

**DESIGN OF A PLANT TO PRODUCE 9MILLION LITERS
OF BIOETHANOL FROM SUGARCANE**

BY

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NOVEMBER, 2007.

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**A RESEARCH PROJECT SUBMITTED TO THE
DEPARMENT OF CHEMICAL ENGINEERING,SCHOOL
OF ENGINEERING AND ENGINEERING
TECHNOLOGY,FEDERAL UNIVERSITY OF
TECHNOLOGY,MINNA NIGER STATE,NIGERIA**

**IN PARTIAL FULFILMENT OF THE REQUIREMENT
FOR THE AWARD OF BACHELOR OF ENGINEERING
(B.ENG.) DEGREE IN CHEMICAL ENGINEERING.**

NOVEMBER, 2007.

DECLARATION

I, AKULA PAUL TERHEMBA (2001/11472) hereby declare that this project, "Design of a plant to produce 9 Million liters per year of bioethanol from sugarcane" carried out under the supervision of Engineer M.S. Galadima and presented in partial fulfillment for the award of bachelor of Engineering (B.Eng) Degree in Chemical Engineering has not been presented for any degree elsewhere, to the best of my knowledge.



AKULA PAUL TERHEMBA

29-11-07
DATE

DEDICATION

This project is dedicated to the Most High God, to my mum, Mrs. R.F. Akula and my dad Mr.I.A.Akula.

ACKNOWLEDGEMENT

My heart is filled with gratitude that words cannot express to Almighty God who has given me life and made it possible for me to have an education.

I seize this opportunity to express my profound gratitude to my supervisor, Engr. M.S. Galadima, who ensured the successful completion of this project, may God continue to bless you.

I will at this point like to specially acknowledge the H.O.D of chemical engineering department; Dr. M. O. Edoga and the entire members of staff of the department for their immeasurable contributions to my academic pursuit.

I love you mum and dad, your full support and relentless prayers has always kept me going. My special thanks goes to Mr. & Mrs. M Yashim and Dr. and Mrs. S. Umazua for their love, coming in contact with you have made me see God in human form.

This report would not be complete without acknowledging Mallam H.Akande for his immense contribution to this project.

Lastly I want to appreciate my friends Mike, I.G, Chelor, Oche, Linus, Bayour, Charles, the Navigators and my entire colleagues, we'll definitely meet at the top.

ABSTRACT

This project was carried out to design a plant to produce 9 Million liters of bioethanol per year (99.98% wt/wt) from sugarcane. The design of the plant was achieved with the aid of computer packages which are Superpro Designer for the material balance, energy balance and economic analysis for the whole plant except the crusher for which MathCAD professional was used for equipment sizing. The material balance over the crusher was carried out manually. 21,520kg/h of sugarcane was fed to the milling plant where 996.03kg/h of sucrose was extracted. The extracted juice was subjected to stoichiometric conversion to ethanol by 109.2kg/h of yeast. The concentration of ethanol produced was increased by microfiltration to remove yeast, distillation and finally adsorption of water molecules to produce 99.98%wt/wt of ethanol. The results of the project shows that the plant has a full capacity of 9,114,003.36 liters of ethanol per annum which can be blended with gasoline to produce E10. The profitability analysis depicts a Net Present Value (NPV) of \$12,083,199, gross margin of 22% and a payback period of 4.32 years.

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CHAPTER ONE

1.0 INTRODUCTION

Ethanol is a clear, colorless liquid with a characteristic, agreeable odor, it is an alcohol, a group of chemical compound whose molecules contain a hydroxyl group,(-OH),bound to a carbon atom. Ethanol melts at -114.1°C ,boils at 78.3°C and has a density of 0.7893 at 20°C .Ethanol is also a high performance motor fuel that cuts poisonous exhaust emissions and is better for the environment. Anhydrous ethanol can be blended with gasoline in varying quantities up to pure ethanol (E100) and most spark ignited gasoline style engines operate well with mixtures of 10% ethanol (E10) .When ethanol is blended with gasoline the octane rating of the petrol goes up by three full points without using harmful additives so that it burns more completely and reduces polluting emissions such as carbon monoxide. (Addison, 2006) Ethanol is also used to power fuel cells and as a feed chemical in the transesterification process for biodiesel.

World demand for industrial alcohol is escalating not least because of its utility as a fuel or fuel supplement (e.g. in a mixture with gasoline) and because of its availability from a renewable source. One of such source is sugarcane and a need exists for a truly economic process fro the conversion of sugarcane into alcohol. Ethanol is produced from sugarcane economically and in bulk and at high purity by a process which involves total utilization of the sugarcane partly as a fuel to provide heat requirement of the process but mainly as a source of fermentable material(Turon,1998)

1.1 Aims and Objectives

This project is aimed at designing a plant to produce 9millions liters of ethanol per year from sugarcane with the following objectives:

- To reduce domestic use of petrol, free up more crude for export and position Nigeria for development of the green fuel.
- To improve automotive exhaust emissions
- Provide more employments via integration of the oil and gas and the agricultural sector.

1.2 Justification

This project is embarked upon to make judicious and economic use of renewable sources of raw materials by converting them into useful products rather than depending on foreign products and exporting cheap raw materials. The choice of sugarcane is based on its availability and high yields of energy. Production of ethanol from sugarcane returns about 8units of energy for each unit of energy expended compared to corn which only returns about 1.34 units of fuel energy for each unit of energy expended³ and the sugars are already in available in a degradable form which can be metabolized directly by yeast cells, thus reducing the cost of production. Moreover, dependence on just one source of raw material will limit the quantity of ethanol produced.

1.3 Scope of Work

The scope of this project is depicted as follows:

(a) Process design

- Prepare a material and energy balance for the complete process carried out by Superpro Designer.

➤ Prepare a process flow diagram for the plant showing major equipment.

(b) Chemical Engineering Design

Prepare a chemical engineering design for the major equipment.

(c) Economic Analysis

Determine the profitability of the plant.

CHAPTER TWO

2.0 LITERATURE REVIEW

Ethanol (ethyl alcohol, grain alcohol) is the drinkable alcohol, the active ingredient in beer, wine and spirits. Henry Ford designed the famed Model T Ford to run on alcohol -- he said it was "the fuel of the future". The oil companies thought otherwise, however -- but the oil crisis of the early 1970s gave ethanol fuel a new lease of life. Ethanol has the molecular formula C_2H_5OH and the following structure. (Addison,2005)

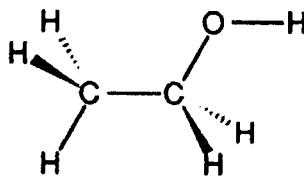


Fig 2.1 Ethanol structure.

2.1 Physical and Chemical Properties of Ethanol.

The physical and chemical properties of ethanol are important factors to be considered when handling the product for a safe and economic production process.

