Production of Fuel Ethanol from Oil Palm Wastes

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ABSTRACT

The potential of producing glucose from oil palm lignocellulosic wastes which include oil palm trunks (OPT), fronds, empty fruit bunches (EFB) and palm pressed fibers (PPF) by sulphuric acid hydrolysis was investigated. The glucose obtained was then fermented using the yeast Saccharomyces cerevisiae. From the total amount of oil palm wastes available, as well as the value of glucose yield obtainable and the fermentation efficiency found, the total amount of ethanol that can be produced can be estimated. Thus, the total energy in the form of ethanol obtainable from these oil palm wastes can be calculated. The results of this study showed that the total energy in the form of ethanol obtainable from the oil palm wastes was approximately 1.32 x 10^{17}J. This is about 20% of the total energy requirements of the transportation sector in Malaysia in the year 2000. This percentage can be further increased if the xylose fractions from these wastes are also utilized to produce ethanol.

1. INTRODUCTION

Lim [1] forecasts that Malaysia's fossil fuel reserves and projected hydropower supply can sustain the nation's energy needs for another 35 years or so (no net export of the country's fossil fuel reserves is assumed). Thus, renewable energy should now be seriously considered. Among the various renewable energy sources, biomass appears to be the most promising, not only because of the abundance of lignocellulosic biomass in the country but also because its use is reasonably environment friendly.

Currently, Malaysia consumes about 290 million boe of commercial energy every year, which does not include biomass. If the biomass is included, the total energy consumption for the country is some 340 boe per year. This means that about 14% of the country's energy consumption comes from biomass. The biomass used for energy purposes is only equivalent to approximately one quarter of the total amount of biowastes generated in this country, meaning about three quarters of biowastes are still not utilized. These biowastes are either left to rot or burnt as a means of disposal. If these biomass resources are also harnessed to produce energy, they can together contribute about 59% of the country's total energy requirement [2]. Thus, Malaysia should give greater attention and priority to bioenergy utilization.

According to Lim [3], the transportation sector uses about 37.5% of the total commercial energy consumption in Malaysia in the year 1995. Considering the great need for transportation fuel and the positive attributes of ethanol, its production from biomass should be given greater attention. If sulphuric acid hydrolysis is used for the ethanol production process, the solid by-products are gypsum, lignin and some cellulose that are not hydrolyzed. The latter two can be combusted for energy purposes while gypsum can be used in products such as gypsum boards. If the liquid portion containing mainly xylose is also fermented to ethanol, the discharge from the production process can be minimized.

Biowastes from agriculture as well as logging and timber processing activities have good potential for ethanol production because they are rich in lignocellulose. Tomimura, et al. [4] reported that, among the various Malaysian woods studied, which includes oil palm trunks (*Elaeis guineensis*), rubber wood (*Hevea brasiliensis*), acacia (*Acacia mangium*), batai (*Paraserianthes falcataria*) and yemane (*Gmelina arborea*), oil palm trunk was found to be the most suitable lignocellulosic raw material for glucose, and thus ethanol production. Oil palm trunks have a low lignin but a high cellulose content. Thus, oil palm trunks should be seriously considered as the raw material for bioethanol production in Malaysia.

Other than oil palm trunks (OPT), the oil palm industry also produces other wastes in large quantities. Fronds, empty fruit bunches (EFB) and palm pressed fibers (PPF) are also important lignocellulosic oil palm wastes. Lim [5] estimated that the dry matter yields of EFB and PPF are respectively, 1483 kg and 1853 kg per 10 000 m^2 per year. While, Mohamad Husin, et al. [6] reported that roughly 11 000 kg of dry fronds are annually pruned from 10 000 m^2 of land. According to the Ministry of Finance Economic Report [7] and the Department of Statistics' Report [8], the planted acreage for oil palms in Malaysia is 25 670 km^2. Hence the biowastes from pruned fronds, EFB and PPF amount to about 28.24 billion kg, 3.81 billion kg and 4.76 billion kg, respectively. The estimated area due for replanting in the year 2000 is 945.51 km^2 [9] and the average amount of biomass available from oil palm replanting was estimated to be 66 000 kg of trunks and 14 400 kg of dry fronds per 10,000 m^2 [5]. Thus, the amount of OPT and fronds from replanting activities are 6.24 billion kg and 1.36 billion kg, respectively for the year 2000. Consequently, the total lignocellulosic biowastes generated by the oil palm industry in the year 2000 is estimated to be approximately 44.41 billion kg dry matter.

