ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF TECHNOLOGY
CHEMICAL ENGINEERING DEPARTMENT
(ENVIRONMENTAL ENGINEERING PROGRAM)

CONVERSION OF SELECTED ADDIS ABABA MUNICIPAL SOLID WASTE TO ETHANOL

(Case study of Yeka sub city)

Thesis submitted to the school of Graduate Studies of Addis Ababa University in partial fulfillment of the Masters Degree in Environmental Engineering

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Advisor: Prof. W. Sokol

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Declaration

I declare that the thesis for the M.Sc. degree at the University of Addis Ababa, hereby submitted by me titled “conversion of selected Addis Ababa municipal solid waste to ethanol”, is my original work and has not previously been submitted for a degree at this or any other university, and that all reference materials contained therein have been duly acknowledged.

Ashenafi Taye

Signature ----------

Date ----------

I LIST OF ACRONYMS

SBPDA	Sanitation, Beautification and Park Development Agency
MTBE	Methyl t-butyl Ether
DWM	Dry Waste Management
GHG	Green House Gases
OAU	Organization of African Unity
ECA	Economic commission for Africa
UNDP	United Nations Development Program
UNICEF	United Nation's International Children Effort Fund
UNHCR	United Nations Higher commissioner for Refugees
FAO	Food and Agriculture Organization of the united nations
ICO	Interagency Committee on Oceanography
ITU	International telecommunication Union
MSE	Micro and Small Enterprise
NUPI	National Urban Planning Institute
NGO	Non-Governmental Organization
UNEP	United Nations Environment Programme
US	United States
AD	Anaerobic Digestion
EU	European Union
LFG	Land Fill Gas
ABE	Acetone-Butanol-Ethanol
FT	Fischer-Tropsch
CTL	Coal-To-Liquid
ETBE	Ethyl t-butyl Ether
IEA	International Energy Agency
OECD	Organization for Economic Cooperation and Development
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand

PCU	Primary Control Unit
CHP	Combined Heat and Power
BIG	Biomass-Integrated-Gasification
CC	Combined-Cycle
OPEC	Organization of Petroleum Exporting Countries

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ABSTRACT

Selected municipal solid wastes (mango and banana peels and remains) were collected, proportioned, dried, and crushed to be used as samples of this research. Principally, three experiments were carried out in series for each of the samples (one after the other), namely: hydrolysis, fermentation and distillation. The effects of factors in hydrolysis step were investigated and the global optimum combination of factor values (temperature, time and acid concentration) was set by experimentation. Factorial design of three-factors-at-two-level ($2^3 = 8$) was applied to the hydrolysis step to purely investigate the effects of hydrolysis parameters on the response variable (ethanol yield). In the analysis section, the principles of factorial design were applied to calculate the main effects, interaction effects and response tendencies. Main effects were found to be -0.125, 0.375 and 0.875 for acid concentration, time and temperature respectively. This implied that, increasing temperature level could result in relatively the highest ethanol yield than the remaining factors. Interaction effects between factors were also calculated. Accordingly, TxC and txC are -10.75 and -5.75 respectively. From this theoretical ground, the factor combination was set at 1%v/v, 60minutes and 150^{o}C and the samples were tested at this determined point and, above and below it (three extra experiments). The highest ethanol yield was 25.5mL/50g (solution) or 24.48mL/50g pure ethanol and 26mL/50g (solution) and 24.44mL/50g pure ethanol for the first 8 and the last 3 experiments respectively. The global optimum factor combination was set at 100^{o}C, 1%v and 60minutes for hydrolysis temperature, acid concentration and hydrolysis time respectively after analysis. It was also estimated that conversion of banana and mango peels and remains to ethanol could eliminate 16.2% of the municipal solid waste in the sub city.

1 INTRODUCTION

A treatment of municipal solid waste goes far back into 18th century when burying the waste was the best option of treatment. In course of time, the scarcity of resources and the soaring pollution level necessitated the need for alternative treatment options. Now a days, there are many treatment options for municipal solid waste among which composting, incineration, land filling and production of different biofuels are some. The choice among these options must be based on different technical and economical criteria of the situation in question. In most developing African countries, municipal solid wastes are disposed of in non-engineered land fills which have always been known to generate green house gases. In developed nations, conversely, municipal solid wastes are treated through such advanced methods as controlled incineration and production of biofuels because of both increasing need of using the so called “waste” as resource and stringent environmental regulations.

Recently, people have become worried about whether fossil fuel is a reliable global energy source. The curtailment in supply of petroleum is becoming the reality of the day. Thinking that municipal solid wastes were considered as solutionless waste is falsified by its being used as a source for ethanol, a gasoline blend or substitute. This situation attracted the attention of many scientists to investigate the possibility of extraction of different biofuels from municipal solid waste. The use of ethanol as a fuel for internal combustion engines, either alone or in combination with other fuels, has been given much attention mostly because of its possible environmental and long-term economical advantages over fossil fuel. Ethanol fuel is an alternative to gasoline. It can be combined with gasoline in any concentration up to pure ethanol (E100).

Ethanol is increasingly used as an oxygenate additive for standard gasoline, as replacement for methyl t-butyl ether (MTBE), the latter chemical being responsible for considerable groundwater and soil contamination. Ethanol can also be used to power fuel cells and to produce biodiesel.

The purpose of this study was to convert a selected municipal solid waste of Addis Ababa-*that is fruit peels and remains*-in to fuel ethanol.

1.1 Background

Like in many developing cities, a rapid population growth and high rural-urban migration poses many environmental challenges for the Addis Ababa city. One of these is a dry waste management. Inadequate dry waste management has resulted in the accumulation of waste on open lands, in drains and in the living area of many people, causing a nuisance and foul-smelling pools, environmental pollution through leaches from piles (water and soil pollution) and burning of waste (air pollution), clogging of drains, and the possible spread of diseases. Unattended piles of waste are a breeding place for insects and rats. This situation is believed to result in poor environmental conditions and an ever-present risk of epidemics, which in turn presents formidable threat to health and productivity. There is thus a need for improved waste management (Tadesse, 2004).

The present system of waste removal in Addis Ababa relies entirely on the municipality which is expected to provide a full range of waste collection and disposal. This is proving to be an impossible task, and except for privileged areas, the services offered are found to be largely inadequate. Even in the privileged areas it accumulates for weeks. This approach neglects many activities and actors that waste management comprise to tackle a range of problems associated with waste management in order to achieve socially and environmentally responsible waste management. Dry waste management may include legitimization of the informal system, community participation and possibly partial privatization. Such an integrated approach seems to be the best option and could well hold the key to effective and sustainable waste management system in developing cities such as Addis Ababa (Tadesse, 2004).

Addis Ababa is the capital city of Ethiopia, diplomatic capital for Africa (OAU, ECA), the seat for regional headquarters like UNDP, UNICEF, UNICEF, UNHCR, FAO, ICO, and ITU (Addis Ababa city Administration, 1998). It is the center for modern economic and social activities that infrastructure services are found relatively in better situation than other cities of Ethiopia. However, their development is too slow to meet the demands of the increasing population due to both natural growth and rural urban migration. In particular, the complete inadequacy of the dry waste management is the major environmental problem in Addis Ababa (Tadesse, 2004).

The daily waste generation is estimated at 0.252kg/capita/day. The current daily waste generation of the city is 2,297m^3 or 851 tones. Of municipal waste per day, 65 % (1,482m^3) is collected (Addis Ababa city SBPDA, 2003). The remaining 35% of waste is disposed off through informal means, except smaller percentage going to incineration and dumped on open sites, drainage channels, rivers and valleys as well as on the streets. The rivers are widely used as disposal sites. As simple observation around rivers bank indicates, large percentage of the uncontrolled waste goes to the rivers. Although the hygiene and environmental sanitation regulation issued by the Addis Ababa city administration (Proclamation Number 1, 1994) prohibits people from disposing waste along roads, avenues, rivers, ponds, and other sites, the regulation is continuously violated by the people due to lack of alternative means for disposal (Tadesse, 2004).

The rapid population growth rate of 3.8% is also resulting in a rise of approximately 5% of urban waste generation (Addis Ababa city Administration, 1998). This implies that if the current waste collection and disposal capacity is not matched with the growing generation, it would result in many environmental problems. These environmental problems also have socio-economic consequences. Poor environmental quality of cities can deprive citizens of a good quality of life as it affects their health and consequently, adversely affect productivity and economic development (Gerlagh et al., 1999). Various concepts have been developed over the years to provide the basis for improving the solid waste conditions in developing countries. Among them, integrated Dry Waste Management (DWM) provides a framework, which has been very successful in various countries (Gerlagh et al., 1999).

Inadequate municipal and industrial dry waste collection and disposal creates a range of environmental problems in Addis Ababa. A considerable amount of waste ends up in open dumps or drainage system, threatening both surface water and ground water quality and causing flooding, which provides a breeding ground for diseases-carrying pests. Open air burning of waste, spontaneous combustion in landfills, and incinerating plants that lack effective treatment for gas emissions are causing air pollution. The situation is exacerbated in slums where households cannot make use of garbage collection containers. Lack of the most basic solid waste services in crowded, low-income neighbors are a major contributor to the high morbidity and mortality among the urban

poor. The adverse effects of inadequate solid waste service on productivity and economic development of the city are significant (Tadesse, 2004).

The present DWM system in Addis Ababa relies entirely on the municipality which is expected to provide the full range of waste collection and disposal. This is proving to be an impossible task, and except for privileged areas, the services offered are found to be largely inadequate. This approach neglects the many activities and actors that waste management comprises to tackle a range of problems associated with waste management in order to achieve socially and environmentally responsible waste management. An integrated approach to DWM seems to be the best option and could well hold the key to effective and sustainable waste management system in developing cities such as Addis Ababa. As effort to improve dry waste management, the city administration has transferred the service provision of dry waste management to the newly established Addis Ababa City Sanitation, Beatification and Park Development Agency (since January 2003), with objective to make the city naturally balanced, green and favorable environment through integrated management and urban recreational area development. (Tadesse, 2004).

1.1.1 Volume and Sources of Dry Waste

Based on the five-year work plan of the Region 14 administration, the total amount of waste to be collected per annum is set to be 65% of the total volume generated in a year. If the plan materializes, 35% remains uncollected every year. This demonstrates that despite of relative improvement in waste collection by employing more efficient means as planned, the volume of actual uncollected waste will continue to increase in proportion to the population (Addis Ababa city administration, 1998).

The city's public spaces like road sides and open spaces attest eye-catching piles of garbage, flying 'festal' (which is increasingly used for packaging), rubbish, construction demolition and moved-earth from new construction sites littering the urban space indefinitely. Obnoxious odors emanating from decomposing solid wastes, semi-liquid and liquid wastes are sickening all citizens (Tadesse, 2004). The city council recognizes six major sources of solid wastes: households, street, commercial institutes, industries, hotels and hospitals. Available data for 1993 shows that households take the lion share of solid wastes generated in the city. The contribution of solid waste generators is

households 71%, street sweepings 10%, commercial institutions 9%, industries 6%, hotels 3% and hospitals 1% (SBPDA, 2003).

Human excreta are the major area of concern even from the household wastes. In 1984 about 30% of the population of the city had no access to latrines. This proportion was estimated to have only slightly fallen to 29.2% in 1997 in relative terms. This means almost one-third of the population of the city has no latrines and experiences open defecation. Hence, human excreta take proportionate share of the solid wastes in the city. Moreover, the available septic tanks used in the latrines usually overflows and pollute most of the older and overcrowded inner city with no short term solutions. The city administration has been making extensive efforts towards providing public latrines towards this end. Ash and smoke are other major components of wastes originating from households. Apart from lighting, electricity has never been an important source of energy for the larger proportion of households. The study conducted by Beyene (1999) indicates that firewood, charcoal, dung cakes and other traditional bi-products are the major sources of energy for domestic use. For instance, the 1994 census result indicates that the domestic energy requirement of about 47 % of housing units of the city is met from fire wood and leaves, charcoal, cow dung cakes and manure and combination of all these and kerosene. The amount of ash and smoke generated through combustion of these materials is immense (Beyene, 1999).

The other household waste worth consideration is "chat" which is being increasingly used by most of the population of the city. It is consumed as means of recreation by many people and serves as a stimulant. However, the increasing number of people using chat, its disposal in the ditches, open space and drainage systems liter the urban area and block the drainage systems to the determent of the environment and the health of population. (Tadesse, 2004).

Landfill sites itself need an attention. Landfill has impact on the surface and ground water. Decomposition of organic materials produces different gases, which has effect on the air above. Hence, proper use of landfill requires certain standard including spreading refuse in the thin layers and compacting by bulldozer before next year spread. All measures meant to control contamination of surface and ground water as well as the air. None of these practices are apparent in the landfill site of the city (Tadesse, 2004).

The increasing problem of urban waste management has its roots in history. When the city was built as an administrative center in 1880s, there was hardly any thought of waste as proportional threat. Neither the settlement pattern, nor the mind setup of residents was in conformity with waste management issues. Thus the current problems are, at least in part, the cumulative effects of the historical development patterns of the city through the century and traditions of its people. With these features, the spread of the city space shows the immensity of the problem with high cost implications to ameliorate it.

1.1.2 Collections, Transportation and Disposal

1.1.2.1 Collection

Municipal waste collection is handled in three ways: door-to-door collection for households along accessible streets, block collection for clients (large hotels, enterprises, and institutions) requesting the municipality to provide them with refuse containers, and containers system, which expects residents to carry and dump their waste in $8m^3$ refuse containers placed supposedly at accessible sites. In practice, 85% of the waste is collected through the container system. Although the objective is to service every 2 to 3 days, containers are actually emptied in longer than a week period on average. Besides, some households are located 1 km away from their closest container that people tend to throw their waste in sewer and ditches. All solid waste collected by the municipality is dumped in the single landfill, Rephi dumping site, 40 years old (located south of the city) that is proved to be difficult to prevent scavengers from scratching through hazardous waste.

The efficiency of this method is limited because of the capacity of the city council to deploy adequate number of vehicles and waste containers, which in tern has direct relationship with revenue generation of the city. Other waste disposal method such as composting of agricultural wastes, incineration and recycling of wastes are not used (Dawit and Yemeserach, 2001). Moreover the city council is mainly solely responsible for its management. Recently, 74 Micro and Small Enterprises (MSE) are engaged primarily in collection of household wastes to municipal containers - improved collection of waste and created job for jobless youths. They charge 10-12 Birr/month (Tadesse, 2004).

A recent study made by the Addis Ababa City Administration shows that the coverage has been constantly increasing from 38% in 1993, to 40% in 1994, and 53.9% in 1996. Generally in Addis Ababa, each kebele (equivalent to neighborhood) has no more than two or three solid waste collection containers. According to the 1994 population census, population of a kebele ranged from 2500- 7000. According to Yami (1999), a single container is shared by about 15,000 people, which is 8 times higher than recommend by NUPI (one container for 2000 people). The settlement pattern of Addis Ababa is a spreading out; people need to travel long distance to use containers while the recommended distance by the same study is not to exceed 200 meters. Besides, containers are not protected from rain and sun that makes the garbage to cause smell pollution, unsightly urban scene and deterioration of the neighborhood and disturbance of human activities. The site is also exposed for animals like dog, cat, and others during scavenging scatter the waste in the surrounding area. The situation in the newly developed parts of the city is not different. Solid waste disposal systems are not integrated with settlement development (Dawit and Yemeserach, 2001).

1.1.2.2 Transportation

Out of 72 trucks, only 35-40 work daily because of the average age of trucks is more than 5 years, maintenance difficulties, negligence of drivers, frequent accidents during traffic congestion. The vehicles carry only a single container at a time to disposal site. A trip is made to and from collection sites only for single container of maximum capacity of $8m^3$ or 2160kg. Considering the cost of fuel, manpower and overhead costs for transportation per single trip, the system is inefficient and uneconomical. Sometimes, the trucks have no container covers and the waste is distributed while they travel to disposal site (Dawit and Yemeserach, 2001).

1.1.2.3 Disposal

Rephi or "Koshe", is the landfill located 13km away from the city center (Giorgis). This site has been giving service since 1968. The present method of disposal is crude open dumping, hauling the wastes by truck, spreading and leveling by bulldozer and compacting by compactor bulldozer. The dumpsite is getting full. It is partly surrounded

by residents and institutions and has no gas control. The gas generated from landfill causes air pollution and green house effects. It contributes enormous amount of methane (green house gas) to the atmosphere. The site has a low area capacity (25 ha) and poor road connection (Dawit and Yemeserach, 2001).

1.1.3 Community and Private Sector involvement

Considering the above stated components of DWM, increased participation of the private sector and community-based organizations seems to the direction for improved waste management in Addis Ababa. Addis Ababa municipality should be involved because it has ultimate responsibility for refuse collection. The private sector should be involved because they have a greater capacity to mobilize resources and run their operations on commercial and business principles. Communities should also be involved because as consumers of the service they have an obligation to pay for it or to make some other contribution that will ensure that the service is provided.

In light of the above, it is essential to put forward a sound institutional arrangement for Addis Ababa municipality that involves community and private sector (including the partial privatization of collection service to contractors) in the city's DWM, as no single government agency acting alone, can ensure comprehensive implementation and effectiveness. This collaboration can help ensure that each and every move fits into an integrated system designed for promoting public health, environmental protection, economic efficiency and good governance (Dawit and Yemeserach, 2001).

The integrative aspect lies in the trade-off between these three dimensions. For example, in certain situations, although recycling may be preferred from an environmental perspective, the economic costs involved or the presence of institutional complications may prevent waste recycling from being promoted and implemented in integrated DWM. The actual integration can take place at various levels (Klundert and Lardinios, 1997).