2.1.1 Physical properties

- i. Ethanol is a colorless, volatile liquid with a characteristic taste and smell
- ii. It is readily soluble in water in all proportions due to the presence of the hydroxyl group.
- iii. It has a boiling point of $78.3^{\circ}C$ and freezing point of $-114.1^{\circ}C$.
- iv. It has density 0.7893 and flash point $14^{\circ}C$.

2.1.2 Chemical properties

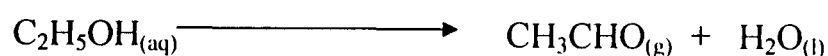
The chemical properties of ethanol are:

a) Combustion

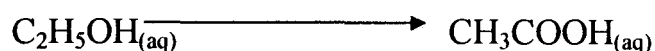
Ethanol readily burns in air or oxygen with a pale blue flame, yielding Carbon (iv) oxide.

b) Oxidation

Ethanol is readily oxidized to ethanal by warming with potassiumheptaoxodichromate(vi) solution which has been acidified with dilute tetraoxosulphate(vi) acid

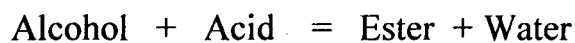


On further oxidation in the presence of excess tetraoxosulphate(vi) acid, the ethanol is converted to ethanoic acid



c) Esterification

Ethanol reacts reversibly with acids forming ethyl esters. This is known as esterification.



Ethanol undergoes a wide range of other reactions like reaction with metals, halogenation, etc.

The properties of ethanol compared with petrol are shown on the next page in Table 2.1.

Table 2.1 Fuel properties of ethanol compared to petrol

Fuel Properties	Ethanol	Petrol
Chemical Formula	C_2H_5OH	C_8H_{15}
Molecular weight[kg/kmol]	46	111
Octane number (RON)	109	97
Octane number (MON)	92	86
Cetane number	11	8
Reid Vapor Pressure[kpa] at 15 ⁰ C	16.5	75
Density [kg/l] at 15 ⁰ C	0.8	0.75
Lower Calorific Value[MJ/kg] at 15 ⁰ C	26.4	41.3
Lower Calorific Value[MJ/l] at 15 ⁰ C	21.2	31
Stoichiometric air/fuel ratio [kg air/kg fuel]	9.0	14.7
Boiling temperature[⁰ C]	78	30-180

Source: Kroon 1996.

2.2 Benefits of ethanol

Ethanol is a much cleaner fuel than petrol (gasoline) and has the following benefits

- 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
- High-level ethanol blends reduce nitrogen oxide emissions by up to 20%
- Ethanol can reduce net carbon dioxide emissions by up to 100% on a full life-cycle basis
- High-level ethanol blends can reduce emissions of Volatile Organic Compounds (VOCs) by 30% or more (VOCs are major sources of ground-level ozone formation)
- As an octane enhancer, ethanol can cut emissions of cancer-causing benzene and butadiene by more than 50%

- Sulphur dioxide and Particulate Matter (PM) emissions are significantly decreased with ethanol. (Addison, 2005)

2.3 Applications of Ethanol

- Ethanol is an important solvent used to dissolve resins, varnishes, lacquer, dyes in various industries.
- It is used as a fuel or fuel supplement
- Ethanol is present in many alcoholic beverages such as beers, wines and spirits (e.g. whisky, gin, brandy, rum etc)
- Ethanol is used as a feed chemical in the transesterification process for biodiesel. (Addison,2005)

2.4 Disadvantages of Fuel Ethanol

The most important problem with respect to the use of pure ethanol in vehicle engines is that at low temperatures, its evaporation is too slow for use in combustion engines. The ignitability of ethanol can be improved by mixing with additives (such as petrol) or heating the alcohol with an electrical heating element at the inlet of the engine.

Another difficulty concerns the lower volumetric energy content of ethanol. This entails that larger fuel flows are needed compared to the original engine design to get the same engine performance. Moreover, less oxygen is needed for combustion. This means that the combustion chamber, the valve, the location of the spark plug and the fuel system need to be able to use pure ethanol. The application of ethanol as a transportation fuel

requires some adaptations of the petrol distribution infrastructure and refueling facilities.

First of all, the energy content of ethanol is lower, which means larger storage tanks are needed. On board of the vehicle, one can also choose a larger fuel tank. If the same tank volume is used, the vehicle range is reduced. For tankers and storage tanks, the materials used should be compatible with ethanol, just like the engine components. Storage tanks should be water tight because ethanol is soluble in water. Furthermore, they must be equipped with fixed roofs and internal floating covers.

Other infrastructural issues concerns the safety of ethanol handling. For extinguishing an ethanol flame, water can be used. However for mixtures with petrol one should use CO₂ or foam instead, because by adding water, the petrol is expelled from the mixture and washed away. As ethanol burns with a visible flame, no special measures have to be taken to improve the luminosity of an ethanol flame (Reith et al, 2001)

2.5 Differences between Ethanol and Gasoline

Gasoline is a complex mixture of hydrocarbons substances comprising just hydrogen and carbon atoms. These hydrocarbons can appear in all forms (as a gas, liquid, or solid), but for our purposes, we're concerned with the fuel in its liquid state. To derive various hydrocarbon fuels, the industry merely refines crude oil (made many millions of years ago as a result of geological and biological cycles) and draws off the desired product at a certain temperature and pressure. Hence there are the lighter, gaseous fuels such as butane, propane, and ethane ... the liquids like octane, pentane, and hexane ... the heavier, oily liquids such as kerosene

and fuel oil ... and so on all the way down through waxes and finally solids.

Gasoline as we know it is a combination of octane, benzene, toluene, various other aromatics, tetraethyl lead, detergents ... and compounds of sulfur, phosphorus, and boron. Because of this complex mixture of ingredients - and because the refineries vary the blend to suit climate, seasonal changes, and altitude - it's difficult to choose a "representative" sample of gasoline for comparison purposes. Nonetheless, the figures that are given in the "Properties of Gasoline, Ethanol, and Methanol" chart which follows are fairly typical of average high-test automotive gasoline. Alcohol, on the other hand, has to be manufactured ... in our case through fermentation and distillation processes. Because of the steps involved in its manufacture, alcohol has always been more expensive than gasoline to produce. But now, with dwindling crude oil supplies, the price of gasoline is skyrocketing ... and soon gasoline itself will probably have to be synthetically manufactured, at a cost far greater - since the production process is much more complicated than that of alcohol.

Alcohol compounds are also hydrocarbons ... but in alcohol, one of the hydrogen atoms has been supplanted by a hydroxyl radical (hence the OH symbol), which is an oxygen atom bonded to a hydrogen atom. Alcohols, too, take many forms and have various levels of complexity, but we're concerned mainly with ethanol (grain-derived alcohol) and - just in passing - methanol (wood- or cellulose-derived alcohol).