This project was initiated to study the potential of producing ethanol from oil palm lignocellulosic wastes to supplement the energy requirement of the transportation sector in Malaysia, in the year 2000.

2. METHODS

One whole and freshly cut oil palm trunk (OPT) of about 25 years old, and one oil palm frond were procured from an oil palm estate in Simpang Ampat, Seberang Perai Selatan, for the study. The OPT was about 11.9 m in height, with diameters of about 0.69 m, 0.42 m and 0.38 m at the butt, middle and the top sections, respectively. EFB and PPF were obtained from M.P.Mathew Palm Oil Mill Sdn. Bhd., Seberang Perai Selatan.

The OPT was sectioned into lengths of about 0.6 m each. Samples were taken from various parts of each section of the trunk, cut into smaller pieces, oven dried, ground to about 0.2 mm in size and thoroughly mixed.

EFB was taken immediately after the steaming process. The spikelets were separated from the EFB stalk. Both stalks and spikelets were then cut into smaller pieces. One fresh oil palm frond was used. The leaflets were separated from the petiole and both were cut into smaller pieces. PPF was cleaned of broken nut shells and other impurities as much as possible. The above oil palm wastes were oven-dried and separately ground to about 0.2 mm in size.

Separately, small quantities (0.5 g to 2.0 g) of the samples were pretreated with sulphuric acid 75% (v/v) at 50°C for 1 hour. Distilled water was then added to the pretreated materials to the required concentration of dilute acid (varying from 1% to 6.0%). For each acid concentration, the sample was refluxed for 4 hours under atmospheric pressure in the dilute solution of boiling sulphuric acid.

After hydrolysis, the sample was allowed to cool, filtered, neutralized with a solution of 2.5M sodium hydroxide and the amount of glucose present in the neutralized solution was then determined enzymatically (glucose enzymatique PAP 1200, Bio Merieux, France). A spectrophotometer (Shimadzu UV-1201) calibrated at 505 nm was used. In this study, glucose yield was expressed as weight of glucose produced over original oven-dried weight of sample used.

3. RESULTS AND DISCUSSION

The mixed samples from various sections of OPT succeeded in producing glucose with a yield of about 28.5% to 32%, based on oven-dried weight. These results were reported in a separate paper [10]. In that study, *Saccharomyces cerevisiae* yeast was successfully used in converting glucose produced from the OPT hydrolysate to ethanol. From the various pH values studied, the highest fermentation efficiency of 94.7% was obtained at a pH value of 4.75. At those conditions, ethanol yield of about 14% based on the dried weight of OPT was found.

The results of the two-stage acid hydrolysis at atmospheric pressure that was done on other oil palm wastes, such as stalk of EFB, spikelets of EFB, oil palm petioles, leaflets and PPF to produce glucose are discussed in the following sections. Every data point shown in Fig. 1 represents the average value for at least 5 similar experimental runs.

3.1 Effect of Acid Concentration on Glucose Yield from EFB Stalk

Figure 1 shows the pattern of glucose yield obtained from hydrolyzing EFB stalk at different acid concentrations. The glucose yield increased when the acid concentration increased, until an acid concentration of about 1.7% is reached. The glucose yield at this point is approximately 24.2%. After this acid concentration, the glucose yield decreased precipitously to about 22.2% when the acid concentration reached 2.0%. From 2.0% to 6% of acid concentration, glucose yield appeared to decrease more gradually.