The problems associated with municipal solid waste management in Addis Ababa can be categorically grouped in to:

- **Socio-economic problems**: It is natural to see piles of solid waste along street sides, in drainage ditches and channels, along river banks, in marketing areas like Mercato, etc. This creates unhappy environment and decreases the productivity of

individuals due to inconvenience. It can also result in epidemic diseases and diseases that are associated with air pollution and pathogenic micro-organisms which feed on the waste. This can be appraised in monetary terms as expense that is gone for medical purposes of the diseased individuals, loss of ambition in productivity and service quality which in turn is loss of time and money.

- **Aesthetics and tourism**: Clean environment is a background for healthy life and a conducive state for increased productivity. In addition to its effects in health, aesthetics also influences many economic, social and environmental variables. One such effect is the effect of solid waste on tourism industry of the state as a whole. Addis Ababa is not only the economic and political capital of the state, but also the seat for many continental and international organizations. This requires a high aesthetical and environmental quality of the city. As Ethiopia is promoting tourism industry, municipal solid waste must not induce negative impression in the tourists' mind and must not frozen their appetite for touring further.
- **Undue usage of resources**: In the 21st century, everything can be considered as a resource. Value addition and/or exergy enhancement is the key in appropriating the use of a given resource for some purpose. Municipal solid waste is not just a waste. It is waste for households, for example, when fruit pills are removed from the fruits and no more useful to them; worn out tires are waste to the vehicle owners when they will no longer ride on it; garment trimmings are no more useful to be used as part of garment. This is only true in relative terms. All the wastes mentioned above can be reused to produce energy and other forms of useful resources. From this we can conclude that the "today's wastes" will be considered as "resources tomorrow" when appropriate knowledge is applied to add value and exergy to them.
- **Lack of awareness** among the community is also one of the major problems adding to the environmental problems caused by municipal solid wastes. Therefore, awareness creation and elimination of sense of externality among the major stakeholders (households) is essential in solving this problem.
- Another prominent problem in Addis Ababa context is that the current municipal solid waste **disposal site** is located at only 13km from the center of the city

(Giorgis). It occupies a significant portion of the city (25hectares), located immediately near the ring road. According to UNEP (2004) the population growth rate of the city was 3.8% per annum. The municipal solid waste generation also increases proportionately with the number of people that generate it. This would certainly create social, environmental and economic complications unless tackled.

These mentions and the increasing demand for alternative fuel motivated the start of this research to produce ethanol from the today's troublesome municipal solid waste in Addis Ababa. In Ethiopian context, E15 (15% ethanol:85% gasoline) can be used in all engines of vehicles without need for engine modification. Due to the curtailing reality of petroleum supply today, it has become the prime priority to search for an alternative energy fuel supply such as ethanol. This research was carried out to convert selected municipal solid wastes (fruit wastes) to ethanol. The advantages of the research are twofold: the first and the primary advantage of it is to motivate private business sector to take part in the business and relieve the burden of the municipality and the second is to offer answer for an increasing and prior questions of the threatening fuel supply.

2 SCOPE OF THE STUDY

Municipal solid waste is the greatest of all socio-economic problems prevailing in Addis Ababa city. According to Meson (1999) solid waste is ranked top of environmental problems in Addis Ababa, scoring 26.5%, and immediately followed by sewerage 20.6%, and then population congestion 14.7%. This situation makes it natural necessity to alleviate the problem caused by the municipal solid waste in the city. As the problems caused by the municipal solid waste are multidimensional (social, environmental and economical), rigorous multidisciplinary approach to the problem solving strategies is of primary importance. Because of this complexity, there is no just a single solution to this problem. The primary goal of treating municipal solid waste is to avoid the nuisance caused by it. The second goal may be the utilization of the waste as resource: these include recycling, reuse, and conversion of organic portion of the waste in to energy resources (fuels) and other forms of valuable products.

The organic portion of municipal solid wastes can be processed mechanically, chemically, biologically, or the combination of some of these methods, to be converted to different valuable products like compost and biofuels such as biodiesel and ethanol. The choice for treatment option and the final targeted product of the waste must be based on profound study of the situation in question. From the perspective of the increasing need for the use of ethanol for gasoline blend and the threat of curtailment of fossil-based fuels, the conversion of municipal solid waste into ethanol would perhaps be the first choice.

The scope of this research is limited to foresee the possibility of ethanol production from selected Addis Ababa municipal solid wastes-fruit peels and remains which result from rotting. Three experiments were carried out in series for each sample: hydrolysis, fermentation and distillation. This means that each sample ought to be passed through these stages of experiments for the last result (ethanol) to be found. Because of the series nature of the three experiments, it was not simple to asses the contribution of change in parametric values of each experiment on the final result. For that reason the factorial design was applied only to the hydrolysis experiment and parameters were changed at two levels to see their directional effects on the response parameter (ethanol yield). The

parametric values for the rest of the experiments were kept constant for the experiment to be sharply justified. Therefore, the optimum values of main variables in hydrolysis process (time, acid concentration and temperature) which give high ethanol yield were set.

3 OBJECTIVES

3.1 General objectives

The general objective of this research was to carry out experimental analysis of conversion of selected Addis Ababa (Yeka Sub city) municipal solid wastes (fruit peels and remains) to ethanol.

3.2 Specific objective

The specific objective of this research was to optimize the parameters (factors), namely: time, temperature and acid concentration for hydrolysis of banana and mango peels to obtain the highest possible ethanol yield.

4 LITERATURE REVIEW

In this section, the historical background of municipal solid waste management options and the possibility and essentiality of producing ethanol from municipal solid wastes were thoroughly included from different literatures. Depending on different technical, socio-economical and environmental factors of the situation in question, one or combination of some treatment options maybe integrated to alleviate the environmental problems caused by municipal solid wastes and make use of resources within it.

4.1 Treatment options for organic portion of municipal solid waste

Energy conversion of organic materials can proceed along three main pathways—thermo chemical, biochemical, and physicochemical. Currently, all three pathways are utilized to varying degrees with fossil fuel feedstock.

Thermo chemical conversion processes include combustion, gasification, and pyrolysis. Biochemical conversion processes include aerobic conversion (i.e., composting), anaerobic decomposition or digestion (which occurs in landfills and controlled reactors or digesters) and anaerobic fermentation (for example, the conversion of sugars from hydrolyzed cellulose and hemicellulose by ethanol producing yeasts and recombinant bacteria (Berglund et al., 2006).

Physicochemical conversion involves the physical and chemical synthesis of products from feedstocks (for example, biodiesel). Biochemical conversion proceeds at lower temperatures and lower reaction rates. Higher moisture feedstocks are generally good candidates for biochemical processes. Thermochemical conversion is characterized by higher temperatures and faster conversion rates. It is best suited for lower moisture feedstocks. For biomass feedstocks, the lignin fraction currently can not be converted biochemically, although research is investigating lignin fermentation processes. On the other hand, thermochemical routes can convert the entire organic portion of suitable feedstocks. The inorganic fraction (ash) of a feedstock does not contribute significantly to the energy products, but does participate in important ways, including fouling of high temperature equipment, increased nutrient (e.g. potassium and phosphorus) loading in facility waste water treatment and disposal, and in some cases by providing marketable

co-products or adding disposal cost. Inorganic constituents may also be catalytic for some of the conversion reactions (Berglund et al., 2006).

4.1.1 Pathways to biofuels

Biofuels are fuel products produced from biomass. In the general sense, biofuel refers to an energy source or carrier that is derived from 'recently' living material. The biofuel can be solid (i.e., wood, crops and their residues, portions of municipal wastes, etc.), liquid (raw plant oils, waste cooking oils, as well as refined biodiesel, ethanol and other alcohols, pyrolysis oils, and biobased liquid hydrocarbons), and gaseous (biomethane, biogas, landfill gas, hydrogen derived from biomass). In the US, biofuel commonly means transportation fuels derived from biomass even though the applications for biofuels extend well beyond the transportation sector (Meta-Alvarez, 2003).

4.1.2 Biochemical conversion

The principal near-term biofuels produced from biochemical routes are biogas (including landfill gas) and ethanol (sometimes referred to as bioethanol). Biobutanol and other fermented alcohols are being investigated and could become important biofuels (Berglund et al., 2006).

4.1.3 Anaerobic Digestion (AD)

Anaerobic digestion (AD) is a fermentation technique that operates without free oxygen and results in a biogas containing mostly methane and carbon dioxide, but frequently carrying impurities such as moisture, H_2S, ammonia, siloxane, and particulate matter. Anaerobic digestion occurs in manure lagoons (covered or not), and is the principal process occurring in landfills. Biomethane from upgraded biogas is the principal biofuel from AD processes. The other common application for biogas is electricity generation. Hydrogen can be manufactured by reforming the methane. (Persson, 2003).

4.1.4 Hydrolysis with fermentation to alcohols

Fermentation is generally used industrially to convert substrates such as glucose to ethanol for use in beverage, fuel, and chemical applications and to other chemicals (e.g., lactic acid used in producing renewable plastics) and products (e.g. enzymes for detergents). Fermentation of starch and sugar based feedstocks (i.e. corn and sugar cane)

into ethanol is fully commercial. Cellulosic feedstocks, including the majority of the organic fraction of municipal solid waste, need hydrolysis pretreatment (acid, enzymatic, or hydrothermal hydrolysis) to depolymerize cellulose and hemicellulose to simple sugars needed by the yeast and bacteria for the fermentation process. Lignin in biomass is refractory to fermentation and as a byproduct is typically considered for use as boiler fuel or as a feedstock for thermochemical conversion to other fuels and products. Hydrolysis of lignocellulosic feedstocks is the subject of intense research (Lynd, 1996).

4.1.4.1 Ethanol

Cellulosic ethanol processes can be differentiated primarily by the method of hydrolysis employed. Hydrolysis pretreatment methods that have been investigated in depth are acid processes, enzymatic hydrolysis, and steam explosion. With the possible exception of acid recycling and recovery, acid processes are technologically mature, but enzymatic processes are projected to have a significant cost advantage once improved (Lynd, 1996). Steam explosion yields less sugar and releases more material that inhibits fermentation. After hydrolysis, the sugars can undergo microbial fermentation producing ethanol and CO_2. Ethanol inhibits microbial growth, essentially halting the process when ethanol concentration is near 12%. Ethanol must be separated from the fermentation broth and concentrated by conventional distillation technology and dehydrated to yield fuel grade anhydrous ethanol. Wet-ethanol fuels (ethanol-water mixtures that reduce the need for full distillation and dehydration) are being investigated. The remaining liquid broth is recycled or sent to a wastewater treatment facility for appropriate management (Lynd, 1996).

4.1.4.2 Butanol

Butanol is a four-carbon alcohol that can be obtained by fermentation from the same feedstocks used in ethanol fermentation. Some properties of butanol are superior to ethanol for fuel—butanol has more energy/gallon than ethanol, it does not absorb water easily which unlike ethanol may allow it to be transported via gasoline pipeline ,and butanol-gasoline blends have lower vapor pressure than ethanol-gasoline blends which is important in reducing evaporative hydrocarbon emissions(Ramey et al., 2004).

Traditionally, butanol is fermented from *Clostridium acetobutylicum* via the so called acetone-butanol-ethanol (ABE) fermentation. ABE fermentation yields 3 parts acetone, 6 parts butanol, and 1 part ethanol (3:6:1). However, butanol from ABE fermentation is less economic than ethanol, essentially because the fermentation is impeded by low concentrations of the products (end-product inhibition) requiring larger process stream volumes, reactors, and tanks (Jesse et al., 2002, Ezeji et al., 2005).

4.1.4.3 Mixed Alcohols

The "MixAlco Process" developed by Holtzapple and coworkers at Texas A&M University (TAMU) is an alternative biochemical route to mixed alcohols. Biomass feedstock is mixed with water and pretreated with hydrated lime ($Ca(OH)_2$) followed by fermentation using acid forming microbes which form carboxylic acids. This is followed by addition of calcium carbonate ($CaCO_3$) which neutralizes the solution and forms dilute carboxylate salts. The salts are then dried and sent to a heated reactor where they are converted to ketones (e.g. acetone), releasing calcium carbonate. Finally, the ketones are hydrogenated to mixed alcohols, predominately propanol, butanol and pentanol (Holtzapple et al., 1999)

4.1.5 Thermochemical conversion

Thermochemical conversion processes include combustion, gasification, and pyrolysis. Potential biofuels from thermochemical routes include ethanol, methanol, mixed alcohols, Fischer-Tropsch (FT) liquids, 36 other renewable gasoline and diesels, pyrolysis oils, and others. Direct electricity production can also be used for transportation through plug-in hybrids and battery-electric vehicles. Fischer-Tropsch synthesis is a process for producing mainly straight-chain hydrocarbons (C_xH_y) from a synthesis gas rich in CO and H_2 usually employing catalysts. The synthesis gas must have very low tar and particulate matter. Biomass derived synthesis gas for FT liquid production is still developmental due to gas cleaning issues (Holtzapple et al., 1999).

4.1.5.1 Combustion

Combustion means oxidation of the fuel for the production of heat at elevated temperatures without generating useful intermediate fuel gases, liquids, or solids. Combustion normally employs excess oxidizer (air) to ensure maximum fuel conversion.

Products of combustion processes include heat, oxidized species (e.g. CO_2, H_2O), products of incomplete combustion (e.g. CO and hydrocarbons), other reaction products (most as pollutants), and ash. Electricity can be produced using boilers and steam-driven engines and turbogenerators, or through organic Rankine, Brayton (gas turbine), and combined cycles (Holtzapple et al., 1999).

4.1.5.2 Gasification

Gasification typically refers to conversion via partial oxidation using substoichiometric (insufficient) air or oxygen or by indirect heating to produce fuel gases (synthesis gas, producer gas). The product, or synthesis gas, is principally CO, H_2, methane, and lighter hydrocarbons, but depending on the process used, the product gas can contain significant amounts of CO_2 and N_2, the latter mostly from air. Gasification processes also produce liquids (tars, oils, and other condensates) and solids (char, ash) from solids feedstocks. The combustion of gasification-derived fuel gases generates the same categories of products as direct combustion of solids, but pollution control and conversion efficiencies may be improved.Electricity and heat can be produced by burning the synthesis gas in a steam boiler and turbine plant, a gas turbine or an internal combustion or stirling engine generator, or synthesis gases can be reacted to fuel products and other chemicals (Rajagopalan et al., 2002).

4.1.5.3 Pyrolysis

Pyrolysis means the thermal degradation of a material usually without the addition of any air or oxygen. The process is similar to gasification but generally optimized for the production of fuel liquids or pyrolysis oils (sometimes called bio-oils if biomass feedstock is used). Pyrolysis also produces gases and a solid char product (Rajagopalan et al., 2002).

4.1.5.4 Biomass to Liquids (BTL)

Biofuels produced via gasification routes include direct gasoline and diesel substitutes made from gas-to-liquid processes (i.e., the Fischer-Tropsch process), methanol, ethanol, mixed alcohols, and hydrogen. Gas-to-liquids technologies are utilized commercially using natural gas or stranded natural gas as feedstock. Coal was used extensively by Germany in WWII and is still used in the Sasol (South Africa) facilities for gasoline and

diesel fuel synthesis coal-to-liquids (CTL) along with a wide variety of other products. For biomass feedstocks, the process is still being developed. Gas cleaning, catalyst durability and selectivity, feedstock preparation and handling, and production costs are the primary issues needing investigation (Spath, 2003)

4.2 Cellulosic Ethanol

One of the attractions of biofuels is they can be used in most internal combustion engines with little or no modification. Ethanol and biodiesel are the two most immediate candidates for adoption into the existing petroleum fuel infrastructure. For decades, ethanol has been used alone and with petroleum-based gasoline in internal combustion engines. Now, the renewable nature of its feedstocks has focused national attention and government assistance on ethanol as a renewable fuel. Present U.S. ethanol production is primarily by the bioconversion of the grain from corn and wheat, and in some instances, sugarcane (Spath, 2003).

Current grain-based ethanol production systems are an obvious first step in developing an agricultural-based industrial sector that addresses part of America's national biofuel need. The industry is based on existing and proven crop production and transportation infrastructure models as well as a proven, workable fermentation production technology. However, grain-based production is limited by food-material-inflation and available grain feedstocks and their prices as valuable multi-use commodities. Any way to increase the efficiency of the grain-based processing systems increases their profitability for their owners and investors (Spath, 2003).

For this reason, research engineers and industrialists have sought to make conventional, grain-based ethanol systems more efficient by not just fermenting (fermentation processing) the grain, but by bioprocessing as much of the plant (cellulose and hemicellulose) as possible. This technology looks to digest (enzymatic digestion) much of the plant into usable subunits that can then be efficiently converted (bio-catalysis) to sugars for fermentation processing. The less usable co-products (lignin, ash and hard-to-process proteins) can be combusted to provide power and heat for the ethanol production facility and the residual non-combustible ash and gypsum can become a marketed co-product for field fertilizer. This is the basic system envisioned for cellulosic ethanol production. Cellulosic (plant fiber) conversion, along with hydrogen, is viewed by many

environmental and social policy organizations as being the transportation fuel future of the United States, if not the world (Spath, 2003).