These two alcohols are the only practical alcohol fuels ... and of the

two, ethanol is more economically feasible on a small scale. (The raw material used to make methanol - wood chips, garbage, or cellulose matter - is relatively inexpensive, but the manufacturing process necessary to produce methyl alcohol is economical only on an industrial level.)

On the surface, the difference between alcohol and gasoline might appear relatively minor: Alcohol contains oxygen, while gasoline doesn't. In reality, however, the dissimilarities are far more complex than that. Additionally, under compression - as is the case in an engine's combustion chamber - things get even more complicated ... but we'll get more into detail on these points later.

Regardless of the inherent differences between gasoline and alcohol, though, the fact is that alcohols make ideal motor fuels. The first practical internal combustion engine - patented by Nikolaus Otto in 1877 - ran on alcohol (gasoline had not been "discovered" yet), and the Model A Ford, produced from 1928 to 1931, was designed to burn a variety of fuels ... alcohol being one of them. In addition, Studebaker trucks built for export in the 1930's (and various domestic tractors sold both in the U.S. and abroad) were offered with either gasoline or alcohol fuel systems. (Indeed, at the start of the "motorized era", alcohol was just as common as - if not more so than - fossil fuels. But as time went on, the petroleum industry - which was organized and thus more powerful than the independent, often farm-based alcohol producers - lobbied successfully for the wholesale use of "superior" gasoline, fuels. Strangely enough, in areas where petroleum had to be exclusively imported, or during time of

war when gasoline supplies were rationed, alcohol suddenly became an excellent motor fuel again ... and was touted as such by the petroleum distributors who were selling it!)

Be that as it may, alcohol has characteristics that make it a natural engine fuel: [1] It has a high "octane" rating, which prevents engine detonation (knock) under load, [2] it burns clean ... so clean, in fact, that not only are noxious emissions drastically reduced, but the internal parts of the engine are purged of carbon and gum deposits ... which, of course, do not build up as long as alcohol is used as fuel, [3] an alcohol burning engine tends to run cooler than its gasoline-powered counterpart, thus extending engine life and reducing the chance of overheating. At this point, we can detail exactly how these and other characteristics of alcohol affect engine performance. (Addison, 2005)

2.5.1 "Octane" rating

Actually, when referring to alcohol fuels, the word "octane" does not apply, since octane (in its pure form) is merely the hydrocarbon in gasoline which is assigned the numerical value of 100 for fuel-rating purposes. The octane number given automotive fuels is really an indication of the ability of the fuel to resist premature detonation within the combustion chamber. (Premature detonation, or engine knock, comes about when the fuel/air mixture ignites spontaneously toward the end of the compression stroke because of intense heat and pressure within the combustion chamber. Since the spark plug is supposed to ignite the mixture at a slightly later point in the engine cycle, pre-ignition is undesirable, and can actually damage or even ruin an engine.)

Because a high compression ratio in an engine results in more power per stroke, greater efficiency, and better economy, it's easy to see why a fuel that resists pre-ignition even under high compression conditions is especially desirable ... and alcohol is, on the average, about 16 points higher on the research octane scale than premium gasoline.

2.5.2 Heat value

The heating value of a fuel is a measure of how much energy we can get from it on a per-unit basis, be it pounds or gallons. When comparing alcohol to gasoline using this "measuring stick", it's obvious that ethanol contains only about 63% of the energy that gasoline does ... mainly because of the presence of oxygen in the alcohol's structure. But since alcohol undergoes different changes as it's vaporized and compressed in an engine, the outright heating value of the ethanol isn't as important when it's used as a motor fuel.

The fact that there's oxygen in the alcohol's structure also means that this fuel will naturally be "leaner" in comparison to gasoline fuel without making any changes to the jets in the carburetor. This is one reason why we must enrich the air/fuel mixture (add more fuel) when burning alcohol by increasing the size of the jets, which we'll discuss further in another section.

2.5.3 Volatility

The volatility of a fuel refers to its ability to be vaporized. This is an important factor, because if vaporization doesn't occur readily, the fuel can't be evenly mixed with air and is of little value in an engine. Some substances that are highly volatile can't easily be used as a motor fuel ... and others,

which have excellent heating value, aren't volatile enough to be used in an engine (such as tars and waxes).

Another point to keep in mind is that a very volatile fuel is potentially dangerous, because of the chance of explosion from heat or sparks. This is one reason why alcohol, with a higher flash point than gasoline, is a much safer automotive fuel ... especially considering that the average car's storage tank is really quite vulnerable.

2.5.4 Latent heat of vaporization

Latent heat of vaporization is the phenomenon that results in an alcohol-powered engine's running cooler than its gasoline-fueled counterpart. When a substance is about to undergo a change in form (from a liquid to a vapor, in this case), it must absorb a certain amount of additional heat from its surroundings in order for the change to take place. Since alcohol must absorb roughly 2-1/2 times the amount of heat that gasoline does, and the heat naturally is taken from the engine block, the engine should operate at a much lower temperature but this is not the case in practice.

What happens in reality is that the alcohol/air mixture doesn't have time to absorb all the heat it could during its short trip through the engine manifold. So instead of running 2-1/2 times cooler on alcohol than it does on gasoline (which, by the way, would not be desirable ... since an engine must retain a certain amount of heat to run efficiently), the engine operates at temperatures only slightly cooler - about 20-40 deg F lower, depending on the specific engine when using alcohol fuel.

2.5.5 Exhaust emissions

When gasoline is burned in an engine, it produces carbon monoxide and other poisonous fumes ... mostly because of the fact that the fuel never combusts completely, and also because it's subjected to extreme temperatures and pressures. In addition, as we mentioned before, gasoline is a complex mixture of many substances ... and some of those substances are lead, sulfur, and other noxious materials. These, too, add to the contaminative effects of the engine's exhaust fumes.

Alcohol, on the other hand, burns much cleaner. Even though it, too, never combusts completely, the volume of noxious fumes is drastically reduced in an alcohol-burning engine ... because alcohol contains oxygen in its structure (which means more thorough combustion) but doesn't contain all the other pollutants necessary as additives in gasoline.

2.6 Production of Ethanol

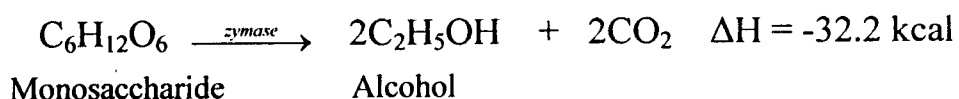
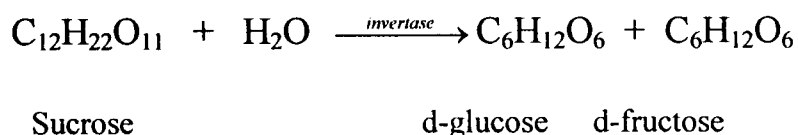
Ethanol may be produced from a variety of raw materials or feedstock which falls into four general classifications:

- I. Sugars (sugar beets, sugarcane, ripe fruits, sweet sorghum, molasses etc)
- II. Starchy materials(cereals, grains, potatoes, cassava)
- III. Cellulose materials (wood, bagasse, agricultural residues).
- IV. Hydrocarbon gases(ethylene)

Ethanol can be mass-produced by fermentation of sugar or by hydration of ethylene from petroleum and other sources. Current interest in ethanol mainly lies in bio-ethanol, produced from the starch or sugar in a wide variety of crops.

