

Production of cellulosic ethanol from wood sawdust

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Abstract: Energy from fossil fuels has played a very important role in our lives, but such an important role has been clouded out due to the environment hazards caused from fossil emissions. This has led to a new dimension in energy utilization known as renewable energy fuels. To fully support this type of energy from biological mass, adequate biomass source must be harnessed. This work thus was carried out to utilize a local available biomass waste as an alternative source of ethanol which is currently used for spark ignition engines as a renewable energy fuel. It also determined the yield of ethanol from the sawdust used. The sawdust sample was collected from the Nsukka Sawmill (Timbershade). Materials used included 18 m (78% concentration) of sulphuric acid, 6 m of sodium hydroxide for hydrolysis, and fermentation process. The hydrolysis involves the extraction of fermentable sugar from a cellulosic biomass. The sawdust of sulfuric acid mixture was allowed to sit for 48 hours, then the distilled water was used to dilute in order to bring its pH between 5.0 - 6.0. 10 kg of sawdust gave 500 cm³ of ethanol using Beer-Lambert plot of ethanol water mixture. The success of the extraction of ethanol shows there are possibilities for improvement.

Keywords: Biofuel, climate change, ethanol yield, fermentation, wood sawdust

Citation: Nwakaire J. N., S. L. Ezeoha, and B. O. Ugwuishiwu. 2013. Production of cellulosic ethanol from wood sawdust. Agric Eng Int: CIGR Journal, 15(3): 136–140.

1 Introduction

Energy, particularly one from fossil fuels, has played very important roles in our lives. Consider the case of a baby Michael born in August 2003, a gasoline powered automobile rushed her mother to the maternity ward, a coal fired power plant lit the hospital in which he was born and a central heating system burning natural gas warms the room in which he took his first breath. Had any of these sources of energy failed, little Michael's life would have been lost. This simple illustration underscores the essential role of energy to our lives.

However in recent times, there has been renewed interest in the search and development of alternative energy sources. This can be seen from the investment of huge sum of money by various government and agencies around the world. For instance, the Nigerian

government recently established more energy research centers to work in this area of research with a view of finding a way forward in renewable energy development and utilization. This growing concern for alternative energy can be attributed to the need to reduce the dependence on foreign sources of energy. The global oil market is run by a few cabals from oil producing nation. The cabal influences the supply of this important commodity. So to avoid this problem associated with this unreliable supply as shown by the events of 1973 and 1979 oil crisis and the gulf war of early 1990's, most countries are now developing alternative source to avert such a problem. Alternative energy development helps diversify agricultural activities, thus in a quiet way supports agricultural mechanization. It provides the platform to create more jobs, thus empowering the poor.

Most importantly, the greatest reason for research and development of alternative energy is the environmental consequences emanating from the exploitation of fossil fuel. The goal is to achieve zero net carbon (IV) oxide balance and improvement in urban air quality (A sweet

Received date: 2010-04-19 **Accepted date:** 2013-07-14

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solution, 2006). Hence, to reduce the several impacts of fossil energy, renewable sources of energy have been proposed as alternatives. These are sustainable in that they do not pose serious threat to the environment when properly managed. Also they can be replaced rapidly by natural on-going processes.

Bio-ethanol is ethanol derived from the process of fermentation of biological materials. This is accomplished by the action of micro organism like yeast. Since the micro organism utilizes only simple sugars, starchy and cellulosic materials are first converted into simple sugars by a process of hydrolysis before they are subjected to fermentation. According to Rob (2008), the worldwide production of cellulosic ethanol will amount to at least 16.5 billion gallons in 2020, if the target set in the United States, China, Europe, Japan and Brazil are achieved. Based on currently proposed and signed legislation, the United States would account for over 63.9% of that market, while the EU and China would account for 10.4% and 11.5% respectively. Although Brazil does not have any official legislation on cellulosic ethanol, it is included based on its market penetration, which amount to around 2.1 billion gallons (12.9%) in 2020. Japan would account for only 1.3% based on currently proposed legislation. It is important to note that all the countries mentioned have mechanized their agricultural productions in order to balance the raw material demand with the demand from their populace. United States significantly is using corn and wheat, while Brazil is using sugarcane as its main biomass source. Ethanol has several uses in transport. It can be blended with gasoline as an octane enhancer (10%-15%); used as a gasoline substitute in a modified internal combustion engine; used as a blend in flexible-fuel vehicles (up to 85%); mixed with diesel using a stabilizing additive (e-diesel); and used as fuel for diesel buses with an ignition improver (BRAC, 2006). Ethanol has lower energy content than gasoline (70%).