4.2.1 Conventional (Starch) Ethanol versus Cellulosic Ethanol

Conventional ethanol is derived from grains such as corn and wheat or soybeans. Cellulosic ethanol can be produced from a wide variety of cellulosic biomass feedstocks including agricultural plant wastes (corn stover, cereal straws, sugarcane bagasse), plant wastes from industrial processes (sawdust, paper pulp) and energy crops grown specifically for fuel production, such as switchgrass. Cellulosic biomass is composed of cellulose, hemicellulose and lignin, with smaller amounts of proteins, lipids (fats, waxes and oils) and ash.Cellulosic ethanol exhibits net energy content three times higher than conventional ethanol from corn kernel grain, and some of the cellulosic production systems emit far lower net levels of greenhouse gases. This is because cellulosic ethanol production can be supplied energy from the lignin and hard-to-process protein portion of the biomass while conventional (starch-to-ethanol)processes use fossil fuel to produce heat for fermentation and other aspects of processing and produces greenhouse gas emissions. Cellulosic ethanol production uses part of the input-biomass feedstock (lignin, hard-to-process proteins) instead of fossil fuel. This very positively changes the "Well to Wheel" life-cycle analysis model used to calculate overall greenhouse gas emissions from fuels and internal combustion engines. Life-cycle analyses look at the environmental impact of a product from its inception to the end of its useful life (Burden, 2008).

Cellulosic ethanol also may provide additional positive environmental benefits in the form of reductions in greenhouse gas emissions and air pollution. Some researchers calculate that since lignin is a renewable fuel with no net greenhouse gas emissions, the greenhouse gases produced by the combustion of biomass are essentially offset by the CO_2 absorbed by the plant material (biomass crop) because it sequesters carbon during its growth (Burden, 2008).

Conventional ethanol and cellulosic ethanol result in the same product, ethanol, but are produced using different feedstocks and processes. Conventional ethanol is predominantly derived from corn grain. Corn is converted to ethanol in either a dry- or wet-mill process. In dry-milling operations, liquefied corn starch is produced by heating corn meal with water and enzymes. A second enzyme converts the liquefied starch to

sugars, which are fermented by yeast into ethanol and carbon dioxide. Wet-milling operations separate the fiber, germ (oil) and protein from the starch before it is fermented into ethanol (Burden, 2008).

With respect to conventional ethanol, technological research primarily is concentrated in two areas: ethanol yield improvement and overall production efficiency. Both seek to reduce production cost and create a viable technology to replace imported oil, as well as make crop, crop residue and alternative feedstock-based ethanol a sustainable, domestic bio-fuel. Much of this research is applicable to converting or transitioning existing conventional grain-based production facilities to cellulosic systems. Cellulosic ethanol is a potential replacement for gasoline and grain-based ethanol in cars and trucks. Additionally, cellulosic ethanol is promoted, as are other biofuels, to reduce the nation's dependence on imported oil, increase energy security and reduce the trade deficit. Rural economies will benefit from new job creation and in the form of increased farm incomes (Burden, 2008).

4.2.2 Producing Cellulosic Ethanol

In general, the bioconversion of cellulose to ethanol requires three major processing steps: pretreatment, saccharification and fermentation. In order to use woody wastes, it is first necessary to break down the woody compounds into fermentable sugars. This has taken the form of a number of different pretreatment (pre-fermentation) strategies. Pretreatment requirements vary with the feedstock and are often substantially less in the case of various paper and hydrolysis waste streams (Burden, 2008).

4.2.2.1 Pretreatment

Pretreatment is the physicochemical, thermochemical or chemical process by which lignocellulosic biomass is decrystallized (not depolymerized as the case in saccharification). Pretreatment is an essential step for bioconversion of most lignocellulosic materials which contain lignin in significant quantity. Roughly two-thirds of the lignocellulosic materials is present as cellulose and hemicellulose (the two main components of plants that give them structure), and lignin makes up the bulk of the remaining dry mass. To efficiently and economically produce cellulosic ethanol, the complex polymeric structures must be separated into fermentable sugars. The sugars in

cellulose and hemicellulose are locked in complex carbohydrates called polysaccharides (long chains of monosaccharides, or simple sugars). Pretreatment breaks apart the structure of biomass to allow for the efficient, effective hydrolysis of cellulosic sugars, but this involves extremely complex chemical engineering. Usually the systems use processes to disrupt the hemicellulose/lignin sheath that surrounds the cellulose in plant material (Burden, 2008).

Pretreatments maximize subsequent bioconversion yields and minimize the formation of inhibitory compounds. They include acid hydrolysis (a controlled breakdown using dilute acid), alkali treatment, ammonia fiber explosion (liquid ammonia under moderate heat and pressure to separate the biomass components), autohydrolysis, chemical pulping, heat, mechanical size reduction, solvent extraction, steam, steam explosion, weak acid hydrolysis and various combinations of these separate processes. These technologies have different strategies for accessing the cellulose and hemicellulose and then dealing with the lignin, smaller amounts of other proteins, lipids (fats, waxes and oils) and ash(Burden, 2008).

4.2.2.1.1 Autohydrolysis

Autohydrolysis is the process of converting lignocellulose into fermentable sugars by exposure to high-temperature steam. Many lignocellulosic materials contain significant quantities of acetylated hemicellulose. Steam releases these in the form of acetic acid, which subsequently carries out a partial hydrolysis of the hemicellulosic and cellulosic sugars. The principal disadvantage of this approach is that sugar yields are generally very low (Burden, 2008).

4.2.2.1.2 Steam treatment

Usually performed in a tumbling reactor, steam treatment is a convenient way to facilitate separation of plastics and fibers while increasing digestibility of municipal solid waste. In this type of treatment, garbage is introduced into a large, cylindrical, horizontal autoclave that is slowly rotated on its side while steam treatment takes place. The plastic materials collapse and the fibrous materials form a pulp. Metals and other nonfibrous materials (for example, old shoes, composite material containers, plastic objects) are readily separated on screens after treatment. The organic portion (cellulosic biomass) of

the municipal solid waste is decrystalized and partially liquefied. The liquefied portion will underflow the screen and collected to be further treated in saccharification processes (Burden, 2008).

4.2.2.1.3 Weak acid hydrolysis

The process known as weak acid hydrolysis consists of sulfur dioxide combined with steam. It is particularly effective as a pretreatment for enzymatic cellulose saccharification. Sulfur dioxide is often used in combination with autohydrolysis because it gives better sugar yields and helps to modify lignin for subsequent extraction or recovery (Burden, 2008).

4.2.2.2 Saccharification

Cellulose saccharification is the process of turning polymeric lignocellulosic materials into fermentable sugars and can be accomplished by a number of processes including acid and enzymatic hydrolysis. Acid hydrolysis and enzymatic hydrolysis are currently the main two processes used to create fermentable sugars from cellulosic biomass. Acid hydrolysis processing breaks down the complex carbohydrates into simple sugars. Enzymatic hydrolysis processing uses a complex pretreatment processing stage to reduce the size of the material, making it more efficient than acid hydrolysis. In both processes, enzymes are used to convert the cellulosic biomass into fermentable sugars and then microbial fermentation (as in current corn-based systems) is used to produce ethanol. As with current corn-based systems, carbon dioxide is produced as a co-product in this final stage of production (Burden, 2008).

4.2.2.2.1 Dilute acid hydrolysis

Dilute acid hydrolysis with 1% to 5% sulfuric acid is generally considered the most cost-effective means of hydrolysing wood and agricultural residues. Yields of hemicellulosic sugars can be 80% to 95% of theoretical. Yields of glucose from cellulose are generally less than 50% but can approach 55% at elevated temperatures (Burden, 2008).

4.2.2.2.2 Strong acid hydrolysis

Strong acid hydrolysis, often using a concentrated form of sulfuric acid, usually separates and recycles the acid catalyst, limiting the total acid losses to approximately 3%, or the same as the dilute process. Use of the concentrated acid, however, allows lower temperature and pressure hydrolysis with fewer byproducts produced. Concentrated hydrochloric acid at a concentration of about 47 % is sometimes used for strong acid hydrolysis because it is relatively easy to recover. Hydrolysis with concentrated hydrochloric acid gives one of the highest sugar yields of any acid hydrolysis process. It is carried out at room temperature. The chief drawback is that it is highly corrosive, volatile, expensive and almost complete recovery is essential to make the process economical. Ultimately, the goal is to get higher sugar yields as efficiently as possible without degrading the feedstock materials. This is easier said than done. Each technology has advantages and disadvantages in terms of costs, yields, material degradation, downstream processing and generation of process wastes (Burden, 2008).

4.2.3 Fermentation

4.2.3.1 Yeast strains isolated from ripe banana peels

According to Brooks, (2008) the increasing demand for ethanol for various industrial purposes such as alternative source of energy, industrial solvents, cleansing agents and preservatives, has necessitated increased production of this alcohol. Ethanol production is usually accomplished by chemical synthesis of petrochemical substrates and microbial conversion of carbohydrates present in agricultural products. Owing to the depleting reserves and competing industrial needs of petrochemical feed stocks, there is global emphasis in ethanol production by fermentation process.

Increased yield of ethanol production by microbial fermentation depends on the use of ideal microbial strain, appropriate fermentation substrate and suitable process technology. According to Stewart et al. (1982), an ideal microorganism used for ethanol production must have rapid fermentative potential, improved flocculating ability, appreciable osmotolerance, enhanced ethanol tolerance and good thermo tolerance. Although no microbial strain has all these desirable qualities, few yeast strains have been found to possess appreciable characteristics for ethanol production (Stewart et al., 1982 and

Hacking et al., 1984). The technological behavior of industrial micro-organisms remains the main stay of industrial secret in fermentation industry; hence most industrial microorganisms are patented and may not be available for use outside their country of origin. This is of serious economic concern as it does not allow for rapid expansion of fermentation industries, hence the need to source for indigenous and suitable yeast strains from local substrates for sustainable ethanol production.

Various strains of indigenous yeasts capable of producing ethanol have been isolated from different local sources such as molasses (Rose, 1976), sugar mill effluents (Anderson et al., 1986) and local fermented foods (Ameh et al., 1989) and fermented pineapple juice (Eghafona et al., 1999). In most of these studies, the preferred candidate for industrial production of ethanol has been *Saccharomyces cerevisiae.* This yeast also has the ability to produce ethanol which is not contaminated by other products from the substrate. The following tabulated findings are the research results of A. A. Brooks, (2008) presented on the title of ethanol production potential of local yeast strains isolated from ripe banana peels.

Table 4.1 Attributes of the yeast strains isolated from waste banana peels for ethanol production

Yeast strain	Ethanol yield in 10% (V/V) glucose		Flocculation rate (ml/10minute)	Fermentative capacity (μLCO_2) with 2% glucose		Fermentative capacity (μLCO_2) with 40% glucose at 37°C	Ethanol tolerance			
	30°C	37°C		37 °C	42 °C		6%	8%	10%	12%
S.cerevisiae R-2	4.6	3.0	0.80	170	120	140	+	+	-	-
S. cerevisiae R-8	7.2	4.8	2.6	320	150	190	+	+	+	+
S. cerevisiae T-7	4.3	4.0	1.00	160	100	125	+	+	-	-
S. kluyveri K-6	4.8	3.8	0.40	80	46	54	+	+	-	-
D. hansenii B-2	3.6	3.1	0.20	40	-	-	+	-	-	-
							+ = tolerant; - = not tolerant			

Source: Ethanol production potential of local yeast strains isolated from ripe banana peels A. A. Brooks, 2008

The result of the assessment of the 5 yeast stains for attributes essential in industrial fermentation of ethanol is presented in Table 4.1. Only *S. cerevisiae* R-8 was highly flocculent. The rest were poorly flocculent. There were variations in the rate of tolerance to different levels of alcohol. *D. hansenii* B-2 and *S. kluyveri* K-6 tolerated 6% and 8% ethanol, respectively, while *S. cerevisiae* R-8 was tolerant to 12% (v/v) ethanol. This table also shows the thermotolerance exhibited by the various yeast strains and their ability to ferment 40% glucose. *S. cerevisiae* R-8 rapidly fermented 2% (w/v) glucose at 37^{o}C and 42^{o}C with the liberation of 320µL and 150µL of CO_2, respectively. *S. cerevisiae* R-2 and *S. cerevisiae* T-7 exhibited moderately rapid fermentation, while *D. hansenii* and *S. kluyveri* exhibited low rates of fermentation at both temperatures.

Table 4.1 also shows the ethanol production capability of the five strains of yeasts at 30^{o}C and 37^{o}C respectively. The result shows that all the strains performed better at 30^{o}C. *S. cerevisiae* R-8 was the most active strain at temperatures, yielding 7.2% (v/v) and 4.8% (v/v) ethanol at 30^{o}C and 37^{o}C respectively. At 37^{o}C the yields of ethanol produced by *D. hansenii, S. kluyveri* and *S. cerevisiae* T-7 were 3.1, 3.8 and 4.0% (v/v) respectively. Except *D. hansenii*, other strains fermented 40% glucose rapidly at 37 ^{o}C, with *S. cerevisiae* R-8 being the best, having produced the highest level of CO_2 (190µL of CO_2) at 37^{o}C in 6hr (Brooks, 2008).

Table 4.2 Fermentation of simple sugars other than glucose by the yeast strains isolated from waste banana peels.

Rate of fermentation of the sugars (µl CO2/ 6 hr)								
Yeast strain	Cellobiose	Maltose	Mannose	Galactose	Ribose	Xylose	Sucrose	Arabinose
*S.cerevisiae*R-2	-	150.0	84.60	42.60	-	-	60.40	-
*S.cerevisiae*R-8	-	100.0	120.80	39.20	-	-	130.00	-
*S.cerevisiae*T-7	-	76.0	64.10	36.40	-	-	34.60	-
S.kluyveri K-6	-	47.0	70.40	20.50	-	-	40.0	-
D.hansenii B-2	-	53.0	41.30	30.40	-	-	30.40	-
The final concentration of all the sugars used was 2% (v/v).								

Source: Ethanol production potential of local yeast strains isolated from ripe banana peels
A. A. Brooks, 2008

Table 4.2 shows the fermentation of simple sugars other than glucose by five strains of yeast isolated from waste banana peels. *S. kluyveri* and *D. hansenii* showed minimal fermentation rates on galactose, liberating 20.50 and 30.40µL of CO_2 in 6h respectively. All the five strains failed to ferment arabinose, ribose, cellobiose and xylose. Table 4.3 shows the percentage viability of the different yeast strains at 12% concentration of ethanol. *S. cerevisiae* R-8 shows the highest tolerance with 70% viability while *D. hansenii* showed the least tolerant with 30% viability at this concentration.

Table 4.3. Percentage viability of the yeast strains isolated from waste banana peels in 12% (v/v) ethanol incubated at 30°C.

Mean viable counts (x104cfu/ml)				
Yeast strain	0 hr	24 hr	48 hr	Cell viability (%)
S. cerevisiae R-2	2.8 ± 0.03	4.3 ± 0.08	1.32 ± 0.01	47.0
S. cerevisiae R-8	4.2 ± 0.14	6.4 ± 0.11	2.94 ± 0.18	70.0
S. cerevisiae T-7	2.3 ± 0.76	4.0 ± 0.24	1.22 ± 0.03	53.0
S. *kluyveri* K-6	3.6 ± 0.01	5.0 ± 0.03	1.44 ± 0.11	40.0
D. *hansenii* B-2	3.0 ± 0.04	4.4 ± 0.14	0.60 ± 0.06	30.0
Cell viability (%) = (Viable count at 48 h / Viable count at 0 h) x 100; Values are means ± standard deviation from three determinations.				

Source: Ethanol production potential of local yeast strains isolated from ripe banana peels
A. A. Brooks, 2008

According to Brooks, (2008) *S. cerevisiae* R-8 exhibited considerable potential for industrial production of ethanol. The strain exhibited high flocculation ability, good osmo and thermo-tolerance and fermented higher concentrations of sugar to yield appreciable amount of ethanol. These attributes are the requisite criteria for selecting yeasts as candidates for industrial production of ethanol (Hacking et al., 1984; Rose, 1976). However, this strain could not ferment pentose sugars and cellobiose and may therefore not be suitable for the fermentation of cellulosic materials.

Benitez et al. (1983) described wine yeasts which could grow well at 10% (v/v) and fairly well at 15% (v/v) ethanol. Although the level of ethanol tolerance recorded in this study (Brooks, 2008) is less then that reported by Benitez et al. (1983), the isolates could be manipulated genetically for higher ethanol tolerance. The proximate analysis of ripe banana peels was not determined in this study, but Essien et al. (2005) recorded crude protein and crude fat contents of 7.8 and 11.6%, respectively in banana peels. Protein is

essential nutrient for yeast growth while fat is vital to the structure and biological functions of the cells and can be utilized as alternative source of energy by the cells. It appears therefore that the impressive performance of yeasts in banana peels is due, partly, to the high contents of fat and protein. The import of the study by Brooks, (2008) is that it has been able to produce 5 yeast strains with appreciable fermentation ability. Although the ethanol yield is low, maximum being 7.2% produced by *S. cerevisiae* R-8, the strains could be genetically manipulated under suitable environment for higher yield of ethanol.

Therefore, this study can be taken as initial point for further optimization of fermentation step recommended by this (Ashenafi, 2009) thesis research in section 9.

4.2.3.2 Feedstocks

Cellulosic ethanol can be produced from a wide variety of cellulosic biomass feedstocks. These include agricultural plant wastes (corn stover, cereal straws, and sugarcane bagasse), plant wastes from industrial processes (sawdust, paper pulp, distiller grains) and energy crops grown specifically for fuel production, such as switch grass. Growing energy crops and harvesting agricultural residuals are projected to increase the value of farm crops, potentially eliminating the need for some agricultural subsidies. Perennial grasses, such as switch grass and miscanthus, have been discussed as promising feedstocks for cellulosic ethanol production. They use water efficiently and do not need a lot of fertilizers or pesticides. However, their production economics are questionable, and there is little to no production and collection infrastructure in place to drive their acceptance as feedstocks (Burden, 2008).