2.6.1 Sugar crops.

Sugar comprises a large group of organic compounds which are both chemically and structurally very complex. The simplest sugars are the monosaccharides which are the only sugars that can be fermented. They are constituents, or building blocks of the complex sugars. Glucose and fructose are examples of monosaccharide. The fermentation of a polysaccharide or disaccharide needs a hydrolysis step, promoted by a hydrolase, the hydrolysis of sucrose can be accomplished by the hydrolase invertase:



(Addison,2005))

In the production of ethanol from sugar crops, preparation is basically a crushing and extraction of the sugars which the yeast can immediately use. But sugar crops must be dealt with fairly quickly before their sugar and water content causes spoilage. Because of the danger of spoilage, the storage of sugar crops is not practical.

2.6.2 Sugarcane

Sugarcane is the common name of a species of herb belonging to the grass family. The official classification of sugarcane is *Saccharum*

officinarum, and it belongs to the family Gramineae. It is common in tropical and subtropical countries throughout the world. It can grow from eight to twenty feet tall, and is generally about 2 inches thick. Several different horticultural varieties are known, and they differ by their stem color and length (Braun, 1997).

The common sugarcane has been cultivated since ancient times. The most widely used form of cultivation is by stem cuttings, since many varieties do not produce fertile seeds. According to Helen Boyel, (1939) this is one of the many species of plants that would not survive without human intervention. It is a very easy, and profitable plant to grow, but does not naturally reproduce very effectively.

The sugarcane was one of the first "cash crops" of early colonial America. It grew plentifully in the southern states, and was a major source of income for many plantations. It is grown readily in the United States in Hawaii, Louisiana, Florida and Puerto Rico. The countries that produce the largest amounts of sugarcane are Brazil, Cuba, Kazakhstan, Mexico, India, and Australia.

Sugarcane cannot be easily harvested by machine, so for centuries it has been harvested by hand, using large machete like blades. For this reason sugarcane fields have very large amounts of farm hands, and are a major source of employment throughout South America, Central America, and even the Caribbean. In early America, when the plant was readily harvested, it was a major source of slavery in the south. However, with the advent of abolition, it was found that sugarcane could be imported cheaper than it

could be grown (Microsoft Encarta, 1994). This is why the sugarcane industry in the United States has diminished so sharply since the Civil War.

The primary use for sugarcane is to process sugar, which can then be used in an infinite number of products. The type of sugar produced by sugarcane is called sucrose. This is the most important of all the sugars. Sucrose is used as a sweetening agent for foods and in the manufacture of cakes, candies, preservatives, soft drinks, alcohol, and numerous other foods. Although the use of sugar in the human diet is controversial, sucrose supplies about 13 percent of all energy that is derived from foods (Escalona, 1952).

Over half of the World's sugar supply is derived from the sugarcane (Microsoft Encarta, 1994). The sugarcane producing countries are not given much credit for supplying the world with a major source of food and nutrition, but they are given plenty of credit for being a world leader in making money. Billions of dollars are generated every year due to the sugarcane plants that are grown in the west alone. Also of significance is the number of jobs that are created every year to harvest the sugarcane plant in small and underprivileged countries (Escalona, 1952).

2.6.3 Fruits and sugar beet.

Fruit crops (e.g., grapes, apricots, peaches, and pears) are another type of feedstock in the sugar crop category. Typically, fruit crops such as grapes are used as the feedstock in wine production. These crops are not likely to be used as feedstock for production of fuel-grade ethanol because of their high market value for direct human consumption. However, the co products of processing fruit crops are likely to be used as feedstock because

fermentation is an economical method for reducing the potential environmental impact of untreated wastes containing fermentable sugars.

Although sugar beets are grown in many areas of the U.S., they must be rotated with non root crops (1 beet crop per 4 year period is the general rule).sugars beets are not common in tropical regions, hence sugarcane is the main sugar crop in such regions.

2.6.4 Molasses

Sulphured molasses is made from young green sugar cane and is treated with sulfur dioxide fumes, which act as a preservative, during the sugar extraction process. The sugar cane plant is harvested and stripped of its leaves. Its juice is then extracted from the canes, usually by crushing or mashing. The juice is boiled to concentrate and to promote the crystallization of the sugar. The results of this first boiling and removal of sugar crystal is *first molasses*, which has the highest sugar content because comparatively little sugar has been extracted from the juice. *Second molasses* is created from a second boiling and sugar extraction, and has a slight bitter tinge to its taste.

The third boiling of the sugar syrup gives *blackstrap molasses*. The majority of sucrose from the original juice has been crystallized but blackstrap molasses is still mostly sugar by calories; however, unlike refined sugars, it contains significant amounts of vitamins and minerals. Blackstrap molasses is a source of calcium, magnesium, potassium and iron. One tablespoon provides up to 20 percent of the daily value of each of those nutrients. Blackstrap is often sold as a health supplement, as well as being used in the manufacture of cattle feed, and for other industrial uses.

Molasses that comes from the sugar beet is different from cane molasses. Only the syrup left from the final crystallization stage is called molasses; intermediate syrups are referred to as *high green* and *low green* and these are recycled within the crystallization plant to maximize extraction. Beet molasses is about 50% sugar by dry weight, predominantly sucrose but also containing significant amounts of glucose and fructose. Beet molasses is limited in biotin (Vitamin H or B₇) for cell growth; hence it may need to be supplemented with a biotin source. The non-sugar content includes many salts such as calcium, potassium, oxalate and chloride. These are either as a result of concentration from the original plant material or as a result of chemicals used in the processing. As such, it is unpalatable and is mainly used as an additive to animal feed (called "molassed sugar beet feed") or as a fermentation feedstock.

It is possible to extract additional sugar from beet molasses through a process known as molasses desugarisation. This technique exploits industrial scale chromatography to separate sucrose from non-sugar components. The technique is economically viable in trade protected areas where the price of sugar is supported above the world market price. As such it is practiced in the US and parts of Europe.(Braun,1997).