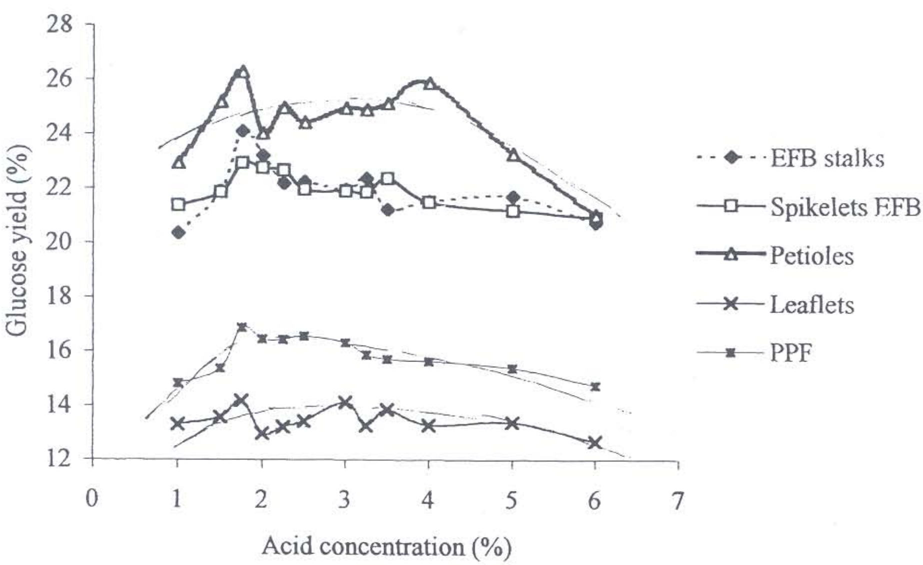

Fig. 1. Glucose yield as a function of hydrolyzing acid concentration for various types of oil palm wastes.

3.2 Effect of Acid Concentration on Glucose Yield from EFB Spikelets

The results of hydrolyzing EFB spikelets at different acid concentrations as shown in Fig. 1 are very similar to those obtained for EFB stalks. A maximum glucose yield of about 23% was obtained at an acid concentration of about 1.7%. This yield value is slightly smaller than the maximum glucose yield obtained when EFB stalks were hydrolyzed. A smaller peak in yield of about 22.3% was also obtained at an acid concentration of about 3.5%. This yield value is slightly lower compared to the value at the acid concentration of around 1.7%.

3.3 Effect of Acid Concentration on Glucose Yield from Oil Palm Petioles

The effects of acid concentration on hydrolyzing oil palm petioles are shown in Fig. 1. The result shows that although the glucose yield was low at both ends of the graph, the yield appears to be less sensitive to the changes of acid concentrations of 2% to 4%. Even so, a maximum glucose yield of about 26.5% was also observed at an acid concentration of about 1.7%. Another peak that gave glucose yield of about 26% was also observed at an acid concentration of about 4%. This result shows that in certain conditions where a higher concentration of glucose is preferred, such as to reduce the distillation cost, hydrolyzing the oil palm petioles at an acid concentration of 4% may be more desirable.

3.4 Effect of Acid Concentration on Glucose Yield from Oil Palm Leaflets

Also shown in Fig. 1 is the effect of acid concentration on glucose yield from oil palm leaflets. The graph shows that the changes in glucose yield are quite unstable over the range of acid concentrations studied. However at an acid concentration of about 1.7%, a peak in yield of approximately 14.2% was again observed. Similar to the other graphs discussed, the glucose yield appears to be also slightly lower at both low and high acid concentrations.

3.5 Effect of Acid Concentration on Glucose Yield from PPF

The glucose yields obtained after hydrolysis of PPF at different acid concentrations are also shown in Fig. 1. Again at both low and high acid concentrations, the glucose yield was low. Similar to the other oil palm biowastes studied, the maximum glucose yield of about 17.0% was again observed at an acid concentration of about 1.7%. The decrease in yield as acid concentration increased was however gradual after this peak.

Although the results of Fig. 1 do seem to indicate that glucose yields tend to be somewhat higher at an acid concentration of 1.7% for all the oil palm wastes studied, it must however be admitted that reasonable yields can be obtained when the hydrolyzing acid concentration varies from about 1.5% to 5%.

3.6 Meeting Malaysia's Transportation Fuel Requirements with Ethanol from Oil Palm Wastes

From the information on the quantity of the various oil palm wastes available and the results of experiments on glucose yield obtainable from these wastes after sulphuric acid hydrolysis, as well as the efficiency of our fermentation process, the total amount of ethanol that can potentially be produced from each class of wastes can be estimated. Using the known net calorific value of 27 GJ per 1000 kg for ethanol, the total energy potentially obtainable from the ethanol from oil palm wastes can then be calculated.

