from a normal system when the initial concentration of ethanol was lower than 50 % v/v. Vorayos and Kiatsiriroat [14] studied the performances and economic viability of continuous solar ethanol distillation systems having flat-plate and evacuated heat pipe solar collectors. Jareanjit et al. [15] purposed models for the management of the ethanol waste of a solar ethanol distillation system prototype. Compared to a distillation process without recycling, the amount of cassava broth fed to the system can be reduced by over 180,000 L/year by using scenario 3.

## 4. Materials and methods

Batavia or pineapple Sri Racha (Scientific name: *Ananas comosus*) was used as raw material. The pineapple juice was fermented using yeasts strains of *Saccharomyces cerevisiae* (NCIM No. 3319). The fermentation was to obtain 40-100 L of 8-10 % v/v (% by volume). Fig. 1 was shown the ethanol production process from pineapple juice. From Fig. 1, the process can separate in two major processes including fermentation and distillation. The detail of each process was described in the next section.



Fig. 1 Bioethanol production from pineapple juice.

This research was to study the efficiency of bubble pump distiller when solar energy was used to compare with LPG consumption. The process flow diagrams of the distillation process were shown in Fig. 2 and Fig. 3

### 4.1 Solar ethanol distillation

Fig. 2 was the solar energy distillation. The flat plate solar collector area was 2.2 m<sup>2</sup> with 14 degrees to horizontal angle of inclination. The flow rate through the collector was 0.0035 kg/s and was controlled by a rotameter. The condenser was 0.751 m tall and 0.025 m I.D. The tube heat exchanger with heat exchanger area was 0.059 m<sup>2</sup>. The experiment was performed between 08.00 – 16.00 (8 hours per day), and the

solar radiation was measured using pyranometer (Kipp&Zonen) model CM11B with resolution of  $\pm 2 \text{ W/m}^2$ .

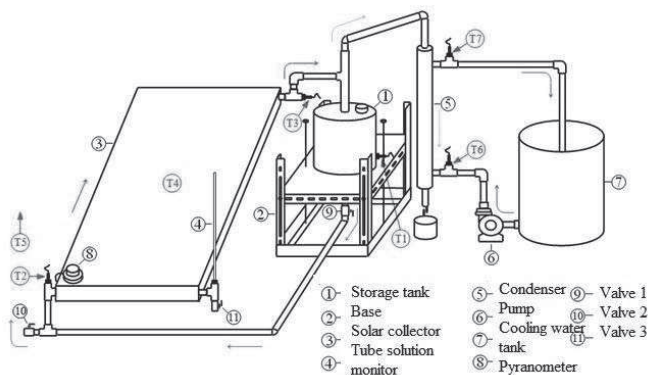


Fig. 2 Schematic diagram of solar ethanol distillation.

#### 4.2 LPG fuel in bubble pump distillation technique

In Fig. 3, the LPG was used as fuel. The process started from the ethanol solution with an initial concentration of ethanol 10 % v/v (by volume) was kept in the storage tank. Then it was flowed into filling tank to keep the constant level of solution (19 cm). The mixture (ethanol-water) to be separated was added to a distilling tank where it was heated to the boiling point. Lower boiling components will vaporize first. The ethanol was a lower boiling point ( $79^\circ\text{C}$ ) or a higher vapor pressure substance while the water was a higher boiling point ( $100^\circ\text{C}$ ) or a lower vapor pressure substance. The resulting vapor passes into a distilling head and then into a condenser. Within the condenser the vapor was cooled and it liquefied. The resulting liquid was then collected in a receiving tank. The distillation process

was repeated until the product solution reaches 20 % v/v (%by volume) concentration. The area of heat transfer surface was  $8.35 \text{ m}^2$ .

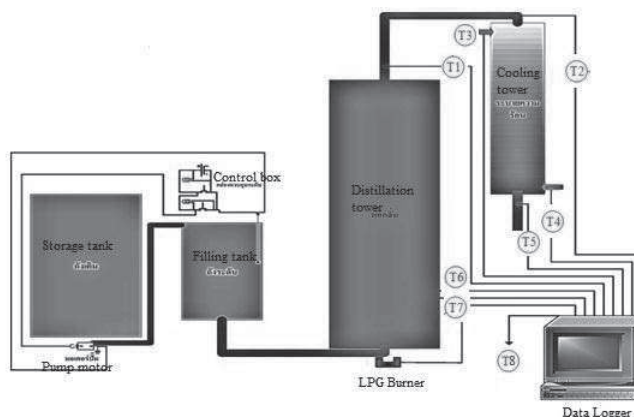


Fig. 3 Schematic diagram of LPG fuel in bubble pump ethanol distillation.