The flow sheet for the production of ethanol from sugar and molasses is shown on the next page in Fig 2.1

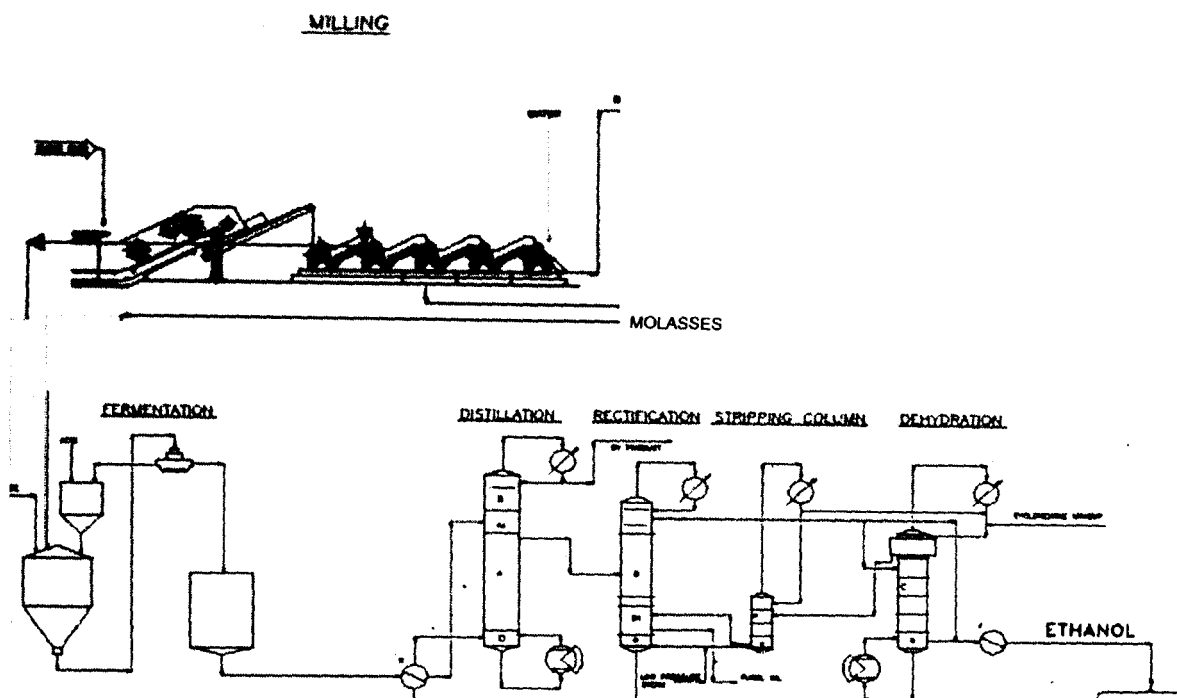


Fig 2.2 Flow sheet for the production of ethanol from sugarcane and molasses.

2.6.5 Starchy crops

Ethanol production from starchy crops includes crops such as corn, cassava, potatoes etc. There are two production processes, Wet milling and dry milling. Corn dry milling is the most common type of ethanol production in the United States. In dry milling, the entire corn kernel is first ground into flour and the starch in the flour is converted to ethanol via fermentation. The other products are carbon dioxide (used in the carbonated beverage industry) and an animal feed called distillers dried grain with solubles.

Corn wet milling is the process of separating the corn kernel into starch, protein, germ and fiber in an aqueous medium prior to fermentation. The primary products of wet milling include starch and starch-derived products (e.g. high fructose corn syrup and ethanol), corn oil, corn gluten, and corn gluten.(www.genomics.energy.gov)

2.6.6 Dry milling

Grain is used to produce alcohol (ethanol) and its co-products in a well-developed dry milling process with little waste.

Milling: The grain first passes through hammer mills, which grinds it into a fine powder called meal. The meal is then fed to the mashing system

Mashing: The meal is mixed with water and enzymes, and passes through cookers. The action of heat liquefies the starch, and enzymes begin the process of breaking down the starch to sugars. The mash from the cookers is then cooled and pumped to a fermenter.

Fermentation: Yeast is added to the mash to convert the sugars to ethanol and carbon dioxide. Using a continuous process, the fermenting mash is allowed to flow, or cascade, through several fermenters, until the mash leaving the final tank is fully fermented.

Distillation: The fermented mash, now called "beer", contains about 10% alcohol, as well as all the non-fermentable solids from the grain and the yeast cells. The mash is then pumped to the distillation system, where the alcohol is removed from the solids and water. The alcohol leaves the top of the final column at about 96% strength, and the residue mash, called stillage, is transferred from the base of the column to the co-product processing area.

Dehydration: The alcohol from the top of the column passes through a patented dehydration system where the remaining water is removed. The alcohol product at this stage is called anhydrous (pure) alcohol or ethanol