With heterogeneous waste streams such as municipal solid waste, it may be necessary to include costly, complex sorting and filtering steps to separate usable material from those that may inhibit the process before carrying out pretreatment. In the case of agricultural residues, particle size reduction can often be done simply with grinding. For dry corn or soybean residues, density is often lower than what is desirable, and particle size reduction is not an issue. Municipal solid wastes present a particular problem because of their extremely heterogeneous nature. Large quantities of plastics, wood, metals and other materials are often present. If certain heavy metals or toxic compounds

are present in the mixture when acid is added, they can create severe downstream problems in fermentation and product formation (Burden, 2008).

Many cellulosic ethanol advocates see cellulosic conversion as a one-stop, one-size-fits-all fuel production system. This is partly due to their lack of understanding of the complexity of the chemical engineering and biological components of the processing system and partly due to their wishful thinking regarding exploitation of agricultural wastes. Agricultural wastes, agricultural residue material that is plowed into the soil for fertilizer, composted, burned or disposed of in landfills, are more abundant and contain greater potential energy than simple starches and sugars. Additionally, the collection, transportation and perhaps processing of these residues would present farmers and agricultural services providers with another lucrative crop-based profit center (Burden, 2008).

The popular press has promoted cellulosic processing as a system in which any cellulose-containing waste (farm field, industrial and municipal) and waste (newsprint, homeowner leaf and yard waste, sawdust, wild native grasses) can be processed by the same system within the same facility. A range of material this varied would have vast differences in chemical makeup, as well as the contaminant load that each would carry into the system. The biological components of any processing system seldom are amenable to introduced molds, bacteria and other contaminants. In current ethanol production technologies, food production systems and so on, these biological contaminants tend to wreak havoc with production efficiencies and can even curtail operation of a processing facility and force shutdowns, requiring costly restarts (Burden, 2008).

The problem is that the complex chemical and biological engineering needed to optimally convert (in a manner suitable for profitable, large-scale fuel production) a single homogeneous feedstock, for example, wheat straw, may be very different from another homogeneous feedstock, for example, corn stalks. Add to this the harvest and storage technologies that may not exist at this time (yet have been evolving for over a century for grain-based production systems). However, Cellulosic conversion dialed-in to a specific feedstock could be a great solution for taking some waste materials from a landfill and converting them to fuel and usable co-products. This bio-remediation of an

industrial waste stream has the potential to eliminate a costly expense for a company and turns it into a new profit center. Others are various wood wastes and field stovers. Perhaps the most promising application is using cellulosic conversion to re-use or further process the dried distiller's grain component produced as a co-product from conventional grain ethanol production. This system is using an extremely homogeneous pre-processed feedstock, and there is no need for complex new handling and storage systems (Burden, 2008).

4.3 Global trend in ethanol production and use

It has been known for over 100 years that acids act as catalyst to convert "hydrolyze" cellulose and hemicellulose into simple sugars (hexose and pentose, or "C_6 and C_5" sugars). The Germans and Russians used this simple procedure in the early part of this century to produce alcohol fuels and chemicals from wood in order to supply their war efforts. During this same period, a similar plant was operated in the United States in Oregon. However they all shared a similar characteristic - they were not economically competitive with low cost petroleum products because of poor yields, high wastage, and the large volume of unmarketable by-products. Except for a few plants in Russia, the technology fell out of use after World War II. However, interest in the conversion of biomass-to-sugars picked up in the mid 1970's due to the oil embargo and the United States' desire to lessen its dependence on foreign chemical and fuel feedstocks. Further interest was stirred in 1983 when DuPont published an article in Science magazine detailing the variety of chemical products that could be produced via fermentation of sugar. Since that time many universities and government laboratories have been studying the hydrolysis of cellulose, either through the application of various acids or enzymes. Most notable in regard to acid hydrolysis, had been the work undertaken at the Tennessee Valley Authority and Mississippi State University (U.S EIA, 2006)..

The US now uses more than 15 billion gallons of cleaner, ethanol-blended petrol a year, totalling 12% of fuel sales in the US. Most of it is a 10% blend, but 85% and even 95% blends are now being tested. Ethanol blends are increasingly used in South Africa, while Brazil, the world leader, produces four billion gallons of ethanol a year: all Brazilian fuel contains at least 24% ethanol, and much of it is 100% ethanol (engines can be designed to run on 100% ethanol) (U.S EIA, 2006).

4.4 Ethanol as a fuel or fossil-fuel-blend

Ethanol is a very high octane fuel, replacing lead as an octane enhancer in gasoline. The octane rating of a spark ignition engine fuel is the detonation resistance (anti-knock rating) compared to a mixture of iso-octane (2,2,4-trimethylpentane, an isomer of octane) and n-heptane. By definition, iso-octane is assigned an octane rating of 100 and heptane is assigned an octane rating of zero. An 87-octane gasoline, for example, possesses the same anti-knock rating of a mixture of 87% (by volume) iso-octane and 13% (by volume) n-heptane. This does not mean, however, that the gasoline actually contains these hydrocarbons in these proportions. It simply means that it has the same detonation resistance as the described mixture. Octane rating does not relate to the energy content of the fuel. It is only a measure of the fuel's tendency to burn rather than explode.

Fuels that burn too quickly (explodes) make the engine ‘knock’. The higher the octane rating, the slower the fuel burns, and the less likely the engine will knock. When ethanol is blended with gasoline, the octane rating of the petrol goes up by three full points, without using harmful additives. Furthermore, adding ethanol to gasoline ‘oxygenates’ the fuel, adding oxygen to the fuel mixture so that it burns more completely and reduces polluting emissions such as carbon monoxide. Ethanol and ETBE oxygenator, made from ethanol, are much safer than the toxic and polluting MTBE fossil-fuel-derived oxygenator used by oil companies.

4.5 Biofuels for Transport

According to International Energy Agency (2004), the worldwide use of oil in transport will nearly double between 2000 and 2030 leading to a similar increase in greenhouse gas emissions. Biofuels, such as ethanol, biodiesel and other fuels derived from biomass could help change this picture, by offering an important low-greenhouse-gas alternative to petroleum over this time frame.”

This new IEA publication looks at recent trends in biofuel production and considers how the future may look if recent initiatives in IEA countries and around the world are fully implemented. The report takes a global perspective on the nascent biofuels industry, assessing regional similarities and differences as well as the cost and benefits of the various biofuel options and technologies (IEA, 2004).

A major finding of the IEA's analysis is that recent policy initiatives, if fully implemented, could result in up to a 5% displacement of motor gasoline use with biofuel (mainly ethanol) worldwide by 2010. This would represent an important step. However, in OECD regions most of this production will likely be of conventional ethanol using grain feedstocks such as corn and wheat. While this type of biofuels production can provide important benefits, production costs are generally high and reductions in fossil energy use and CO_2 emissions are modest. Further, grain-based ethanol (as well as conventional oil-seed-based biodiesel) must compete for land with crop production for other purposes, such as for food and animal feed, and supplies are likely to be limited. "Biofuels for Transport: An International Perspective" also reports that countries such as Brazil and India – that can grow and utilize sugar cane as a primary feedstock – are already producing relatively low-cost bio-ethanol with excellent characteristics. The high-yielding sugar cane that these countries use also provides sufficient crop waste to power the conversion of sugar to ethanol, virtually eliminating the need for fossil energy inputs and providing large "well-to-wheel" reductions in CO_2. Since over the next two decades these and other developing countries may be able to produce more sugar cane ethanol than they need domestically, the IEA proposes that a global trade in biofuels be more rigorously pursued and identifies existing obstacles to this trade (IEA, 2004).

However, for the longer term, research into advanced biofuels production techniques is bearing fruit. It now appears likely that within a few years the first commercial-scale production facilities will be built to produce ethanol from cellulosic feedstocks such as crop wastes, grasses and trees, using far less fossil energy and providing much larger reductions in "well-to-wheel" CO_2 emissions per litre of fuel than the current processes. Use of cellulosic feedstocks would also substantially increase potential biofuels supply. Advanced biomass conversion to synthetic diesel fuel is also under development, using gasification and other techniques, which could eventually allow commercial production of much higher yielding, low-greenhouse-gas biodiesel fuel (IEA, 2004).

4.5.1 Benefits of ethanol

- It is a renewable fuel made from plants
- It is not a fossil-fuel: manufacturing it and burning it does not increase the greenhouse effect
- It provides high octane at low cost as an alternative to harmful fuel additives
- Ethanol blends can be used in all petrol engines without modifications
- Ethanol is biodegradable without harmful effects on the environment
- It significantly reduces harmful exhaust emissions
- Ethanol's high oxygen content reduces carbon monoxide levels more than any other oxygenate: by 25-30%, according to the US EPA
- Ethanol blends dramatically reduce emissions of hydrocarbons, a major contributor to the depletion of the ozone layer
- Ethanol can reduce net carbon dioxide emissions by up to 100% on a full life-cycle basis
- As an octane enhancer, ethanol can cut emissions of cancer-causing benzene and butadiene by more than 50%

4.6 Description of the material (sample used)

The material (sample) used for this thesis was the mixture of banana and mango peels and remains with the proportion of 70:30 (%) for banana and mango respectively. The very reason for this proportioning is that banana peels are easily hydrolysable and gives sugar in high quantity than mango does. Quiet significant portion of mango is lignin, which is refractory to hydrolysis reactions. These lignocellulosic materials are composed of structural polysaccharides cellulose, hemicellulose and lignin.

Lignocellulosic biomass is carbon-rich material of plant origin. Therefore, along with its biofuel derivatives, it falls into the field of organic chemistry which is essentially the chemistry of carbon. On a dry basis, most biomass contains a little less than 50% carbon by weight. Because the carbon-containing portions of biomass are made up mostly of sugar type molecules, which are carbon rings, biomass can be considered a carbohydrate-based material, whereas fossil fuels are made up of carbon chains and are often referred

to as hydrocarbons. Individual sugars and starch are components of biomass, but not of lignocellulosic biomass.

Source:http://www.scientificpsychic.com/fitness/carbohydrates.html.

4.7 Description of the product

The main product of this research is ethanol. Ethanol is also a high-performance motor fuel that cuts poisonous exhaust emissions and is better for the environment. Ethanol (ethyl alcohol, grain alcohol), according to the US Department of Energy's National Renewable Energy Laboratory, is a “clear, colorless liquid with a characteristic, agreeable odor and taste”, some would add. The physical characteristics of Ethanol are shown in the following table:

Table 4.4 Properties of ethanol

Physical properties	Description (quantitative and qualitative)
Molecular formula	CH_3CH_2OH
Molar Mass	46.06844(232) g/mol
Appearance	colorless clear liquid
Density	0.789 g/cm³, liquid
Melting point	−114.3 °C (158.8 K)
Boiling point	78.4 °C (351.6 K)
Solubility in water	Fully miscible
Acidity (pK_a)	15.9
Viscosity	1.200 mPa·s (cP) at 20.0 °C
Dipole moment	5.64 fC·fm (1.69 D) (gas)
EU classification	Flammable (**F**)
Flash point	286.15 K (13 °C or 55.4 °F)

Source: Wikipedia encyclopedia

5 EXPERIMENTATION

This section contains information about all equipments, auxiliaries, materials of sample used and the methodologies used for the realization of the research.

5.1 Materials and Methodologies

5.1.1 Equipments, Materials and Samples

The materials section describes the equipments, chemicals, sample materials and auxiliaries that were used in the research. The equipments and materials used comprised of the following:

- Plastic bags (to collect and transport samples from fruit shops to the laboratory)
- Knife (for cutting the fruit wastes in to pieces)
- Digital and non-digital driers or ovens
- Crushers (to crush the dried sample)
- Sieves (to sieve the crushed sample to the particle size of 3mm or less)
- Balances (to weigh samples and yeast)
- Digital pH meter (to measure the pH of the hydrolysates before fermentation)
- Thermostats (to control temperature of the sample under experiment(fermentation and distillation) isothermally at the set point)
- Vessels (to hold samples and additives for hydrolysis, fermentation and distillation experiments)
- Graduated cylinders of different volumes (for volume measurement)
- Autoclave (for sterilization and hydrolysis)
- Sulfuric acid, ammonia(solution), dry instant yeast(saccharomyces cerevisiae)
- Pycnometer (for density measurement)
- Shaker (to shake sample and its additives after hydrolysis and before fermentation)
- Fermentation and distillation set ups
- Samples were taken from banana and mango peels and remains in the proportions mentioned in the ‘sample proportioning’ section.
- Computer (for document preparation and data analysis)

5.2 Methodologies

The ‘methodologies’ section describes about the methodologies and approaches of how experiments were done in this research; it comprised of all steps and procedures of the experiments and the whole picture of the hands-on work of this work.

5.2.1 Sample acquisition and preparation

5.2.1.1 Sample acquisition

The first step in sample acquisition was to identify where and how to find an appropriate sample; to do this, two things were done: the first one was to determine as to what category of municipal solid waste would be preferably dealt with in priority. The severity in environmental problems makes it necessary to find the solution for prevailing situation. Safe disposal alone is the minimum effort that can be applied in municipal solid waste treatment. But resource utilization and safe disposal in combination are two journeys into the problem.

From these perspectives, the research was carried out with the intention of environmental safeguarding (vitally) and resource utilization (essentially) on its way. The second thing was to foresee the best source to obtain the representative sample for the selected category of municipal solid waste. Fruit and vegetable shops were opted to be the best place to find uncontaminated fruit wastes. This option had two advantages: one is that, in fruit and vegetables shops, fruit peels and remains could be obtained in pure form with out being mixed with other solid municipal solid wastes. This eliminated (minimized) the labor and time required for sorting. It also had the advantage of providing guarantee to find the intended results as the samples were pure. Secondly, fetching the sample by sorting fruit wastes from other solid municipal solid wastes incurs the possibility of heavy metal contamination. Heavy metal contamination of samples, in turn, entails the deactivation of yeast during fermentation process.

Microbially decomposable organic portion of municipal solid waste can be categorically grouped into:

- kitchen and yard trimmings and food-material-remaining
- paper, wood and cardboard
- fruit peels and remaining (both from household and fruits shops)

Even though the prime goal of the research was to give engineering solution to the prevailing environmental problem, ethanol production from the solid waste was a twofold socioeconomic and environmental benefit. From 1970's on, global energy crisis has been affecting every thing in all dimensions. The supply of fossil-based fuel and its derivatives is certainly shorting and its curtailment is becoming the reality of this new millennium. New technological advancements are propagating from time to time to realize the economically and environmentally feasible way of production of green biofuels. Green biofuels are fuels that are renewable in nature such as those which are produced from biomass (plants).

Fruit wastes and remains can be considered as renewable source of ethanol production as their sources are green plants which are renewable. There are three persuasive reasons for municipal solid waste to be transformed to biofuels: the first one is that environmental degradation due to this waste will be alleviated or minimized. Secondly, the increasing cost and need for energy necessitates the need for renewable energy forms. Thirdly, in addition to minimizing environmental burden of these wastes, production of ethanol from such wastes and its usage in transport industry increases the energy yielding efficiency of gasoline and reduces the knocking effect in internal combustion engines. Ethanol also increases the octane number of the gasoline itself. Therefore, from environmental and economic points of views, fruit peels and remains were opted to be investigated in this research.

Fruit peels and remains are easy to treat, potentially reliable source of cellulose and sugars which are readily fermentable and are environmentally threatening if directly disposed off into ambient environment. According to Fitsum (2007) about 55.35% (by weight) of municipal solid waste is food waste by weight. This signifies that quiet significant portion of the municipal solid waste is food waste. It is also clear fact that quiet significant portion of such food wastes is the encompassment of different fruit wastes (peels and remains) such as of avocado, banana, mango, orange, papaya etc. From the data found from the Trade and Industry Department of Yeka sub city and from pieces of information informally found from 10 fruit and vegetable shops, the contribution of fruit wastes (banana and mango) was estimated to be 16.2% (by weight) of the total municipal solid waste generated in the sub city.

5.2.1.2 Sample preparation

5.2.1.2.1 Sample handling and transportation

Samples were taken from two fruit and vegetable shops in plastic bags and by the experimenter manually into the technology faculty chemical engineering laboratory. After they were unloaded plastic bags were dropped in to the trash plastic baskets of the faculty. Excess fruit wastes were also discarded with the bags into the same plastic baskets.

5.2.1.2.2 Preparation processes

The sample that was acquired had to be prepared and conditioned for it to be hydrolyzed, fermented and distilled. Sample preparation process encompassed: sorting, drying, proportioning (weighing), grinding, sieving and putting the sample in an appropriate plastic package, condition and place. The samples were collected from two fruit and vegetable shops. Samples of banana and mango peels and remains were collected and proportioned in ratios of 7:3 (seven to three or 70%:30% ratio) for banana and mango respectively. 5% of the peels in weight for each type of fruit were the fruit remains. This means that 5% in dry weight of the whole sample is fruit remains.

5.2.1.2.2.1 Sorting

Sample sorting was the collection of fruit wastes which belong to the same type of original fruit in a distinct container. That was how banana and mango peels and remains were collected separately and dried for proportioning after drying.

5.2.1.2.2.2 Manual size reduction

After samples were sorted according to their category, they were cut by knife into pieces of about 20mm particle size for easy drying and grinding.