#### 4.3 Temperature measurement and calculation of ethanol distillation efficiency

From the both ways of ethanol distillation, the temperature were measured at various locations using a thermocouple type K with a resolution of  $\pm 0.1^\circ\text{C}$ . The temperature were recorded every 10 min using a data logger (Yokogawa) Model Fx112.

The distillation volume and concentration were measured at every 10 min time intervals. Furthermore, the separation performance of ethanol distiller ( $\eta_{distill}$ ) was determined based on the ethanol quantity of the distillation product ( $m_{product}$ ) and initial quantity of ethanol ( $m_{initial}$ ) in the solution in  $\text{mm}^3$ , which can be calculated from the equation as follow:

$$\eta_{distill} = \frac{m_{product} \times (\% \text{ v/v})_{product}}{m_{initial} \times (\% \text{ v/v})_{initial}} \times 100\% \quad (1)$$

#### 4.4 Appraisal of ethanol distillation cost

Economics analysis. Economic analysis was a procedure for assessing the opportunity of a project by considering the benefits compared to the costs, both elements being considered economically. The economic analysis used the same indicators as financial analysis. For this work, it has in considering such as:

1. Investment cost,  $C_I$
2. Operating and maintenance cost,  $C_{O\&M}$
3. Energy cost,  $C_E$
4. Fermentation cost,  $C_F$

Thus, the equation for examining the annual cost was:

$$\text{Annual cost} = C_I + C_{O\&M} + C_E \quad (2)$$

The capital cost per unit distillation was following:

$$\text{Capital cost} = \frac{\text{Annual cost (THB)} + C_F \text{ (THB)}}{\text{Production (L)}} \quad (3)$$

per unit

## 5. Results and discussions

### 5.1 Ethanol from fermentation

Ethanol fermentation or alcoholic fermentation was a biological process that converted sugars such as glucose, fructose, and sucrose into cellular energy, producing ethanol and carbon dioxide as by-products. Thus, ethanol in pineapple juice was produced by the fermentation of glucose by yeasts. In this work, the ethanol concentration rapidly increased for 2 days fermentation and it was constant at 6 days ago as

seen in Fig. 4. The ethanol solution with an initial concentration of ethanol 10 % v/v was distilled with bubble pump technique. The next topics were shown the performance of bubble pump technique for ethanol distillation when solar energy is used compared with LPG consumption.

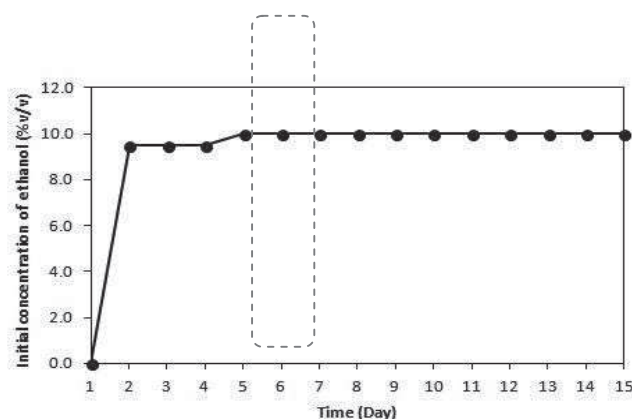


Fig. 4 The increasing of ethanol concentration per day in the fermentation process.

### 5.2 Efficiency of solar energy distillation

This process was operated during November to December 2017 under Thailand climate at Nakorn Prathom Province. The average solar radiation from 09.00 a.m. to 03.00 p.m. and average temperature at all point of system was show in Fig. 5. From Fig. 5, It can be seen that the temperature at each point slowly varies with the solar radiation value from the accumulated heat of the ethanol-water solution, in which the outlet temperature of solar collector (T3), inlet temperature of the solar collector (T2), and solution temperature (T1) were similar at approximately 70-80°C between 12:00-15:00. The temperature of ambient (T5), water inlet (T6),

and outlet (T7) were lower, approximately 30-40°C. The temperature of solar collector (T4) was significantly changed according to solar radiation.