Nigeria is not fully producing bio-ethanol due to the problem of appropriate sourcing of raw material for bio-ethanol. During the tenure of former president Obasanjo, Nigeria started the importation of cellulosic ethanol from Brazil. Thereafter there was a call to mass

produce cassava as a raw material for cellulosic ethanol production. The argument was that Nigeria has not properly produced enough cassava for its populace. It seems as if the push has died down. This paper thus, is focused at establishing the fact that sawdust can be used as a veritable resource for bio-ethanol production. The specific objectives of the work are to produce bio-ethanol from wood sawdust, and to determine the yield of the bio-ethanol from wood sawdust.

1.1 Sources ethanol production

Ethanol can be produced from any biological feedstock that contains appreciable amounts of sugar or materials that can be converted into sugar such as starch and cellulose. In the US, ethanol is principally produced from starch crops (corn); in the EU from starch (barley and wheat) and sugar (beet) crops; and in China from starch (corn and wheat) and to a lesser degree sugar (sugar cane) crops (IEA, 2004). Ethanol is generally produced from the fermentation of sugars. First generation processes typically rely on yeasts that convert six-carbon sugars (mainly glucose) to ethanol (and carbon dioxide). Starch is easily converted to sugar by acid or enzyme hydrolysis. The organisms and enzymes required for starch conversion of starch and glucose fermentation on a commercial scale are readily available. The conversion of cellulose to sugar is more complicated due to the presence of lignin and because cellulose is usually converted into both five and six carbon sugars (pentose and hexose, respectively) which require more sophisticated organisms for fermentation. There is virtually no commercial production of ethanol from cellulose, however, there is substantial research in the area and it is considered to be the next generation of technology for the production of ethanol ("second generation technology") (IEA, 2004). There are four main sources of cellulose resources ("feedstock"): wood residues from the wood industry, including paper mills, saw mills and furniture manufacturing; agricultural residues including straw, corn stover, bagasse and husks; dedicated energy crops including woody and herbaceous crops, primarily tall grasses; and municipal solid waste, including paper and other cellulosic materials. Table 1 shows various ethanol yields from different feedstock.

Table 1 Ethanol yield from different feedstock

Feedstock	Theoretical ethanol yield (gal per dry ton of feedstock)
Corn grain	124.4
Corn stover	113.0
Rice straw	109.9
Cotton gin trash	56.8
Forest thinnings	81.5
Hardwood sawdust	100.8
Bagasse	111.5
Mixed paper	116.2
Switchgrass	96.7

Source: U.S. Department of Energy Biomass Program (2013).

1.2 Summary of the process technology

The conversion of cellulose to ethanol requires: pre-treatment (or delignification) to liberate cellulose and hemicelluloses from their complex with lignin; hydrolysis of the carbohydrate polymers to produce free sugars; and fermentation of free sugars (hexose and pentose) to produce ethanol (Lin and Tanaka, 2006). There are a number of pre-treatment methods available which broadly fit into two categories: physical (e.g. high pressure steam explosion or liquid hot water treatment) and chemical (e.g. dilute acid, lime or ammonia treatment) pre-treatment (Mosier et al, 2005). Pretreatment has been viewed as one of the most expensive processing steps in the production of cellulose to ethanol. However, pretreatment also has great potential for improvement of efficiency and lowering of cost through research and development. Cellulose and hemicellulose can be hydrolytically broken down into free sugars either enzymatically (cellulase and hemicellulase) or chemically (sulphuric or other acids). Hydrolysis of cellulose and hemicellulose produces both pentose (e.g. xylose and arabinose) and hexose (e.g. glucose, galactose and mannose) sugars. Acid hydrolysis is expensive and the process appears to have limited potential to be improved. Considerable research is being invested in improving the efficiency and reducing the cost of enzymatic hydrolysis (IEA, 2004). Hexose is readily fermented to ethanol by many naturally occurring organisms but pentose is fermented to ethanol by only a few native strains and usually at relatively low yields. Xylose and arabinose generally comprise a significant portion of hardwoods, agricultural residues and grasses, and must be utilized to