5.2.1.2.2.3 Drying

Sample drying was carried out to obtain easily crushable material. The sample was dried in an incubator and in a digital oven at a temperature of 60^{o}C. The time required for sample to be dried varied with the type of fruit wastes. Banana peels and remains were dried in the time range of 72-96 hours. Mango peels have got plastic nature when they were not fully dried. They rolled up in crushers than being crushed in to fine powder. Because of this fact, mango peels were dried for more than 72 hours on the sheet of

plastics placed on the tray of the incubator or of the oven. There was not any specific time for drying and the sign for the dried sample except visual judgment that the dried samples were easily breakable and crushed at ease. The samples were taken out of their respective driers when they were dried enough to be crushed. The mill used to crush the samples was the cutting mill. The maximum particle size of the ground sample was 3mm.

5.2.1.2.2.4 Sample proportioning

The proportioning was the quantification and mixing of the samples (banana and mango) in predetermined proportions. The proportions of these components were determined on the real basis of their in-market quantities and length of duration for their availability. This was done because, if some business happens to be based on this finding and the commercialization is to be effected, the source for raw material has to be reliably continuous and consistently ubiquitous to manufacturer ethanol from such sources.

Most of banana fruit is its peel. The fruit peel of banana and mango are about 65% and 35% respectively, of the total weight of the banana and mango fruits. The banana and mango peels and remains were mixed respectively in the proportion of 70%:30% in dry weight. The sample of each component also constituted 5% in dry weight of the remains of the fruits. This proportioning was taken from the reality that the fruits degrade into wastes during transportation, storage and delivery. More than 5% of fruits are discarded as wastes for such reasons as mechanical damage of fruits and microbial decomposition of ripe fruits after they were transported to market places (areas).

5.2.1.2.2.5 Sample grinding

After drying, the samples were weighed and mixed in the proportions of 70%:30% (7:3) for banana and mango respectively. The mixture was then crushed (ground) in cutting mill. The maximum particle size of the ground mixed sample was 3mm. The ground sample of larger particle size than 3mm was ground over and over again until all particle size was 3mm and less. The ground sample was then kept at temperature of $3^{o}C$ until the next stage of experiment.

5.2.2 Pretreatment by steam

The autoclave was used for steam pretreatment. The pretreatment was mainly meant for decrystallization of the biomass before hydrolysis. Each of 50g sample was soaked in a

distilled water of 500mL. Then, the samples were heated at 120^{o}C for 15 minutes and pressure was abruptly released until it declined to 0.5bar. When the temperature reached 100^{o}C, the pressure valve of the autoclave was closed to avoid delayed boiling in the sample vessel. This accidental pressure release enabled a partial decrystallization of the lignocellulosic biomass.

5.2.3 Dilute acid hydrolysis

To get the final result ethanol, each sample had to pass through three principal experiments that were in series; namely: hydrolysis, fermentation and distillation. The three-parameter and two-level ($2^3 = 8$) factorial design was applied to hydrolysis step of the experimentation. The factorial design was not applied to the remaining stages (fermentation and distillation) of the experiment. This was done for the following persuasive reasoning: each sample was made to pass through each of hydrolysis, fermentation and distillation.

In this research, the factorial design was applied to hydrolysis step and all changes in response were attributed to the changes in parametric values of the hydrolysis step alone. Table 5.1 shows the tabulated code of maximum and minimum values of hydrolysis parameters (temperature, acid concentration and hydrolysis time) that is designed according to the principles of factorial design.

5.2.3.1 The factorial design versus one-factor-at-a-time approach

The one-factor-at-a-time, in which experimental factors were varied one at a time, with the remaining factors held constant, was formerly regarded as the only correct way to conduct research. The method provides an estimate of the effect of a single variable at selected fixed conditions of other variables. However, for such an estimate to have general relevance it is necessary to assume that the effect would be the same at other settings of the other variable-that, over the range of current interest, the variables act on the response additively. However,

1. if the variables do act additively, the factorial does the job with more precision; and
2. if the variables do not act additively, the factorial, unlike the one-factor-at-a-time design, can detect and estimate interactions that measure the non additivity.

Table 5.1 Experimental design formulated for hydrolysis stage

Serial number	Hydrolysis temperature	Hydrolysis time	Acid concentration	Remarks
1	-	-	-	Mi Mi Mi
2	+	-	-	Ma Mi Mi
3	-	+	-	Mi Ma Mi
4	+	+	-	Ma Ma Mi
5	-	-	+	Mi Mi Ma
6	+	-	+	Ma Mi Ma
7	-	+	+	Mi Ma Ma
8	+	+	+	Ma Ma Ma
+ (Ma) = maximum value; - (Mi) = minimum value				

The hydrolysis experiment was carried out with autoclave. Excluding extra experiments carried out for optimization purpose, the experiments carried out with experimental design were 8 for hydrolysis step only. In two level-factorial design, the tendency of the response in relation to the change in level of each parameter only could be seen; but it does not give the whole history of it. From the tendency that was observed in the response, three extra experiments were carried out to optimize the parametric values of hydrolysis step for maximum ethanol yield. Direct and interaction effect of each parameter was calculated and theoretical combination of parametric values were set from the analysis.

To see the consistence between the theoretical ethanol yield at theoretical combination of parametric values and the actual result at that point, three extra experiments were carried out at and around the calculated best combination. The actual result of ethanol yield at theoretical combination was slightly more than what was expected. That part will be discussed in more detail in the “analysis and discussion” sections. The (-) sign in table 5.1 represents the minimum value of the respective parameter and the (+) sign represents the maximum value of the respective parameter. Table 5.2 shows the parameters in hydrolysis step and their respective maximum and minimum.

Three steps were carried out in the hydrolysis step and before fermentation:

5.2.3.2 The procedure

- The first step was to prepare the acid solution to the predetermined strength or concentration. The sulfuric acid originally at 97% (by volume to water) was taken and diluted to 1% and 5%.
- The dried and crushed sample of 10% V/W to the prepared dilute acid solution was then added into the glass vessel. 3L of water was added to the autoclave for steam production for each of the samples treated. Then the prepared sample was put into the autoclave with the vessels unlided. All hydrolysis experiments were carried out at the autoclave chamber pressure of about 1bar. The pressure in the chamber could be relieved by releasing steam through the top valve of the autoclave.
- The sample was then filtered to remove the non-fermentable lignin portion.
- Two parts (by volume) of water was added to the hydrolyzed mixture. 50g dried fruit waste sample was used for each experiment. The diluted hydrolyzed sample was then shaken for 1hour.
- The sample was conditioned to temperature of 30^{o}C before fermentation step was started. This was the temperature at which all fermentation experiments were carried out.

Table 5.2 Maximum and minimum values of parameters

	Minimum	Maximum
Hydrolysis temperature (^{o}C)	80	100
Hydrolysis time (minutes)	30	60
Acid concentration (% by volume to distilled water)	1	5

The tabulated numeric representation of the factorial design of this research is shown in table 5.3. For each one the factors in hydrolysis step, namely: acid concentration, hydrolysis time and hydrolysis temperature there are four low and four high levels in the design shown in the table (table 5.3).

Table 5.3 Numeric values of parameters in hydrolysis according to factorial design

Sample number	Acid concentration (% by volume)	Hydrolysis time (minute)	Hydrolysis temperature (^oC)	Coded representation of parameters
1	1	30	80	- - -
2	5	30	80	+ - -
3	1	60	80	- + -
4	5	60	80	+ + -
5	1	30	100	- - +
6	5	30	100	+ - +
7	1	60	100	- + +
8	5	60	100	+ + +

5.2.4 Sterilization

In this work, all fermentation equipments, samples and, cleaning and additive waters were sterilized in the autoclave used for hydrolysis purpose. The sterilization was carried out at a temperature of 120^oC and a pressure of about 1bar.

5.2.5 The fermentation step:

Initially, it was planned to carry out fermentation experiments in a modular bench top fermentor available in the chemical engineering lab. After installation of all components and auxiliary fittings, the PCU (primary control unit) of the fermentation setup could not recognize its modules. The modules constituted such features as:

- pH probe,
- Dissolved oxygen probe,
- Gas analyzer,
- Sparger,
- Pumps of additives and the main sample,
- Sampler,
- Level detector,
- Temperature sensor,
- Vessel heating jacket,
- Agitation motor and others.

It was after this trial that other fermentation setup was arranged in the laboratory with the absence of most of the above features.

The fermentation setup in this research constituted the following components:

5.2.5.1 Components of experimental setup

- Fermentation vessel of 1L or 500mL (both were used) size
- Plastic lid with hole at its center through which hollow glass tube was inserted. Cotton was inserted some 10mm deep in to the glass tube to prevent free air in to the sample and allow CO_2 out as the fermentation product.
- The thermostat, to control the temperature of the sample during the fermentation process at 30^oC which is the optimum temperature for fermentation process with saccharomyces cerevisiae.
- The beaker, in which the active part of the thermostat was placed in water for; the thermostat controls the sample temperature by circulating the water through the beaker.
- Stands, holding arms and fitting screws, to suspend the fermentation vessels in the beaker filled with water and also to hold the supporting metal bar in place.

5.2.5.2 Process description for fermentation

The fermentation experiments were carried out by using the components mentioned in section **5.2.5.1** in the following manner: As the fermentation step had to be kept constant (30^oC), the thermostat was used to keep constant the temperature of the water (in the beaker) in which the vessel containing the sample was suspended. The thermostat maintains the set temperature by circulating the water through the vessel containing beaker. The thermostat was supported by the beaker's edge and a flat metal bar placed on the beaker. The vessel containing the sample was suspended from the stand near the beaker. The vessel was lided and a hollow glass tube was inserted into the vessel's neck through the center of the plastic lid to let out the CO_2 produced as a fermentative product. The ginned cotton was loosely inserted into the glass tube to the depth of 10mm to guard the sample from ambient air and contaminating microorganisms.

5.2.5.3 The procedure of experiment:

- First, to separate soluble and fermentable solution from the non-fermentable lignin portion the hydrolyzed material was filtered.

- Then the hydrolyzed, filtered, diluted and shaken substrate was primarily checked for pH using a digital pH meter. The pH ranged from 2.2 (at 5% acid concentration) to 4.1 (at 1% acid concentration). The pH was then adjusted to 6 by adding 28% stock ammonia (without diluting it).
- The thermostat was then set at 30^{o}C and the prepared sample was dipped into the water-filled-beaker until a set temperature and temperature of the water in the beaker became equal.
- The yeast *Saccharomyces cerevisiae* (manufactured in France by S.I. Lesaffre) with the strain 'saf-instant' was weighed with the proportion of 1:10 to the weight of the dried and crushed sample in the hydrolyzed sample.
- The yeast was then added and stirred with the preconditioned substrate as above.
- The vessel was then lided and a piece of ginned cotton was inserted into the glass tube to a depth of about 10mm.
- It was then hanged on to the fitting stand and inserted into the beaker so that the sample level in the vessel was all covered by water.
- Fermentation was let to take place.
- 72 hours of fermentation, the sample was taken out and distilled.
- The parameters of fermentation i.e. incubation time, yeast concentration (yeast proportion) and fermentation temperature were set to be at 72 hour, 10% and 30^{o}C respectively.

The fermentation step also encompassed the process of yeast adaptation to the media. Brewery yeast was brought from Meta Abo Brewery Share Company from the recycling point called 'milk yeast'. This was done just to compare ethanol productivity of dry active yeast (*Saccharomyces cerevisiae*) and the milky slurry of recyclable yeast after brewing cycle.

In this step:

- Because of the fact that the yeast culture was previously accustomed to wort extracted from grain, the first task was to adapt the yeast to the new substrate (fruit wastes). For that purpose, 1kg of barely (which was made to germinate, 'biqil') was prepared, squashed, and mixed to the crushed and prepared sample 1:1 (w/w) for first pitching; 3:1 (w/w) for second pitching and 1:0 (w/w) for the

third pitching all at 4^{o}C. The time interval between each pitching was 48, 72 and 96 hours respectively. This was done to alleviate a strange exposure of the yeast to the new environment and substrate.

- Finally when the yeast was made to function on the sample, it could only produce 8mL of unknown proportion of ethanol out of 50g of dried sample, which is non-countable for comparison purpose.

5.2.6 Distillation

Distillation was the last step in the series of experiments carried out in this work. The following components were used in the distillation experiment:

5.2.6.1 Components of experimental setup

- Distillation vessel
- Special top-fit of distillation vessel
- Condenser
- 90^{o} diverting glass that fits at the end of condenser and the top of harvesting vessel
- Condenser tubings
- Harvesting vessel
- Stands and fixing screws
- The beaker
- The thermostat
- The thermostat supporting flat metal bar

Distillation experiments were the last principal experiments in the thesis. All distillation experiments were carried out at a temperature of 85^{o}C and a distillation time (counted from ambient temperature through to the set point) of 3 hours.

5.2.6.2 Process description for distillation

The distillation experiments were carried out by using the components mentioned in section **5.2.6.1** in the following manner: The condenser and the sample containing vessel were suspended from the stands. As used in the fermentation step, the thermostat was used in this experiment to maintain the distillation temperature at the set point of 85^{o}C.

Before the thermostat was started, the 'μ' shaped glass was fitted to both of the vessel neck and the condenser. Then, the harvesting vessel was fitted to the other end of the condenser. To condenser were also fitted water supply and discharge tubings for condensing purpose. Then, the thermostat was started. In 3hours counted from when the set temperature was reached, the yields were harvested.

5.2.7 Density measurement

A distillate was evaluated for its ethanol content; this was done by conditioning the distillate to a temperature of 20^{o}C and measuring the corresponding density of it. The density was measured with pycnometer. On the table taken for reference, the ethanol percentage of the solution is projected on a vertical axis and the temperature on horizontal axis at which the solution is measured for density. At all coordinate points are corresponding densities (Perry et al., p 3-89).

In this research, the temperature at which the solution density was measured was 20^{o}C and the average density of the solution was 0.81886g/cm^{3}. This value corresponded to the ethanol percentage of 89.45%. This was the ethanol yield per 50g of dry sample weight. Each of the ethanol yield values given in this work pertains to 50g of dry sample weight.

6 RESULTS AND DISCUSSION

The experimental results are shown in table 6.1. As discussed in the hydrolysis sections, factorial design was only applied to the hydrolysis step and not to the remaining steps of the whole experiment. It could have been possible to apply factorial designs to each one of the steps simultaneously. But it could not be possible to hold responsible any one singular step amongst the others as long as parameter values are changed in all steps simultaneously. That is why only hydrolysis step was selected to be investigated for its parameters at two levels.

The two-level factorial design is always direction-indicating strategy for further investigation. It shows the tendency of the response with respect to the change in levels of a given independent variable. This relationship is known as main effect of an independent variable. It can also indicate the interaction effect of independent variables among themselves.

Table 6.1 shows the numeric representation of parameter values of hydrolysis experiment and corresponding ethanol yield of this research.

Table 6.1 numeric entry of factorial design of hydrolysis experiment and the results

No	C (% by volume)	t (minute)	T (^oC)	Yield (Y_i) (mL/50gram)* (*ethanol in solution form*)	ρ At 20^oC (g/cm^3)	Volume of pure ethanol (V) (mL)
1	1	30	80	16	0.82323	14.08
2	5	30	80	21	0.81529	19.11
3	1	60	80	19.5	0.82062	17.36
4	5	60	80	25	0.80424	23.75
5	1	30	100	22.5	0.80983	20.93
6	5	30	100	23	0.80983	21.39
7	1	60	100	25.5	0.80138	24.48
8	5	60	100	14	0.82323	12.32
* the ethanol yield in mL was expressed per 50gram of dry sample weight						

6.1 Calculation of main and interaction effects

The analysis was focused on investigating the effect of acid concentration on ethanol yield at different levels of temperature and hydrolysis time.

80	30	1	16
80	30	5	21

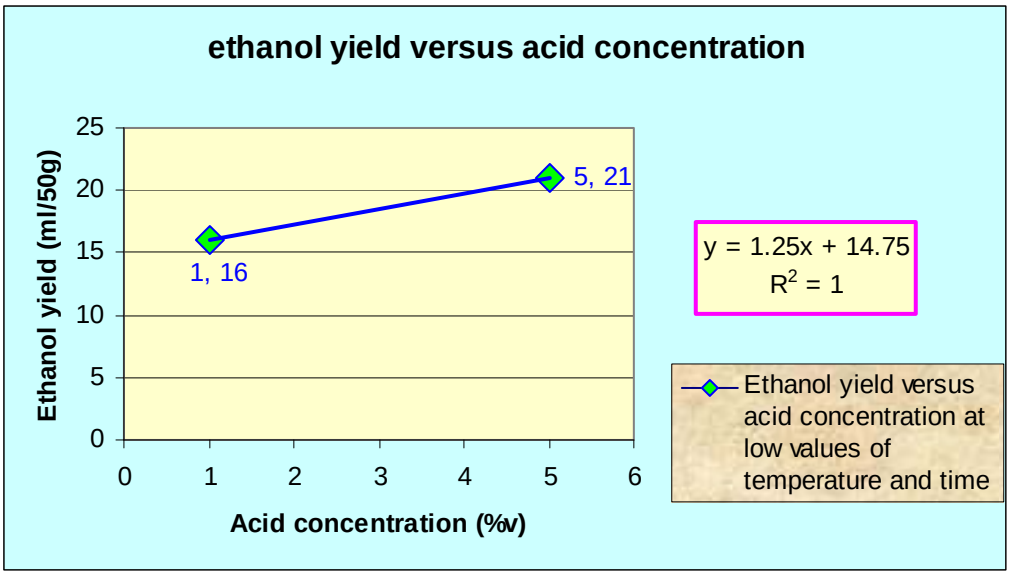

Figure 6.1 Ethanol yield versus acid concentration at low levels of temperature and time

As can be seen from figure 6.1, increase in level of acid concentration favored ethanol yield (from 16mL to 21mL) when both of hydrolysis and hydrolysis temperature were at their low levels. The main effect of acid concentration at low levels of temperature and time was 5.