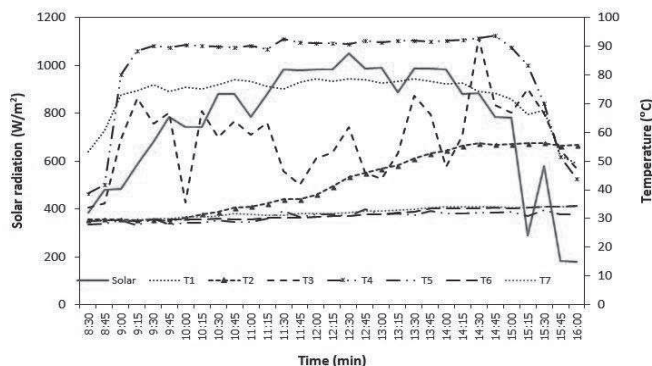


Fig. 5 Average solar radiation changing time in 15 minutes and average temperature at each points of solar ethanol distillation system.

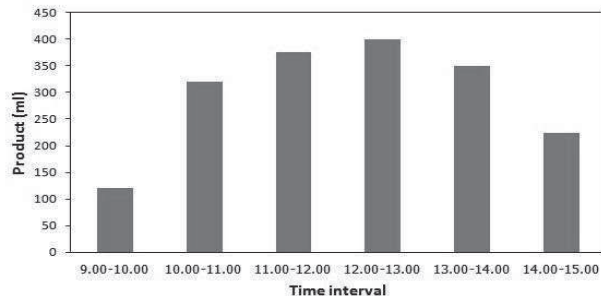


Fig. 6 The average distilled ethanol volume per hours.

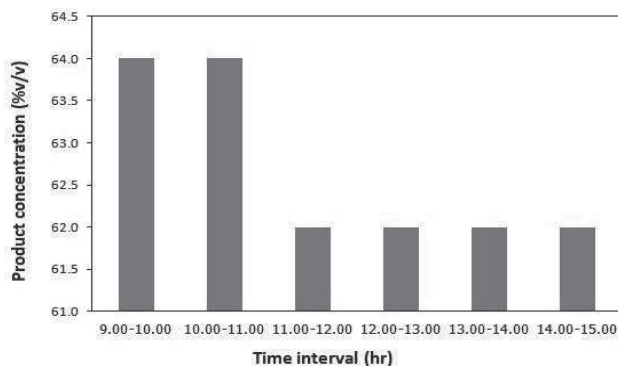


Fig. 7 The average distilled ethanol concentration per hours.

The experiments were repeated three times. The average ethanol volume and average ethanol concentration from distillation process changing time in hours were shown in Fig. 6 and Fig. 7, respectively. Using Fig. 6 and 7, it can be clearly observed that the volume of distillation varied based on the solution temperature in the solar collector (T4). In addition, the product concentration clearly had an inverse relationship with the amount of distillation increased based on the batch system, and the product concentration was proportional to the remaining ethanol volume of the ethanol-water solution in the distillation tank. Finally, it can be concluded that the average solar collection was  $6.48 \text{ kWh/m}^2$ , the collection efficiency was 43% (calculated by Eq. (1)), and the average ethanol concentration was 54.8 % v/v.

### 5.3 Efficiency of bubble pump technique with LPG fuel

The experiments on LPG fuel in ethanol distillation were conducted in three times and to compare in the distillation efficiency; the details of the study were following.

Fig. 8 shown that the temperature at each point slowly varies with time distillation, in which the outlet temperatures of solution of distillation tank (T1), the inlet temperature of solution of condenser (T2) were similar at approximately 70-80°C. The outlet temperature of water of condenser (T3), the inlet temperature of water of condenser (T4), the outlet temperatures of solution of condenser, and the ambient temperature were approximately 25-30°C. Finally,

the inlet temperature of water of distillation tank (T6) and the outlet temperature of water of distillation tank (T7) were approximately 90-100°C. Similar changing features are exhibited by the solar distillation system as well.

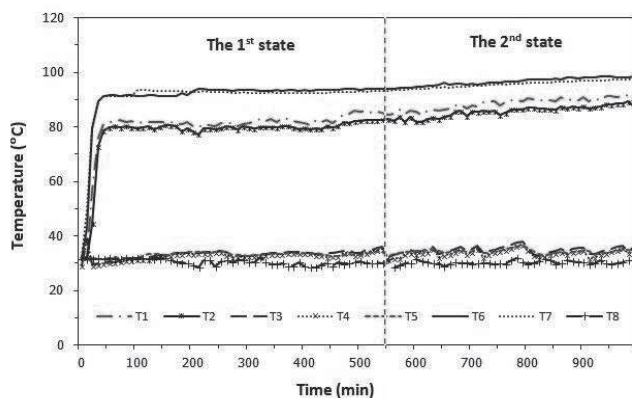


Fig. 8 The average temperature at various location changing in time.