make the economics of biomass processing feasible (Lydn et al, 1999). Genetic modification of bacteria and transformation of yeast with bacterial genes has produced strains capable of co-fermenting both pentose and hexose to ethanol and other value-added products at high yields. In the long term, it is expected that ethanol will be only one of a variety of value-added products that may be extracted from cellulosic biomass ('bio-refinery') (Mabee et al, 2004). In addition to ethanol, forty chemicals and feedstock have been identified as potential products from cellulosic biomass.

2 Materials and methods

The materials used in the experiment to produce bio-ethanol were from Food and Bioprocess laboratory, in the Department of Agricultural and Bioresources engineering, University of Nigeria, Nsukka. The materials were 30 kg of wood sawdust collected from the Nsukka Sawmill which were divided into 10 kg each, 18 moles (78% concentration) of Tetra-oxo-sulphate (6) acid, 6 M of sodium hydroxide, packages of commercial yeast (EBY 100 strain), distilled water, test tubes, 600 mL beakers, measuring cylinders, glass bioreactor, and electronic balance. 18 M of 100 cm³ of sulphuric acid was used to hydrolyze 10 kg of wood sawdust, after pretreatment to remove impurities, and was allowed to sit for 48 h. After hydrolysis, the pH was reduced to a proper level of within 5.0-6.0 using distilled water. Then the products from the pH normalization were inoculated with yeast for fermentation to proceed. The mixture was allowed to stand for 72 h, after which the products were separated with fractional distillation. The GC-FID analytical procedure for measuring ethanol content in fuel ethanol found in ASTM D5501 was used to determine the purity of the ethanol produced.

The experiment was replicated three times so that average product yield would be used. The quantity of ethanol derived was determined using the calibration curve method on Beer's law similar to that used in quantitative analysis of metals (Olaniyi, 2000). Using the 100 mL anhydrous ethanol, several dilutions of ethanol with water in 0%, 25%, 50%, 75%, and 100% in test tubes were made. The mass and volume of each solution was measured using the electronic balance and

measuring cylinder as shown in Table 2. This data was used to calculate the densities of each solution also shown in Table 2. This was used to produce a standard

calibration graph or Beer’s plot of density against percentage volume of ethanol in solution and this is shown in Figure 1.

Table 2 Ethanol dilution table

Percentage volume of anhydrous ethanol/%	Volume ethanol-water	Mass of ethanol-water mixture/g				Density of ethanol-water mixture/g mL ⁻¹
		1 st reading	2 nd reading	Mean	Standard deviation (SD)	
0	10	11.0	10.0	10.05	0.707	1.05
25	10	10.0	9.0	9.50	0.707	0.95
50	10	9.0	9.0	9.00	0	0.90
75	10	8.0	8.0	8.00	0	0.80
100	10	7.0	7.0	7.00	0	0.70

Volume/mL	Mass/g			Density/g mL ⁻¹
	1 st reading	2 nd reading	Mean	
10	10.43	10.35	10.39	1.039

Source: Obileku (2007).