100	60	1	25.5
100	60	5	14

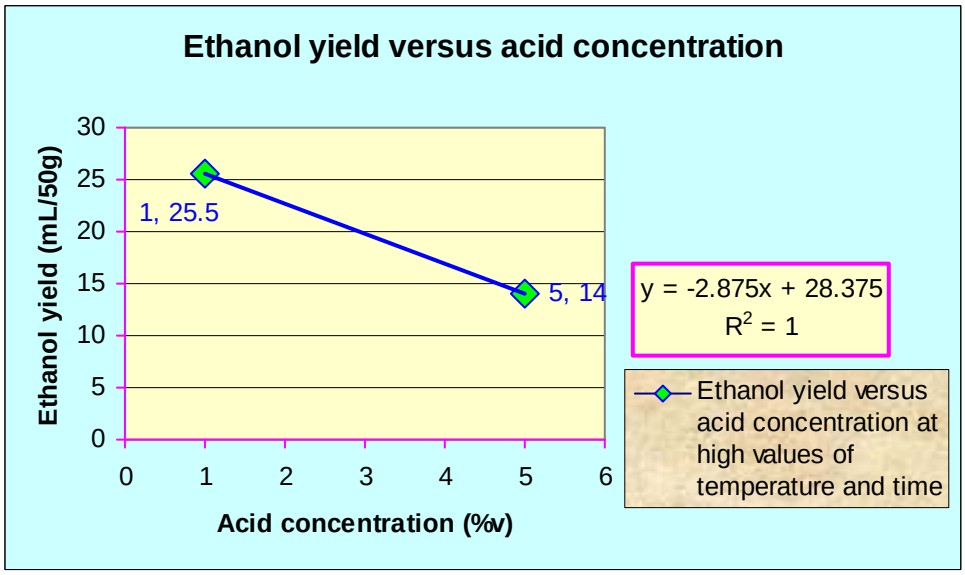

Figure 6.2 Ethanol yield versus acid concentration at high values of temperature and time

The rate of increase of ethanol yield when acid concentration was increased from 1% to 5% was reduced when both temperature and time levels were increased from low to high (see figures 6.1 and 6.2).

The slope of the ethanol yield curve at low levels of these parameters is 1.25 (figure 6.1) and the slope is -2.875 (figure 6.2) at high levels. The slope was reduced by 4.125. Now, because both temperature and time were increased from low level to high level simultaneously, it was not clear whether the reduction in the slope of ethanol yield curve was due to increase in level of temperature or time. Furthermore, the ethanol yield at the second coordinate was also reduced from 21mL/50g to 14mL/50g. To explicitly recognize the effect of each of temperature and time the levels were alternatively changed instead (see figure 6.3 and 6.4).

80	30	1	15.5
80	60	5	25

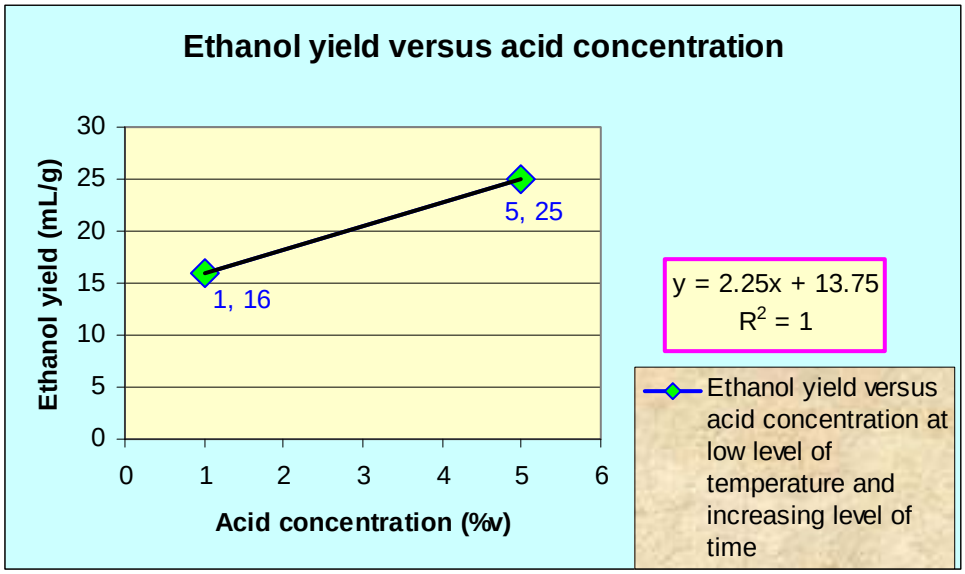

Figure 6.3 Ethanol yield versus acid concentration at low level of temperature and increasing level of time

When the time was increased from 30minutes to 60minutes, at the low level of temperature (80^{o}C) the slope of ethanol yield curve was 2.25 (figure 6.3) when acid concentration was increased from 1% (%v/v) to 5% (%v/v).

80	30	1	16
100	30	5	25.5

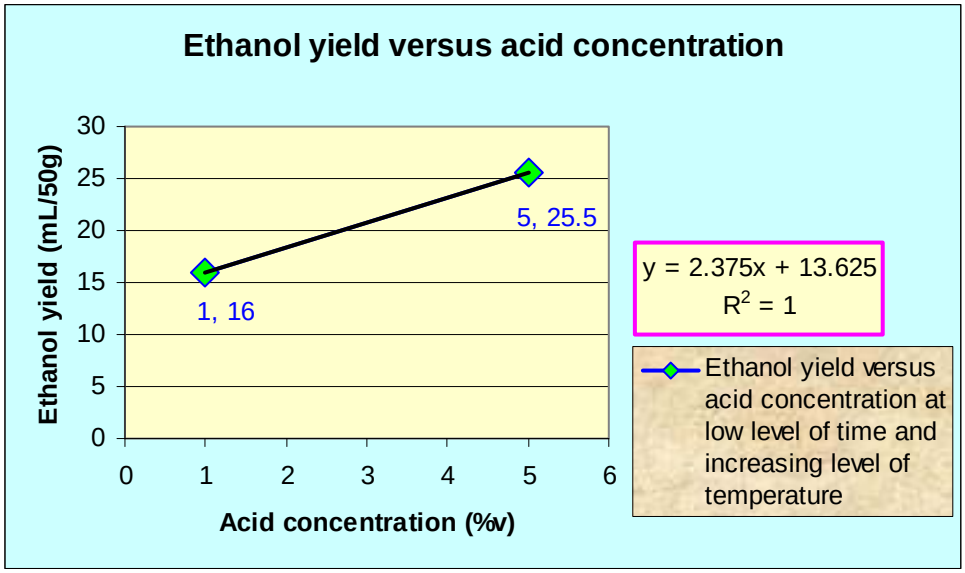

Figure 6.4 Ethanol yield versus acid concentration at increasing levels of temperature and low level of time

But when the time was held at low level (30minutes) and the temperature level was increased from low level (80^{o}C) to high level (100^{o}C) the slope of ethanol yield curve was 2.375 (figure 6.4). This shows the existence of interaction effect between temperature and acid concentration. The implication is that the decrement in level of temperature along with increment in level of acid concentration played a positive role on ethanol yield. When temperature was kept at low level and hydrolysis time at high level, increasing the acid concentration yielded high ethanol yield with increased rate.

Once this relationship was known, the main effects and interaction effects could be calculated.

6.1.1 Main effects

6.1.1.1 Averaging individual measures of effects

To calculate the main effect of one independent variable in a three-factor two-level factorial design, there are four combinations of pairs for which the level of the respective

independent variable switches from low level to high level of that parameter. This attribute pertains to each parameter that has participated in the experimental design (temperature, time and acid concentration in this case). Therefore, the main effects of acid concentration on ethanol yield (response) can be calculated as in the following: the main effect of acid concentration is found by subtracting the average of response variable (ethanol yield) at low level of acid concentration from average of response variable (ethanol yield) at high level of acid concentration for all possible combinations. In short, the main effect of acid concentration is calculated as average response variable (ethanol yield) at high level of acid concentration minus average response variable (ethanol yield) at low level of acid concentration (see table 6.2).

Table 6.2 main effects of acid concentration

Individual measure of the effect of changing acid concentration from 1 to 5%	Condition at which comparison is made	
	Time (t)	Temperature (T)
y_2-y_1 = 21-16 = 5	30	80
y_4-y_3 = 25-19.5 = 5.5	60	80
y_6-y_5 = 23-22.5 = 0.5	30	100
y_8-y_7 = 14-25.5 = -11.5	60	100
Main effect of acid concentration is $= \left\{\frac{5+5.5+0.5-11.5}{4}\right\} = -0.125$		

$$\textit{Effect of acid concentration} = \left\{\frac{14+23+25+21}{4}\right\} - \left\{\frac{25.5+22.5+19.5+16}{4}\right\} = -0.125$$

In the same manner the main effect of hydrolysis time can be calculated by subtracting the average response variable (ethanol yield) at low level of time from the average response variable (ethanol yield) at high level of time (see table 6.3).

Table 6.3 main effects of hydrolysis time

Individual measure of the effect of changing time from 30 to 60minutes	Condition at which comparison is made	
	Acid concentration (C) (in % by volume)	Temperature (T) (in ^{o}C)
Y_3-y_1 = 19.5-16 = 3.5	1	80
y_4-y_2 = 25-21 = 4	5	80
Y_7-y_5 = 25.5-22.5 = 3	1	100
y_8-y_6 = 14-23 = -9	5	100
Main effect of time is $= \left\{\frac{3.5+4+3-9}{4}\right\} = 0.375$		

$$\textit{Effect of time} = \left\{\frac{19.5+25+25.5+14}{4}\right\} - \left\{\frac{16+21+22.5+23}{4}\right\} = 0.375$$

In the same manner, the main effect of hydrolysis temperature is calculated by subtracting the average response variable (ethanol yield) at low level of temperature from the average response variable (ethanol yield) at high level of hydrolysis temperature (see table 6.4).

Table 6.4 Main effects of hydrolysis temperature

Individual measure of the effect of changing temperature from 80 to 100^{o}C	Condition at which comparison is made	
	Acid concentration (C) (in % by volume)	time (t) (in minutes)
Y_5-y_1 = 22.5-16 = 6.5	1	30
Y_6-y_2 = 23-21 = 2	5	30
Y_7-y_3 = 25.5-19.5 = 6	1	60
y_8-y_4 = 14-25= -11	5	60
Main effect of temperature is $= \left\{\frac{6.5+2+6-11}{4}\right\} = 0.875$		

That is,

$$Effect\ of\ temperature = \left\{\frac{22.5+23+25.5+14}{4}\right\} - \left\{\frac{16+21+19.5+25}{4}\right\} = 0.875$$

As can be seen from tables 6.2, 6.3 and 6.4, the effect of acid concentration is lower than both effects of hydrolysis time and hydrolysis temperature. But it is not directly apparent from this analysis whether the effect of acid concentration is favored or negatively affected by changes in levels of the remaining factors (temperature and time). To clearly see the effect of change in levels of other parameters on the main effect of acid concentration, high and low levels of temperature and time were treated separately.

At low level of temperature the main effect of acid concentration is 5.25 and of hydrolysis time is 3.75. In similar fashion, at high level of hydrolysis temperature the main effect of acid concentration is -5.5 and of hydrolysis time is -3. When the main effects of acid concentration and hydrolysis time were compared at low and high levels of temperature both effects were seen to decrease from low level to high level of temperature. The main effect of acid concentration was decreased from 5.25 to -5.5 and the main effect of hydrolysis time was decreased from 3.75 to -3. This means that both acid concentration and hydrolysis time favor the quantity of ethanol yield at low level of hydrolysis temperature. At low level of hydrolysis temperature (80^oC) the main effect of acid concentration is 5.25 and it is -5.5 at high level of hydrolysis temperature (100^oC). The main effect of hydrolysis time also declined from 3.75 to -3 when temperature is varied from low level to high level. These tendencies reveal that the main effects of both factors (acid concentration and hydrolysis time) are dependent on the level of hydrolysis temperature.

From this analysis it could be seen that the factors have interaction effects on one another in addition to their main effects.

6.1.2 Interaction effects

Interaction effects are effects that independent variable impose on one another. All controllable factors are obvious variables which affect the out put of the response variable. In factorial design all factors are made to vary simultaneously in a systematic way. When the levels of more than one factor are made to vary, two things happen: one is that each factor has its own intrinsic nature of affecting the response variable when it is

varied. Secondly, its variation may affect the effects of other factors on the response variable or be affected by others. The second phenomenon is interaction effect between independent controllable variables. In this research, there are three controllable factors in the hydrolysis step, namely: hydrolysis temperature, hydrolysis time and acid concentration. As explained in section 6.1.1, the main effects of acid concentration and hydrolysis time depended on the level of hydrolysis temperature.

There could be three combinations of factors when two factors are taken at a time: acid concentration by time (C×t), acid concentration by temperature (C×T) and temperature by time (T×t). In the second case all the three factors are treated at a time.

6.1.2.1 Taking two factors at a time

6.1.2.1.1 Interaction between acid concentration and hydrolysis temperature

The interaction between hydrolysis temperature and acid concentration is calculated by subtracting the average main effect of acid concentration at low hydrolysis temperature level from the average main effect of acid concentration at high hydrolysis temperature level. That is, from table 6.2

$$T\times C = \left\{\frac{\left(0.5+\left(-11.5\right)\right)-\left(5+5.5\right)}{2}\right\} = -10.75$$

6.1.2.1.2 Interaction between hydrolysis temperature and hydrolysis time

Following the same procedure, the interaction of time by acid concentration can be calculated from table 6.3 as shown below.

$$t\times C = \left\{\frac{\left(4+\left(-9\right)\right)-\left(3.5+3\right)}{2}\right\} = -5.75$$

Now the question is, “how can we find the theoretical optimum point from this analysis?”. The answer is, in addition to main effects of the factors (temperature, time and acid concentration) on the overall scenario, main effect of each factor should be analyzed at different levels of other factors.

6.1.3 Analysis, interpretation and description

To start with, the main effect of acid concentration was calculated for low and high levels of hydrolysis temperature and hydrolysis time. The main effects of acid concentration were 5.25 and -5.5 for low and high levels of hydrolysis temperature

respectively. This showed that the increase in acid concentration resulted in increased ethanol yield at low level of hydrolysis temperature. Therefore if acid concentration had to play positive role in ethanol production from fruit wastes, low temperature operations were preferable. Or else, acid concentration be kept low and temperature be increased depending on whether economic optimum or technical optimum is the choice or the combination. Technically optimum operations do not necessarily provide economically optimum performances.

To opt from or to systematically combine the two optimums, such variables as environment socio-economic situations and accessibility of relevant technologies must be evaluated profoundly. From environmental point of view, pollution-free or closed-loop systems are preferred to environmental unfriendly and open end processes. Taking in to consideration the economy of production any ways, using as low quantity of chemicals as possible is beneficial for environment in that treatment and disposal costs are significant portions of production costs. Therefore, using as minimum acid as possible is advisable if possible. Increasing hydrolysis temperature and reducing acid concentration could be economically feasible and environmentally beneficial as heat for steam generation could be derived from non-fermentable lignin-rich fraction of the waste with out the threat of any polluting emissions. When the main effect of hydrolysis time was seen, it declined from 3.75 to -3 from low to high level of hydrolysis temperature. This means that the hydrolysis time affected the response variable positively at low level of hydrolysis temperature. Giving longer time for reaction at low level of temperature and low acid concentration was seen to give higher ethanol yield.