The flowsheet for the above process is shown in Fig 2.2

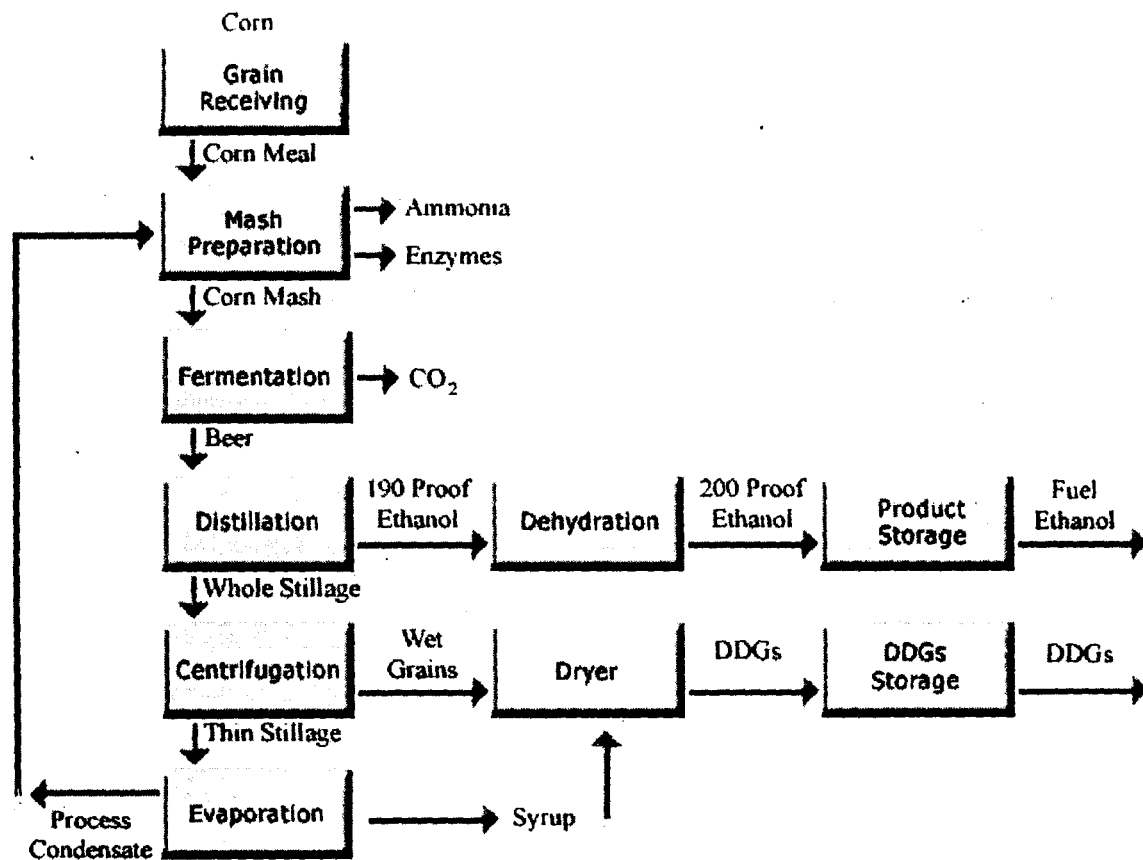


Fig 2.3 production of ethanol from corn-Dry milling.

2.6.7 Wet milling

In wet milling, the grain is soaked or "steeped" in water and dilute sulfurous acid for 24 to 48 hours. This steeping facilitates the separation of the grain into its many component parts. After steeping; the corn slurry is processed through a series of grinders to separate the corn germ. The corn oil from the germ is either extracted on-site or sold to crushers who extract

the corn oil. The remaining fiber, gluten and starch components are further segregated using centrifugal, screen and hydroclonic separators. The steeping liquor is concentrated in an evaporator. This concentrated product, heavy steep water, is co-dried with the fiber component and is then sold as corn gluten feed to the livestock industry. Heavy steep water is also sold by itself as a feed ingredient and is used as a component in Ice Ban, an environmentally friendly alternative to salt for removing ice from roads.

The gluten component (protein) is filtered and dried to produce the corn gluten meal co-product. This product is highly sought after as a feed ingredient in poultry broiler operations. The starch and any remaining water from the mash can then be processed in one of three ways: fermented into ethanol, dried and sold as dried or modified corn starch, or processed into corn syrup. The fermentation process for ethanol is very similar to the dry mill process described above(www.cogeneration.net/ethanolplant.html)

.Below is the flow sheet for the wet milling process.

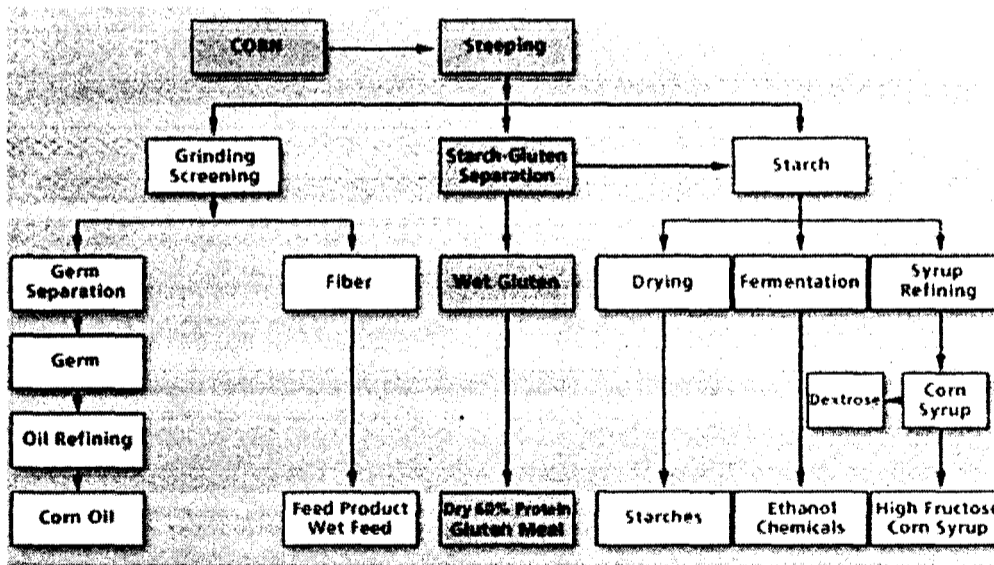


Fig2.4 Ethanol production process-wet milling

2.6.8 Cellulosic materials

Conversion of cellulosic biomass to ethanol is less productive and more expensive than the conversion of corn grain to ethanol. Cellulosic biomass, however, is a less expensive and more abundant feedstock than corn grain; more efficient processing is needed to take advantage of this plentiful and renewable resource. The structural complexity of cellulosic biomass is what makes this feedstock such a challenge to break down into simple sugars that can be converted to ethanol. Compared to cornstarch ethanol production, several factors make cellulosic ethanol production more costly and less efficient. One important barrier is lower sugar yields due to the heterogeneous and recalcitrant nature of cellulosic biomass. More effort is needed to pretreat and solubilize hemicellulose and cellulose because they are locked into a rigid cell-wall structure with lignin. Harsher thermochemical pretreatments generate chemical by-products that inhibit enzyme hydrolysis and decrease the productivity of fermentative microbes. The crystallinity of cellulose also makes it more difficult for aqueous solutions of enzymes to convert cellulose to glucose.

Another barrier is the mix of sugars generated from hemicellulose hydrolysis. Microorganisms that can ferment both 5- and 6-carbon sugars exist, but they have lower production rates and exhibit less tolerance for the end-product ethanol. Broth produced from a mix of 5- and 6-carbon sugars is about 6% ethanol instead of 10 to 14% ethanol produced from cornstarch glucose fermentation. Overcoming these and other barriers will require a more complete understanding of several biological factors that impact the conversion process.

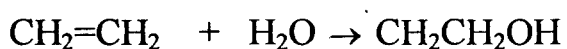
One multi-step process for converting cellulosic biomass to ethanol is outlined below.

1. **Mechanical Preprocessing.** Dirt and debris are removed from incoming biomass (e.g., bales of corn stover, wheat straw, or grasses), which is shredded into small particles.
2. **Pretreatment.** Heat, pressure, or acid treatments are applied to release cellulose, hemicellulose, and lignin and to make cellulose more accessible to enzymatic breakdown (hydrolysis). Hemicellulose is hydrolyzed into a soluble mix of 5- and 6-carbon sugars. A small portion of cellulose may be converted to glucose. If acid treatments are used, toxic by-products are neutralized by the addition of lime. Since cellulose biomass can come from many different sources (e.g., grasses, wheat straw, corn stover, paper products, hardwood, softwood), a single pretreatment process suitable for all forms of biomass does not exist.
3. **Solid-Liquid Separation.** The liquefied syrup of hemicellulose sugars is separated from the solid fibers containing crystalline cellulose and lignin.
4. **Fermentation of Hemicellulosic Sugars.** Through a series of biochemical reactions, bacteria convert xylose and other hemicellulose sugars to ethanol.
5. **Enzyme Production.** Some of the biomass solids are used to produce cellulase enzymes that break down crystalline cellulose. The enzymes are harvested from cultured microbes. Purchasing enzymes from a commercial supplier would eliminate this step.