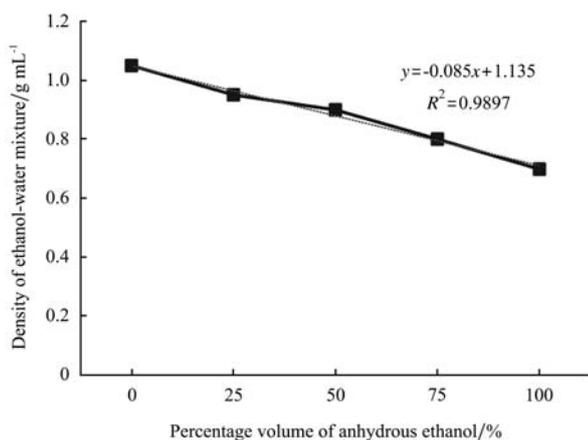


Figure 1 Beer-Lambert plot of ethanol-water mixture

3 Results and discussion

The results of different mass densities of ethanol-water mixture and the substrate or fermentation product are shown in Table 2. The result shows that at 0%, 25%, 50%, 75%, and 100% volume of anhydrous ethanol, with 10 mL of ethanol water mixture, the corresponding mean mass of ethanol-water mixture and density of ethanol-water mixture were 10.5 g, 9.5 g, 9.0 g, 8.0 g, 7.0 g, and 1.0 g mL⁻¹, 0.95 g mL⁻¹, 0.90 g mL⁻¹, 0.80 g mL⁻¹, 0.70g mL⁻¹ respectively. The filtrate yield was 500 mL; 10 mL was used for the determination of the percentage volume of ethanol in the filtrate. The mean mass reading was 10.30 g with an approximate density of 1.030 g mL⁻¹ as shown in Table 2.

From the plot, the equation of the regression line is $Y = -0.035X + 1.135$, where Y is density in g mL⁻¹, X is the percentage volume of ethanol in the filtrate. Hence, if the filtrate is 1.030 g mL⁻¹, then:

$$1.030 = -0.035X + 1.135$$

$$0.035X = 1.135 - 1.030$$

$$0.035X = 0.105$$

$$X = \frac{0.105}{0.035}$$

$$X = 3.0\%$$

Expressing the concentration of the filtrate in mg mL⁻¹, 1.030 g mL⁻¹ is equivalent to 1,030 mg mL⁻¹. 3% of 1,030 mg mL⁻¹ is equivalent to 30.9 mg mL⁻¹, which implies that the concentration of ethanol in the filtrate was 30.9 mg mL⁻¹. The purity of the ethanol was determined to be 92% which is 28.43 mg mL⁻¹.

From Table 2, the density of the filtrate shows a marked difference from the densities of ethanol-water solution at the different concentrations or dilutions. Moreover, it was observed that increase in the density of the filtrate results in decrease in percentage volume of ethanol contained in the filtrate. This is due to the fact that an increase in density of the filtrate above 0.7 g mL⁻¹ implies an increase in the quantity of water and impurities. Therefore from the Beer-Lambert plot of ethanol-water mixture, the estimated yield of ethanol in the filtrate in percentage volume is approximately 3.0% or 30.9 mg mL⁻¹,

with purity of 28.43 mg mL⁻¹. The estimated yield is higher when compared with others in literature. This is due to differences in wood type used at the Sawmill. Shide et al (2004) in their work reported 6.6 mg mL⁻¹ from pretreated wood sawdust and Toshiyaki (2007) reported an estimated yield of 1.9% maximum ethanol concentration from waste paper and an approximately 22% conversion from yellow pine wood sawdust.

4 Conclusion

It can be concluded that the production of ethanol from wood sawdust is possible locally in Nigeria, without depending on the edible ethanol sources. Furthermore, ethanol yield from wood sawdust was estimated to be 30.9 mg mL⁻¹ with 28.43 mg mL⁻¹ purity from 10 kg of

Sawdust. Even though it cannot yet replace saccharine and starchy materials, their consideration as possible substitute for grain based ethanol, stems from the fact that they reduce green gas emission substantially thereby changing the emission calculation. According to “Well to Wheel” model created by Michael Wang of Argonne National Laboratories, cellulosic ethanol showed green gas emission reduction of about 80% (over gasoline), Corn ethanol showed 20%-30% reduction. Moreover, cellulosic feedstocks derived from agricultural waste are abundant and have more potential energy than simple sugars and starch. Besides their collection and utilization, they can provide additional source of income to the farmers from existing acreage.

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