It was also possible to calculate and interpret the main effects of acid concentration at low and high levels hydrolysis time. Accordingly, the main effects of acid concentration were 2.75 and -.2.5 at low and high levels of hydrolysis time respectively. This implied that increased acid concentration at longer time of reaction would not result increased ethanol yield. Therefore, as long as longer reaction time was permitted, there was no need of increasing acid concentration. When the above conclusions were compiled to one, high hydrolysis time and high hydrolysis temperature would yield maximum ethanol yield at low acid concentration. This conclusion was consistent with the actual data at 1% acid concentration 60minutes hydrolysis time and 100^{o}C hydrolysis temperature. From table

6.1 the maximum ethanol yield found was 25.5mL at (1% v, 60minutes, 100^{o}C) of acid concentration, hydrolysis time and hydrolysis temperature respectively. Now, from the tendencies of the response variable it was seen that increasing temperature would give high ethanol yield. Hypothetical combination of factor values were theoretically set at 1%v/v (acid concentration), 60minutes (time), 150^{o}C (temperature) and three actual samples were tested around and at that selected point including the point itself to locate the global optimum factor combination

6.1.4 Tendency analysis of the response variable

Now, once the main and interaction effects were calculated in the previous section, the next step would be analysis of response tendencies at different levels of hydrolysis time and hydrolysis temperature; in the above analysis it was clearly stated why low level of acid concentration was opted. In this section all tendencies of main response were evaluated for change in levels of temperature and time, but at fixed (low) level of acid concentration. Accordingly, the tendency of average ethanol yield with respect to change in the level of hydrolysis temperature was characterized by equation

$$Y = 0.3125T - 7.25$$

where, Y is average ethanol yield and

T is hydrolysis temperature

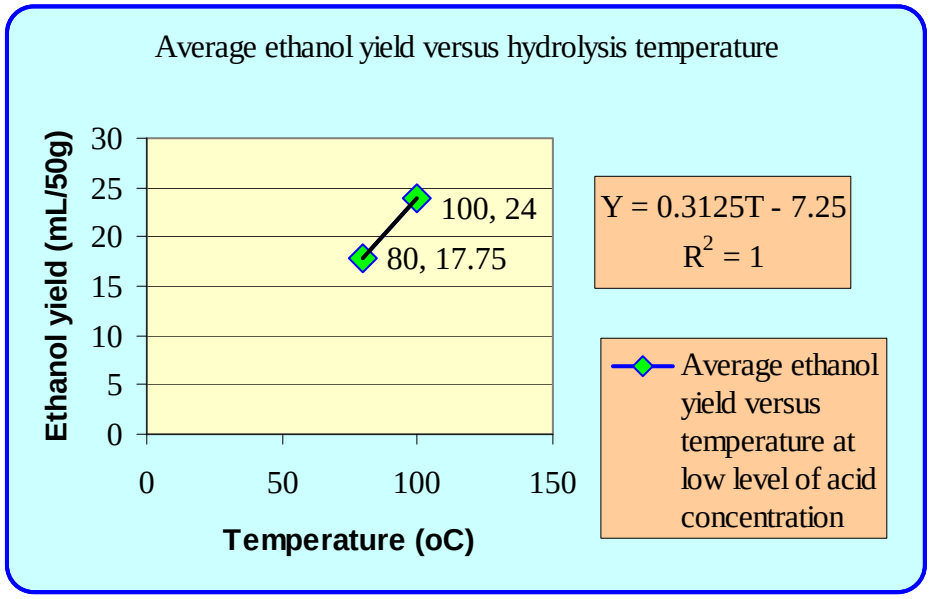

Figure 6.5 Average ethanol yield versus temperature at low level of acid concentration

As can be seen from Figure 6.5, the increase in hydrolysis temperature by 1 unit (1^{o}C) resulted in the increase of response variable (ethanol yield) by 0.3125units (mL). Note that the linear equation is valid for the temperature range of 80^{o}C to 100^{o}C. But increasing the hydrolysis time by 1 unit (1minute) resulted in the increase of the response variable by only 34% of that which can be increased by hydrolysis temperature. The linear equation that defines the relationship between average ethanol yield and hydrolysis time at low acid concentration level is given by

$$Y = 0.1083t + 16$$

where, Y is the average ethanol yield and

t is the hydrolysis time

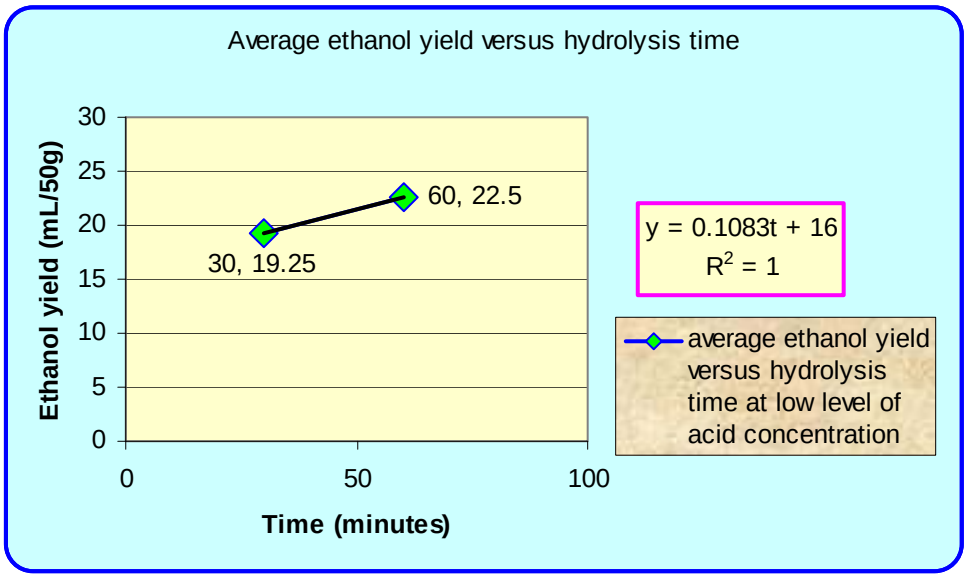

Figure 6.6 Average ethanol yield versus hydrolysis time at low level of acid concentration

From the equation $Y = 0.1083t + 16$, it was clear that the increase in hydrolysis time by one unit resulted in the increase of average ethanol yield by only 0.1083. Therefore, the conclusion was that increasing the temperature above the maximum level that was set for this research outdoes increasing of hydrolysis time even though both of the factors affected the response positively. This implied that increasing hydrolysis temperature was more economical than was increasing hydrolysis time in technical terms. This could be supported further with two extra supportive evidences: the first one was, increased

hydrolysis time along with hydrolysis temperature gives rise to the formation of inhibitive products. Secondly treating reducing sugars that were already in the sample at high temperature and longer time entails the degradation of fermentable sugars; it is obvious that there were limited quantities of reducing sugars in the fruit peels and remains.

Figures 6.5 and 6.6 were derived from table 6.5. As can be seen from the table, all factors were analyzed at their low and high levels except acid concentration which was set at its low level.

Table 6.5 Effect of hydrolysis time and temperature at low level of acid concentration

No	Hydrolysis temperature(^oC)	Hydrolysis time(minutes)	Ethanol yield (mL/50g)	Acid concentration (%v)
1	80	30	16	1
3	80	60	19.5	1
5	100	30	22.5	1
7	100	60	25.5	1

The term average was used with ethanol yield in the above analysis because there were two low and two high levels for each of temperature and time. Therefore the ethanol yield was taken as average for both levels and for each factor. Depending on this analysis three practical experiments were carried out by varying hydrolysis temperature only. Table 6.6 shows the results of the final experiments.

Table 6.6 Results of the optimization experiments

No	T (^oC)	t (minutes)	Y (mL/50g)	C (%v)	ρ (g/cm^3)	Pure ethanol (mL)
9	120	60	26	1	0.80705	24.44
10	150	60	18	1	0.81797	16.2
11	180	60	12	1	0.87477	8.04

As can be seen from table 6.6 the maximum ethanol yield obtained was 26mL/50g at the factors combination of 120^{o}C, 60minutes and 1%v of acid concentration. Now, to find

the optimum factors combination, interpolation between sample 7 and sample 9 was carried out. The figure in figure 6.7 was derived from table 6.7. In going from low to high level of hydrolysis temperature (100 to 120^{o}C), the response variable (ethanol yield) could only increase from 25.5 to 26mL/50g-which can be considered as experimental or analysis error. At high level of hydrolysis time, increasing hydrolysis temperature by one unit only resulted in increase of ethanol yield by 0.025 units. When the hydrolysis temperature was increased from 100^{o}C to 120^{o}C the ethanol yield could only increase from 25.5mL/50g to 26mL/50g which could not technically be considered as significant difference. On the other hand, the absolute volume of ethanol in the 26mL and 25.5mL solutions were 24.44mL and 24.48mL respectively.

Table 6.7 Comparison of high-ethanol-yield points

No	T (^{o}C)	t (minute)	ethanol yield(Y_i) (mL/50gram)	C (% by volume)
7	100	60	25.5	1
9	120	60	26	1

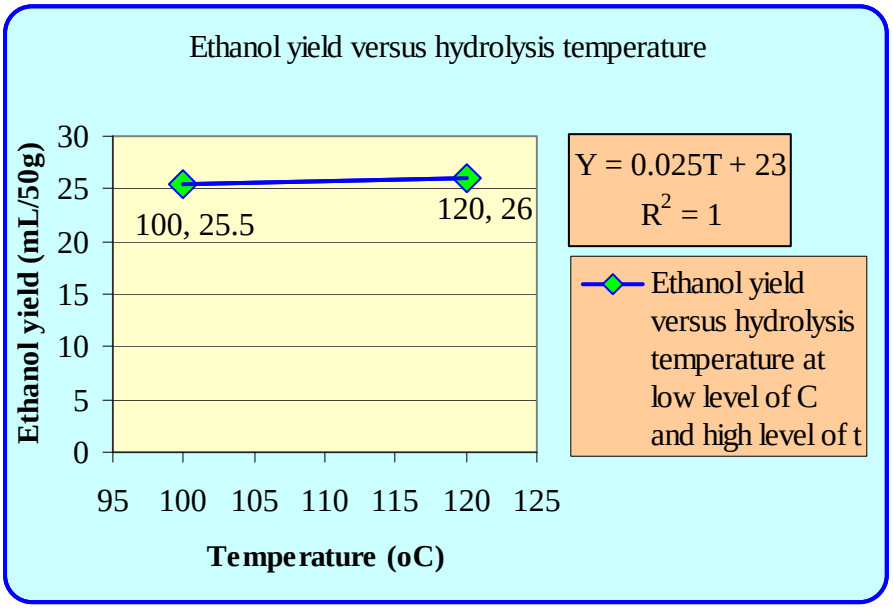

Figure 6.7 Ethanol yield versus hydrolysis temperature at low level of acid concentration and high level of time

Therefore, the optimum combinations of the three factors chosen for optimum ethanol yield were 100^{o}C (hydrolysis temperature), 60minutes (hydrolysis time) and 1%v acid concentration. From economic point of view, the difference of 0.5mL of dehydrated

ethanol means no value in monetary terms. Furthermore, the ethanol content of the solution found at this combination is greater than that which was found at 120^{o}C (hydrolysis temperature), 60minutes (hydrolysis time) and 1%v/v acid concentration. Even if that figure (0.5mL) as a significant difference, the energy expended to produce it was the energy that was gone to increase the temperature of the mixture (sample, acid and water) from 100^{o}C to 120^{o}C. Therefore, the optimum combination of the factors was set to be 100^{o}C, 60minutes and 1%v for temperature, time and acid concentration respectively. This was global optimum combination of the factors. The local optimization usually requires hundreds or perhaps thousands of experiments between these two temperature values (100^{o}C and 120^{o}C). The gross choice between these two factors values do not purely rely on the technical success of the experiment. It also had to consider the economic variables of ethanol production and also whether the production is pilot scale or large scale; that is not the scope of the research.

7 ENVIRONMENTAL IMPLICATION OF CONVERTING FRUIT WASTES TO ETHANOL

Yeka is one of the ten sub cities found in Addis Ababa city administration regional state. The populations' number of the sub city in 2006 was 397,236(source: Yeka sub city Trade and Industry Department, 2008) and 428,000 in 2008 when projected by the annual population growth rate of 3.8%. In this sub city, there are 219 fruit and vegetable shops, 7 fruits shops and 103 vegetables shops (source: Yeka sub city Trade and Industry Department).

From interviews taken from 10 shops it was seen that the average daily sale of banana was 52.5kg/shop/day and of mango 66.5kg/shop/day. The supply of mango completely curtails at the end of July and begins at the beginning of October. To determine the quantitative contribution of fruit wastes to the total municipal solid waste, the fruit peels and remains quantitative proportion had to first be calculated; banana peel makes up 65% and mango peel makes up 35% of the total fruit mass of the fruits respectively. As mentioned above, the total number of legally registered fruit and vegetable shops were known to be 226 in number. Their market shares significantly differ from shop to shop and from area to area. Because of unwillingness of most of the fruit and vegetable shop owners and workers, strictly reliable data could not be found by interviewing them as to how much exactly they buy and sell per day per shop. By being based on the data found from the sub city trade and industry department and the fruit and vegetables themselves the estimated daily dispatch of the fruits from the shops were calculated as follows: Banana daily sale = 52.5kg/shop/day * 226shops = 11,865kg/day. The peel was considered to be 65% of the total fruit mass; therefore, 0.65*11865kg/day = 7712.25kg/day of peel was generated from registered fruit and vegetable shops leaving alone that which is generated from informal (unregistered) shops and mobile, manually driven carts. In the same manner the mass of mango peel generated per day in the sub city was calculated to be 5260.15kg. According to Fitsum (2007), the household solid waste generation rate of French Legasion area (one of the areas in the Yeka sub city) was 1.372 Kg/cap/week and 5.88 Kg/cap/month, respectively. This is equal to 0.196kg/cap/day. If this could fairly be applied to the whole sub city, the total solid waste generated from households would be 0.196*428,000 = 83,888kg/day. The fruit peels sum up to

12972.4kg/day. The assumption is that all fruit shops in the sub city sell their fruits to the people in the sub city and all fruit wastes are collected with in the boundaries of the sub city. It was also found from the interview that 5% (during summer) to 10% (during winter) by mass of the total fruit wastes gets degraded by mechanical damage incurred by fruits during transportation and/or microbial decomposition of ripe fruits after delivery. This implies that the total fruit wastes sum up to 13621.02kg/day by taking the minimum percentage of ruining (5%).

The fruit wastes amount to 16.2% by weight of these municipal solid wastes in total. Therefore, treating these wastes to produce green energy (ethanol from biomass) goes two journeys in to the prevailing problem; the first is that it alleviates the environmental pollution caused by the fruit wastes. As organic portion of the municipal solid wastes are known to bring about such immediate environmental damages as increased surface and ground water BOD and COD, hosting of pathogens and vectors, methane generation, fast dissemination in to water, soil (due to high solubility) and air due to microbial decomposition, they need exceptional care and immediate actions. Mitigating the environmental pollution caused by this category of wastes along with derivation of such useful energy resources as ethanol is a twofold victory. The second advantage is obvious from the increasing need of alternative energy and the likely-declining supply of fossil-based fuels and energy forms. This has two perspectives:

- The first perspective is that the oil price is increasing very rapidly than ever; this may be attributed to the world's political instability and the threat of curtailment of crude oil supply. In October 1973, as a result of the Arab-Israeli War, the Arab oil-producing countries cut back oil production and embargoed oil shipments to the United States and the Netherlands. Although the Arab cutbacks represented a loss of less than 7% in world supply, they created panic on the part of oil companies, consumers, oil traders, and some governments. Wild bidding for crude oil ensued when a few producing nations began to auction off some of their oil. This bidding encouraged the OPEC nations, which now numbered 13, to raise the price of all their crude oil to a level as high as eight times that of a few years earlier. In 1978 a second oil crisis began when, as a result of the revolution that eventually drove the Shah of Iran from his throne, Iranian oil production and

exports dropped precipitously. Because Iran had been a major exporter, consumers again panicked. A replay of 1973 events complete with wild bidding again forced up oil prices during 1979. The outbreak of war between Iran and Iraq in 1980 gave a further boost to oil prices. By the end of 1980 the price of crude oil stood at 19 times what it had been just ten years earlier.(Source: Microsoft ® Encarta ® 2007. © 1993-2006 Microsoft Corporation)

- The second perspective is the associated environmental pollution that is incurred by air (atmosphere), ground and surface waters and the soil. Crude oil (petroleum) entails environmental pollutions in many dimensions from the extraction and refining stages through to the end use of principal products such as kerosene and gasoline. This environmental pollution induces the search for other economically competitive energy sources whose sources are green (renewable). Ethanol and biofuels from biomass are examples of these types of energy sources.
- The oppositely propagating tendency of world demography and petroleum stock is also the very puzzle of the century; World population growth varies from less than 1% in United States, Europe and Russia, to 3% and higher in most African and the Middle East countries. (Source: Encarta Encyclopedia. @Microsoft Corporation, 2007).

The increasing world population number obviously increases the need for energy; in converse, the supply of fossil-based energy sources is declining from time to time. This oppositely oriented progression of these phenomena has greatly stressed politicians and scientists to search for other alternatives of energy sources which are green in nature. Such energy forms as wind energy, solar energy, geothermal energy, and hydroelectric energy are given special attention because they do not release green house gases and are reliable future energy source.

Green energy sources are those which are renewable and of biomass origin; this encompasses straws, corn, sugarcane, organic portion of municipal solid waste, jatropha and other sources of biomass. The cheapest raw material for ethanol production, with possibly negative price, could be organic portion of municipal solid waste in developing countries of our type. Table 7.1 shows the fruit shops' daily selling of banana and mango fruits in the sub city. The quantified description of fruit wastes in the sub city mentioned

above was derived from the data in this table and the information found from trade and industry department of the sub city.

Table7.1 Daily retailing of banana and mango fruits of ten fruit and vegetable shops

Identity	Banana sale (kg/day)	Mango sale (kg/day)
Shop 1	65	80
Shop 2	35	65
Shop 3	45	85
Shop 4	40	65
Shop 5	75	70
Shop 6	65	50
Shop 7	55	65
Shop 8	70	55
Shop 9	35	60
Shop10	40	70
	MEAN = 52.5	MEAN = 66.5

In Addis Ababa context, the fruit wastes amounts to 16.2% by weight of the total municipal solid wastes generated in the city. The aggravated worsening of municipal-solid-waste-related environmental pollutions and the possibility of ethanol production from selected categories of these wastes evacuates the very negatively-oriented criticisms against the need for this research. Ethanol production from green sources is the economic and environmental target of the governments of this age. The inevitable event of curtailment in fossil-based fuels supply and the deteriorative environmental consequences of their use highly excited the global market for ethanol and other biofuels.

Ethanol production from selected municipal solid wastes was the criterion purpose of this research.