6. **Cellulose Hydrolysis.** The fiber residues containing cellulose and lignin are transferred to a fermentation tank where cellulase enzymes are applied. A cocktail of different cellulases work together to attack crystalline cellulose, pull cellulose chains away from the crystal, and ultimately break each cellulose chain into individual glucose molecules.
7. **Fermentation of Cellulosic Sugars (Glucose).** Yeast or other microorganisms consume glucose and generate ethanol and carbon dioxide as products of the glucose fermentation pathway.
8. **Distillation.** Dilute ethanol broth produced during the fermentation of hemicellulosic and cellulosic sugars is distilled to remove water and concentrate the ethanol. Solid residues containing lignin and microbial cells can be burned to produce heat or used to generate electricity consumed by the ethanol-production process. Alternately, the solids could be converted to coproducts (e.g., animal feed, nutrients for crops).
9. **Dehydration.** The last remaining water is removed from the distilled ethanol(www.genomics.energy.gov)

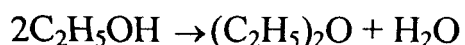
2.6.9 Hydrocarbon gases (Ethylene)

The production of ethanol from ethylene involves the direct hydration of ethylene with a catalytic amount of phosphoric acid. Temperatures averages to 300 to 400⁰C with 1000psi.



Only 4% of the ethylene is converted to alcohol per pass, but this cyclic process eventually gives a net yield of 97 percent .In this direct hydration

process, a supported acid catalyst usually is used. Important factors affecting the conversion include temperature, pressure, the water/ethylene ratio, and the purity of the ethylene. Further, some by-products are formed by other reactions taking place, a primary side reaction being the dehydration of ethyl alcohol into diethyl ether.



To overcome this problem, a large recycle volume of unconverted ethylene usually is required. The process usually consists of a reaction section in which crude ethyl alcohol is formed, a purification section with a product of 95 % (volume) ethyl alcohol, and a dehydration section, which produces high purity ethyl alcohol free of water. For many industrial uses, the 95% purity product from the purification section suffices. (Speight, 2002)

The block diagram for the process is shown below in Fig 2.4

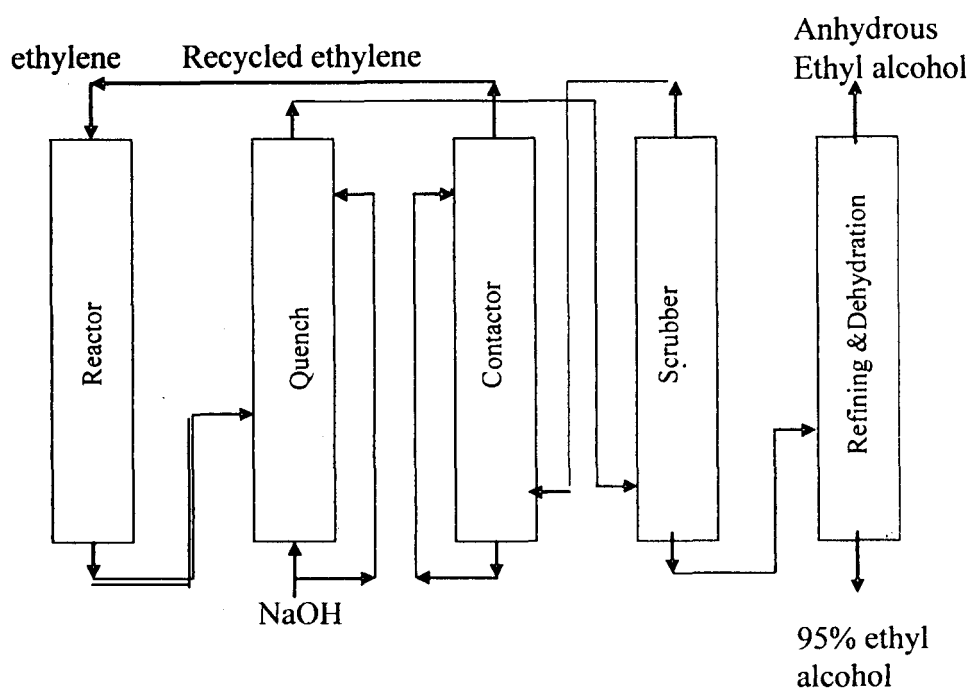


Fig 2.5 Manufacture of ethyl alcohol from ethylene.

2.7 Co product Yields

(a) Ethanol

The yield of ethanol from agricultural crops can be estimated if the amount of fermentable components -- sugar, starch, and cellulose -- is known prior to fermentation. If the yield is predicted based on percentages at the time of harvest, then the loss of fermentable solids during storage must be taken into account. This factor can be significant in the case of sugar crops, as discussed earlier. The potential yield of ethanol is roughly one-half pound of ethanol for each pound of sugar. However, not all of the carbohydrate is made available to the yeasts as fermentable sugars, nor do the yeasts convert all of the fermentable sugars to ethanol. Thus, for estimating purposes, the yield of ethanol is roughly one gallon for each 15 pounds of sugar or starch in the crop at the time the material is actually fermented. Because of the many variables in the conversion of liquefied cellulose to fermentable sugar, it is difficult to estimate active ethanol yields from cellulose.

(b) Carbon Dioxide

The fermentation of six-carbon sugars by yeast results in the formation of carbon dioxide as well as ethanol. For every pound of ethanol produced, 0.957 pound of carbon dioxide is formed; stated another way, for every 1 gallon of ethanol produced, 6.33 pounds of carbon dioxide are formed. This ratio is fixed; it is derived from the chemical equation:



Other Co products

The conversion and fermentation of agricultural crops yield products in addition to ethanol and carbon dioxide. For example, even if pure glucose is fermented, some yeast will be grown, and they would represent a co product. These co products have considerable economic value, but, since they are excellent cultures for microbial contaminants, they may represent a pollutant if dumped onto the land. Therefore, it becomes doubly important that these co products be put to good use. The summary of ethanol feed stock characteristics is shown in Table 2.1 on the next page.