Fig. 9 was shown the volume of distilled ethanol and its concentration at various times, and it can be observed that the distilled volume varies with the temperature of the solution. The concentration of the distilled solution inversely varied with the amount of distillation rate, which appears to be same, that of the solar distillation system. The distilled ethanol in first started at 20 minutes and 12 mL. Then, the distilled volume rapidly increased and kept constant at the second state (from 550 to 990 minutes). The total distilled ethanol volume was 13,890 mL. The heat and mass transport occurred that the ethanol vapor floated in distillation tower has not enough pressure at the first state. After that in second state, the pressure was enough so the process can flow.

Considering distilled ethanol concentration from Fig. 9, distilled ethanol from the process started in 20 minutes, was 59 % v/v. Then, distilled ethanol concentration became to 64 % v/v during 30 to 440 minutes. Last, distilled ethanol concentration rapidly decrease to 59.2 % v/v during 550 to 990 minutes. Furthermore, the use of LPG as fuel in the ethanol distillation caused the average concentration of hourly distilled product to become higher than that of a solar distillation system. However, solar distillation was influencing to hourly concentration, pure ethanol volume and separation performance of ethanol decreased slightly compared to the system that used LPG energy varying with the initial concentration value. The overall efficiency of bubble pump with LPG was 53 %.

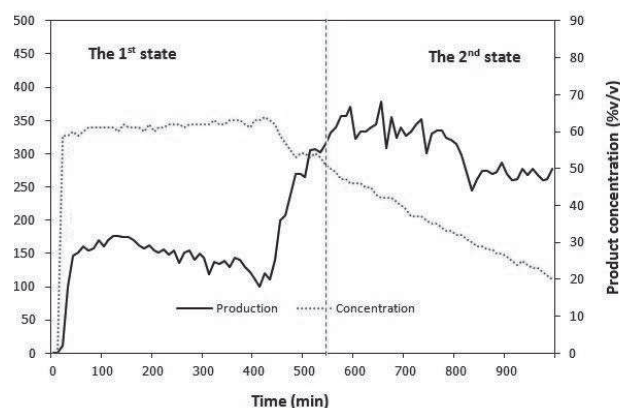


Fig. 9 The average production and concentration of ethanol from the ethanol-water solution.

#### 5.4 Capital cost comparison of ethanol distillation using bubble pump technique

This topic was to compare capital costs associated with the two distillations energy

system. According to Eq. (3), The each parameters were: capital cost was cost of ethanol distillation system; annual cost was sum of investment cost, energy cost, and operating and maintenance cost. By the way, operating and maintenance cost was 10 % of investment cost. The results was presented in Fig. 10. The solar ethanol distillation system cost was approximately 128.82 THB/L while the LPG consumption system was based on 43.68 THB/L, in which LPG cost was 20.29 THB/kg. The investment cost was an important and significant cost for calculating capital cost of two systems.

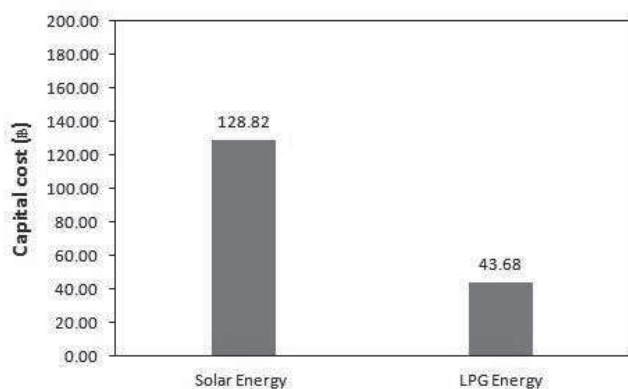


Fig. 10 Comparison of capital cost as a method of ethanol distillation.

## 6. Conclusion

In this paper, it was shown that the efficiency and capital costs per unit distilled in ethanol distillation production both using solar energy and LPG. The cost solar ethanol distillation was higher than using LPG. However, the average concentration of the hourly distilled ethanol product was higher than that of a LPG system at the same or higher distillation rate. The concentration of pure

ethanol product from each distillation system was > 60% v/v when the initial concentration of ethanol of 10 % v/v. Among two technologies, this work provided a data on ethanol distillation process in terms of their economic and energy viability. These technology made the bioethanol process successful at the commercial scale. The data was background information for advantage technology for ethanol distillation in the future.

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