8 CONCLUSIONS

- **Availability and accessibility of the fruit wastes*:*** It could be seen from the experimental analysis that ethanol production from banana and mango fruit wastes was surely possible. The difficult task in this business would be the collection and storage mechanism. From analysis of the interviews taken from 10 fruit and vegetable shop owners, it could be understood that more than 90% of the banana was sold and peeled out of the fruit shops. Conversely, most of the mango imported in to the shop is peeled in there and prepared in to juice. This implies that mango peels and remains can be abundantly retrieved from fruit and vegetable shops through negotiations. Most of the fruit and vegetable shops revealed that they pay up to 100birr per month for disposal services of the fruit wastes with the penalty of non-timely collection of the wastes. Therefore, mango wastes can be retrieved from fruit and vegetable shops with out price. When banana is concerned, most of the fruit is sold out to the customers and used out there. Banana peel is, therefore, more abundantly prevalent in the trash containers of households and communal solid waste containers. Separate and instantaneous collection of the waste requires the oriented awareness and willingness of the community in general as integrated to the business sectors that are likely to join this business.

- **Factorial design:** In this research, three experiments were carried out in series (one after the other) for each of the sample: hydrolysis of the lignocellulosic biomass in to simple and fermentable sugars, fermentation of the sugars and distillation of the fermented solution to extract ethanol. A 2^3 factorial design was formulated for the hydrolysis step only. That was done to specifically and clearly investigate the effect of hydrolysis process on the production of ethanol from banana and mango peels and remains. The maximum ethanol yield found in this experiment was 25.5mL/50g of dehydrated (96% ethanol) or 24.48mL/50g pure ethanol.

- **Economics of the result:** This research was conducted with three principal experiments in series: hydrolysis, fermentation and distillation. Each sample was passed through all experiments in a series manner one after the other. As repeatedly explained, while it was technically possible to be formulated for all, the factorial design was formulated for the hydrolysis step only. The reason is evident from the following persuasive explanation: each sample was passed through hydrolysis, fermentation and distillation in series. Factorial design could have been formulated for each of the experiments simultaneously. If that had been done, there was no way to visualize the effect of each experiment explicitly on the response variable (ethanol yield). In this research, the factors in fermentation (incubation time, yeast strain and concentration, fermentation temperature and pH) and the factors in distillation (distillation temperature, distillation time, reflux ratio etc) were kept constant while factors in hydrolysis step were varied according to the factorial design. Because of this, the variation in the response variable was purely attributed to the hydrolysis step. It is clear that the factor combination of hydrolysis step could be optimized for high ethanol yield; but the ethanol yield found for that optimal factor combination is not necessarily the maximum possible obtainable ethanol quantity as the remaining influential experiments were not optimized. Therefore, carrying out economic analysis would not be relevant and reliable before all experiments will be optimized. So, economic analysis could not be included into this research work at this stage of research maturation.
- **The input of the research:** The main difficulty in ethanol production from conventional sources is that raw material availability is limited and, on the other hand 75% food-material inflation (worldwide) is attributed to using conventional feedstock for ethanol production. As biofuels are very essential for the environment and the economy when they are produced from lignocellulosic biomass, selection of the cheap and appropriate raw material is big task. Municipal solid wastes are so free resources that we can not afford to forgo the opportunity of using it to produce ethanol. Many researches were and are being carried out as to how to use the lignocellulosic material for ethanol production.

One of these researches was carried out by Brooks, (2008) on fermentation of banana peels to ethanol. He found that s*accharomyces cerevisiae* R-8 exhibited rapid fermentative potential, improved flocculating ability, appreciable osmotolerance, enhanced ethanol tolerance and good thermo tolerance. The main theme and input of this research was optimization of the hydrolysis step which requires parameter tuning depending on the feedstock used. The hydrolysis step was optimized for factors: acid concentration, time, and temperature to hydrolyze banana and mango peels and remains. Therefore, impending research on this area can utilize the optimum parameters of hydrolysis step (this thesis) and the optimum parameters in fermentation by Brooks, (2008).

9 RECOMMENDATIONS

Converting the ‘troublesome’ municipal solid waste into green energy ‘Ethanol’ is very interesting business both from environmental and economic points of view. From environmental point of view, primarily, reducing the municipal solid waste by 16.2%w is doing much in sharing the municipality’s burden. Secondly, using ethanol purely or blended with gasoline in internal combustion engines reduces the greenhouse gases and increases the efficiency of gasoline by increasing its octane rating. From economic point of view, producing ethanol from cellulosic biomass means reduction of reliance on imported fossil-based fuels whose prices are soaring from time to time. Municipal solid waste is a freely fetchable raw material for production of ethanol. Conversely, it is a ‘problem’ instead of a ‘resource’ in the context of Addis Ababa. This means that alleviating a problem caused by it and making use of it is a twofold victory. Therefore, I recommend the following:

1. Production of energy carriers like ethanol from a free resource like organic portion of municipal solid waste is doubtlessly an attractive business from economic and environmental point of view. But, as Cellulosic ethanol production is not a single step process, it needs further researching and investigation to bring the business to profitable commercialization. In this research, the parameters (factors) in hydrolysis step were locally optimized. Other researches have to be carried out to optimize the fermentation and distillation steps so that the maximum obtainable quantity of ethanol would be obtained. Finally, the implementation cost and the environmental and social benefits of its implementation have to be researched.
2. The most difficult task of this business is collection and storage mechanism of the fruit wastes. Fruit wastes are highly susceptible to microorganisms and have to be collected and processed as early as possible. But fruit wastes are found very scattered in negligible density. Therefore, community-integrated collection mechanism has to be devised and implemented for this business to be successful. But this requires rigorous study which is based on the reality of the city and people residing in it.

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CONVERSION OF SELECTED ADDIS ABABA MUNICIPAL SOLID WASTE TO ETHANOL

(Case of Yeka sub city)

By: Ashenafi Taye
Advisor: Prof. W. Sokol

January 2008

Table of contents

1 Introduction

The Addis Ababa municipal solid waste:

1

Generation rate in Addis Ababa

- 851ton/day
- 76%(household), 9%(commercial facility), 6%(street sweeping), 5%(industry), 3% (hotel), 1%(hospitals) [AASBPDA, 2004]
- 83.888ton/day is contributed by Yeka Sub city (9.86%)
- Banana = 7712.25kg/day
- Mango = 5260.15kg
- Including 5% remain = 13621.02kg/day
- Banana and mango wastes amount to 13.62ton/day

2 Collection and treatment:

2.1 Collection

Only about 65% is collected by the municipality trucks (1% of CG budget)

Waste in Addis is commonly found

- **Clogging the drains**
- **Piled up at street sides**
- **Accumulated in market places**
- **On open lands**
- **Burning in open air (smoky) etc…**

Disposal and/or treatment

No engineered sanitary land fill:

- Disposed of Rephi open-dumping-site
- Only 13km from city center
- Surrounded by residential areas and ring road

Treatment options available in Addis:

- 5% recycling (metals and plastics)
- Other wastes are considered worthless
- Poor disposal is the only option here.

2 Statement of the problem

MSW ranked top of environmental problems in Addis (Meson, 1999)

- **GHG emissions (air pollution)**
- **Leachate to ground water**
- **Breading place for insects**
- **Possibility of epidemics (pathogens)**
- **Aesthetics (tourism)**
- **Opportunity of ethanol production from organic portion (environmental and economical)**

Statement of the Problem continued…

- Ethiopian government is promoting ethanol-benzene blend (E5) currently.
- Ethiopia is projecting to produce 86 million L/year after 5 years from molasses (13th, November ETV)
- 75% of food-material inflation is attributed to using food grains for ethanol production (so?).

This research was initiated to:

- Solve the environmental problem by MSW
- produce 'ethanol' from the problem to be solved (environmentally worst free resource MSW)

4 Scope of the research

The scope of the research is limited to experimental investigation and analysis of hydrolysis of fruit wastes (banana and Mango wastes) and parameter optimization for the same globally.

- **Waste selection**
- **Experimental analysis**
- **Data analysis and interpretation**
- **Optimum point setting**
- **Environmental and economic implication**

5 Objectives

5.1 General objective

The general objective of this research was to carry out experimental analysis of conversion of selected Addis Ababa (Yeka Sub city) municipal solid wastes (fruit peels and remains) to ethanol.

5.2 Specific objective

The specific objective of this research was to optimize the hydrolysis parameters (factors), namely: time, temperature and acid concentration to obtain the highest possible yield of ethanol.

6 Materials and methodologies

6.1 Materials, equipments and auxiliaries

Yeast

- Dry *saccharomyces cerevisiae* **(Y)**
- Brewery yeast **(N)**

Sample used

- Banana(70%)
- Mango (30%) dry weight

Chemicals used

- Sulfuric acid (97%vw)
- Ammonia (28%vw)
- Non-distilled and distilled water


Banana peel


Mango peel

Equipments

- Crusher
- pH meter
- Sieve
- Incubator
- Digital drier
- Knife
- Plastic bags
- Pycnometer
- Shaker

6.2 Methodologies

6.2.1 Sample acquisition and preparation

Sample acquisition (from fruit shops)

Sample handling (crushed and cool)

Sample sorting (into banana and mango)

Manual size reduction (20mL)

Sample drying (60 ºC, from 72-96 hours)

Sample proportioning (70%B : 30%M)

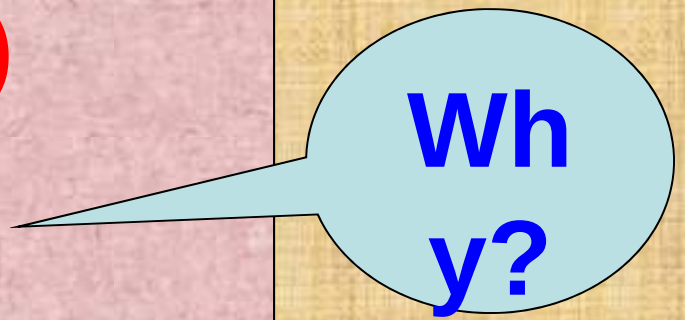
Sample grinding (<= 3mm)

Dilute acid hydrolysis

Factorial design

23 =8 (for hydrolysis only)

hydrolysis-----fermentation-----distillation
(in series)



Serial number	Hydrolysis temperature (°C)	Hydrolysis time (minute)	Acid concentration (%v)	Remarks (code)
1	- (80)	-	-	mi, mi, mi
2	+ (100)	- (30)	-	
3	-	+ (60)	-	
4	+	+	- (1)	
5	-	-	+ (5)	
6	+	-	+	
7	-	+	+	
8	+	+	+	
	+ (ma) = maximum value - (mi) = minimum value			ma, ma, ma

Sterilization

Method of sterilization

Autoclaving:

3L of water, 120 ^{o}C, 30 minutes, about 1bar

The following were sterilized:

Vessels, washing and dilution water, glass stoppers and Sample itself while hydrolyzing

6.3 Fermentation

6.3

X

The use of

- **Benchtop fermentor (modular)**

  pH probe, Dissolved oxygen probe, Gas analyzer, Sparger, Pumps of additives and the main sample, Sampler, Level detector, Temperature sensor, agitator etc.Hyp

- **Brewery recyclable yeast (slurry)**

✓

The use of

- Local laboratory setup
- Dry saccharomyces cerevisiae(S.I. Lesaffre saf-instant)

The fermentation experiment

Parameters controlled in fermentation

- Incubation time (72 hours)
- Yeast concentration (10%w)
- Yeast (*saccharomyces cerevisiae*)
- Strain: saf instant

  (manufactured in France by S.I. Lesaffre)
- Fermentation temperature (30^{o}C)

Distillation

Parameters controlled

-

- Temperature (85 ^{o}C)
- Time (3 hours after temp. maintained)

All experiments were carried out at this point

Results and discussion

Results

1. Factorial design experiments
2. Optimization experiments

Discussion

Purpose:

Parameter optimization in hydrolysis experiments

Parameters:

- Acid concentration
- Hydrolysis temperature
- Hydrolysis time

Experimental method:

- Factorial design ($2^3 = 8$)
- (three-factors-at-two-levels)

Methods of data treatment

1. Calculation of main effects (what?)
2. Calculation of interaction effects (what?)
3. Tendency analysis of the response variable
4. Interpretation and hypothesis

Calculation of main effects

i

Acid concentration

-0.125

ii

Hydrolysis time

0.375

iii

Hydrolysis temperature

0.875

What does this imply?

This analysis is general.

- In the 2^3 factorial design, each factor has four high and four low level; hence the main effect!
- Does this tell us the whole story? No!
- So how can the effect of the level of other factor be determined on the main effect of one?
- By treating the main effects at different levels of other factors!
- How? …

ME treatment at different levels of other factors

ME of acid concentration at:

1. **Ethanol yield versus acid concentration at low levels of temperature and time. Hyp**

2. **Ethanol yield versus acid concentration At high levels of temperature and time. Hyp**

?

Conclusion

- At low levels of temperature and time, increasing acid concentration from Low (1%) to high (5%) favored the ethanol yield (16 to 21mL)
- At high levels of temperature and time, increasing acid concentration from Low (1%) to high (5%) disfavored the ethanol yield (25.5 to 14mL)
- when both T and t were increased from L to H levels, the slope of ethanol yield curve turned negative. This shows IE between AC and, t and T
- which one increase caused this? T or t?

Interaction effects

Interaction effect b/n AC and temperature:

TxC = -10.75

Interaction effect between Time and temperature

txC = -5.75

Increasing one level at a time

ME of acid concentration at:

3

E_y versus **AC** at low level Of **t** and increasing level of **T** from Low to high level

hyp

4

E_y versus **AC** at low level Of **T** and increasing level of **t** from Low to high level

hyp

Separate treatment of levels

- ✓ At low T, ME of AC = 5.25
- ✓ At high T, ME of AC = -5.5

10.75

- ✓ At low T, ME of t = 3.75
- ✓ At high T, ME of t = -3

6.75

Furthermore, as long as acid concentration is kept at low level, increasing both of Temperature and time favored ethanol yield.

Sample No	AC (%v)	Time (min)	Temp (oC)	Soln (mL)	Pure (mL)
1	1	30	80	16	14.08
7	1	60	100	25.5	24.48

Tendency analysis of response (average Y)

Keeping AC at 1%v,

↑ in T by 1°C ≡ ↑ 0.3125mL Y hyp

↑ in t by 1min ≡ ↑ 0.1083mL Y hyp

This implies that,

Av. t on Y = 34% of Av. T on Y

Conclusion

1. Keep acid concentration at low level (1%v)
   (Environmental implication)

2. Keep hydrolysis time at high level, not more
   (60minutes)

3. Increase hydrolysis temperature beyond maximum level (120^{o}C, 150^{o}C and 180^{o}C)
   (The lignin portion can give this energy)

Results found !

No	T °C	t minute	AC (%v)	Y mL/50 g	ρ g/cm³	Pure ethanol (mL)
9	120	60	1	26	**0.80705**	24.44
10	150	60	1	18	**0.81797**	16.2
11	180	60	1	12	**0.87477**	8.04

Analysis

Sample 7 (25.5mL, 24.48mL)
Sample 9 (26mL, 24.44mL)

Conclusion

1. Experimental error(0.5mL)

2. Economy of heating
(From 100 ^{o}C to 120 ^{o}C)

The optimum combination

Temperature

100°C

Acid concentration

1%v

Hydrolysis time

60 minutes

Environmental implication of the research

Yeka sub city population in 2006 was 397,236 and 428,000 in 2008 when projected at 3.8% annual growth

In the sub city:

- 219 fruit and vegetable shops®
- 7 fruit shops ®
- 103 vegetable shops (trade and Industry department of Yeka SS)

Daily sale of:

- Banana was 52.5kg/shop/day
- Mango 66.5kg/shop/day

Continued…

- Fitsum (2007) MSW generation rate in French Legasion Was 0.196kg/cap/day
- MSW generated = 83,888kg/day
- From this:
- Banana peel = 7712.25kg/day
- Mango peel = 5260.15kg
- Sum up to 12972.4kg/day
- 5% of peel = remain (assumption)
- The total Fruit waste =13621.02kg/day
- 16.2% of total MSW in sub the city

Environmental &/or econ. benefits

Eliminates 16.2% of the MSW

It encourages agro-industry:

(economic independence + currency saving (28c/L currently))

Reduces the GHG by replacing 5-15% Gasoline which is:

- **Less oxygenated (According to US EPA ethanol Reduces CO by 25-30%)**
- **Non-renewable and adds net GHG to Atmosphere**

Benefits continued…

Significantly reduces harmful exhaust emissions

Ethanol is biodegradable without harmful effects on the environment

It reduces emissions of hydrocarbons, a major contributor to the depletion of the ozone layer

Reduce NO_x emissions by up to 20%

Ethanol $\downarrow$ net CO_2 emissions by up to 100% on a full life-cycle basis

Increases the octane rating of Gasoline = $\downarrow$ Noise pollution and $\uparrow \eta$

Conclusions

1

Availability of the raw material (waste)

- **Banana, (90%) is sold as fruit and peeled out side of the fruit shops.**
- **Mango can be abundantly acquired from fruit wastes over some months (October to July).**

2

Technical point of view

- **It is possible and useful for environment (13,621.02kg/day) to produce ethanol from fruit wastes**

Conclusion continued…

3

Because factorial design was applied only to hydrolysis step the response variation is entirely attributed to the parameters of that step

4

Maximum ethanol yield found in this research was:

25.5mL(solution), 24.48mL(Pure)

5

Economy of ethanol production from fruit wastes:

Optimization was done only for hydrolysis, because…

As ethanol production is not a single step process others must be optimized if economic analysis is to be done.

Recommendations

For this research to be successful,

1. **Optimization of Fermentation (Ys, YC, time, temp. pH…) Distillation (T, t..) parameters is essential.**

2. **Economic analysis of the implementation after optimization, as this is not true maximum obtainable ethanol yield**

Recommendations...

3

As fruit wastes are susceptible to microorganisms,

- **Instantaneous Collection**
- **Transportation**
- **Storage**

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7. Ehitaferahu sisay

Thank you!