According to Lim, et al. [2], Malaysia currently consumes about 290 million boe of commercially traded energy annually. As one boe equals 6.17 x 10^9 J, the country's commercially traded energy requirement is some 1.789 x 10^{18} J per year. Lim [3] also reported that the transportation sector uses about 37.5% of the total country's energy requirements. As a result, from the above data, the energy required for the transportation sector is about 6.709 x 10^{17} J per year.

Table 1 summarizes the results of experiments and it was found that the total energy obtainable from the cellulose content of oil palm wastes was estimated as 1.32X10^{17} J. This value is about 20% of the total country's energy requirement in the transportation sector. This figure can be further increased if the pentosan hemicellulose content can be also converted to ethanol. However it must be mentioned that the yeast *Saccharomyces cerevisiae* cannot ferment the xylose because it lacks both a xylose-assimilation pathway and adequate levels of key pentose phosphate pathway enzymes. Even

Table 1 Forecast of Ethanol Yield from Selected Oil Palm Lignocellulose Wastes in Malaysia in 2000

Oil palm waste	OPT	Fronds from replanting activity	Prunned fronds	EFB	PPF	Total
Quantity of waste (1x10^6 tons dried weight)[a]	6.24	1.36	28.24	3.81	4.76	44.41
% glucose[b]	28.5	22.4[c]	22.4[c]	23.6[d]	17.0	
% ethanol[e]	13.77	10.82	10.82	11.40	8.21	
Total ethanol produced (1x10^6 tons)	0.86	0.15	3.06	0.43	0.39	4.89
Total energy Produced (1x10^{16} J)	2.32	0.41	8.26	1.16	1.05	13.20

Notes:

a Total quantity of oil palm wastes was estimated from the Ministry of Finance's Economic Report [7], the Department of Statistic's Report [8], Lim [5, 9], and Mohamad, et al. [6].

b Glucose percentage was calculated based on sample dried weight and was obtained from experimental data.

c Glucose percentage for fronds was calculated by assuming that 2/3 of the weight of oil palm frond consists of petioles and another 1/3 consists of leaflets, as reported in Abu Hassan and Azizan [12]. The percentage of glucose yield for petioles and leaflets were obtained from experimental data.

d Glucose percentage for EFB was calculated by assuming that EFB consists of EFB stalks and spikelets in the same ratio based on dried weight.

e Ethanol percentage was calculated by assuming that fermentation efficiency is 94.72% and from theory, about 51% of the glucose weight can be converted into ethanol through fermentation in an ideal situation. Thus, % ethanol = % glucose x 0.51 x 0.9472.

so depending on the micro-organism and the fermentation condition, three types of xylose fermentation processes with varying ethanol yields of 30% to 50% of initial xylose weight have been reported as follows:

(3)XILOSE - fermentation - (5)ETHANOL + (5)CARBON DIOXIDE
(3)XILOSE - fermentation - (4)ETHANOL + (7)CARBON DIOXIDE
(1)XILOSE - fermentation - (2)ETHANOL + (1)CARBON DIOXIDE + (1)WATER

Stephen and Zhang [11] reported that in general, the xylose-fermenting yeasts have been shown to produce ethanol at 78% to 94% of theoretical yield and at concentrations of up to 5% (w/v), but at relatively low productivities (0.3-0.9 $gL^{-1}h^{-1}$), especially in the absence of oxygen (0.1-0.2 $gL^{-1}h^{-1}$). Through an approach called simultaneous fermentation and isomerizaton of xylose (SFIX), ethanol production from xylose that yielded 85% of theoretical value was also reported [11]. The above reports indicate that xylose can be converted to ethanol but since the information on the xylose content of hemicellulose in the oil palm wastes is not available, this makes the forecast on potential ethanol yield from xylose conversion rather difficult. Thus it has been excluded in our study.

4. CONCLUSION

The potential of producing ethanol from the major lignocellulosic wastes of the oil palm industry has been investigated. It was found that when only the glucose fraction from the current amount of wastes generated was considered for conversion to ethanol, the liquid fuel so produced is capable of meeting about 20% of the total energy requirements of the nation's transportation sector. This figure however can be increased further if the xylose component is also converted to ethanol.

5. ACKNOWLEDGEMENT

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