Table 2.2 Summary of feedstock characteristics

Type of Feedstock	Processing Needed Prior to Fermentation	Principal Advantage(s)	Principal Disadvantage(s)
Sugar Crops (e.g., sugar beets, sweet sorghum, sugarcane, fodder beet, Jerusalem artichoke)	Milling to extract sugar.	<ol style="list-style-type: none"> 1. Preparation is minimal. 2. High yields of ethanol per acre. 3. Crop coproducts have value as fuel, livestock feed, or soil amendment. 	<ol style="list-style-type: none"> 1. Storage may result in loss of sugar. 2. Cultivation practices are not wide-spread, especially with "nonconventional" crops.
Starch Crops: Grains (e.g., corn, wheat, sorghum, barley) Tubers (e.g., potatoes, sweet potatoes)	Milling, liquefaction, and saccharification.	<ol style="list-style-type: none"> 1. Storage techniques are well developed. 2. Cultivation practices are widespread with grains. 3. Livestock coproduct is relatively high in protein. 	<ol style="list-style-type: none"> 1. Preparation involves additional equipment, labor, and energy costs. 2. DDG from aflatoxin-contaminated grain is not suitable as animal feed.
Cellulosic: Crop Residues (e.g., corn stover, wheat straw) Forages (e.g., alfalfa, Sudan grass, forage sorghum)	Milling and hydrolysis of the linkages.	<ol style="list-style-type: none"> 1. Use involves no integration with the livestock feed market. 2. Availability is wide-spread. 	<ol style="list-style-type: none"> 1. No commercially cost-effective process exists for hydrolysis of the linkages.

source: www.fuelethanol.org

Sugar crops, after the sugar has been extracted, yield plant residues which consist mostly of cellulose, unextracted sugar, and protein. Some of this material can be used as livestock feed, although the quantity and quality will

vary widely with the particular crop. If the crop is of low feeding value, it may be used as fuel for the ethanol plant. This is commonplace when sugar cane is the feedstock. Sweet sorghum may yield significant quantities of grain (milo), and the plant residue is suitable for silage, which is comparable to corn or sorghum silage except that it has a lower energy value for feeding. Sugar beet pulp from the production of sugar has always been used for livestock feed, as have the tops. Jerusalem artichokes, grown in the Soviet Union on a very large scale, are ensiled and fed to cattle, so the plant residue in this case would be suitable for silage. All of these residues can supply significant amounts of protein and roughage to ruminants. It is evident that all silage production has the potential for the production of significant quantities of ethanol without affecting the present uses or agricultural markets. By planting silage crops of high sugar content and extracting a part of the sugar for the production of ethanol, the ensiled residue satisfies the existing demand for silage.

Starch feedstock consists mostly of grains and, to a smaller extent, root crops such as potatoes (white or sweet). The production of nonfermentable material in these root crops is much less than in grains, and the use of the residue is similar. In the case of grains, it is commonplace to cook, ferment, and distill a mash containing the whole grain. The nonfermentable portion then appears in the stillage (the liquid drawn off the bottom of the beer column after stripping off the ethanol). About three-quarters of the nonfermentable material is in suspension in the form of solids ranging from very coarse to very fine texture, and the remainder is in solution in the water. The suspended material may be separated from the liquid and dried. The

coarser solids, in this case, are distillers' light grains. The soluble portion may be concentrated to a syrup with from 25% to 45% solids, called distillers' solubles. When dried together with the coarser material, the product is called distillers' dark grains. These nonfermentable solids derived from grain are valuable as high-protein supplements for ruminants in particular. However, if very large quantities of grain are fermented, the great quantity supplied may exceed the demand and lower the prices. Fortunately, the potential demand exceeds the present usage as a protein supplement, since feeding experience has shown that these coproducts can substitute for a significant part of the grain. When the liquid stillage is fed either as it comes from the still or somewhat concentrated, it is especially valuable, since it permits the substitution of straw for a significant proportion of the hay (e.g., alfalfa) normally fed to ruminants.

The non fermentable portion of the grain can also be used as human food. In the wet milling industry, the grain components are normally separated and the oil is extracted. The starch may be processed for a number of uses, or it may be used as feedstock for ethanol production. The gluten (the principal portion of the protein in the grain) may be separated and processed for sale as, for example, vital gluten (from wheat) or corn gluten. As another option, the solids may be sent through the fermenters and the beer still to appear as distillers' grains.

Grain processing as practiced in large plants is not feasible for small plants. However, a simple form of processing to produce human food may be feasible. Wheat can be simply processed to separate the starch from the combined germ, gluten, and fiber. They form a cohesive, doughy mass

which has long been used as a base for meat-analogs. This material can also be incorporated into bread dough to enhance its nutritional value by increasing the protein, fiber, and vitamin (germ) content.

Work at the University of Wisconsin has resulted in the development of a simple, practical processing machine that extracts about 60% of the protein from forage crops in the form of a leaf juice . The protein in the juice can be separated in a dry form to be used as a very high quality human food. The fibrous residue is then in good condition to be hydrolyzed to fermentable sugars. Most of the plant sugars are in the leaf juice and, after separation of the protein, are ready for fermentation. Forage crops have the potential for producing large amounts of ethanol per acre together with large amounts of human-food-grade protein. The protein production potential is conservatively 1,000 pounds per acre, equivalent to 140 bushels per acre of 12%-protein wheat.

CHAPTER THREE

3.0 METHODOLOGY

In this chapter the methodology adopted is briefly explained. The process selection, process description and equipment list for the process are clearly delineated. There are two ways of ways by which a process plant can be designed, one is by manual calculation which takes a lot of time and may contain errors and the other is by use of suitable computer aided chemical engineering design software which is faster and more accurate. The first method is adopted for the crusher design while the second method is employed for the remaining components of the plant using Superpro Designer software.

3.1 Process Selection

Process selection is a technique employed by design engineers in choosing the best process among possible alternative processes. In the early stages, coarse screening based on common sense, engineering judgment and rough costing will suffice. The selection of a process route for the production of a chemical will depend upon the following factors or considerations

- (a) Customers' satisfaction
- (b) Possibility of designing, building and operating an economic and safe plant.
- (c) Availability of design data, technology, fabrication methods and materials, raw materials etc.

(d) Environmental friendliness of the products, waste and even the main products.

(e) An energy efficient and minimum maintenance requirement.

(f) Availability of all necessary utilities e.g. electricity, cooling water etc.(Ray,1989)

Although it is unlikely that one process will possess all the advantages and no disadvantage. In view of the above considerations, the process route for the production of bioethanol from sugarcane was chosen as follows with the following unit operations

- MILLING OPERATION
- FERMENTATION
- MICROFILTRATION
- DISTILLATION
- ADSORPTION

The conventional process route from literature involves series of distillation columns, the beer still, aldehyde column and rectifying column. This is avoided by including a filtration step to purify the fermentation product thereby reducing the cost of production by reducing the energy consumption.

3.2 Process Description

The process route selected would be explained in detail now. A continuous process is adopted.

3.2.1 Milling Plant

Harvested sugarcane is chopped and shredded to provide a mass of fiber and juice by passing it through two rotating knife choppers which chops the cane into short length up to 10cm and then through a series rolls called a tandem or milling train. A two mill tandem, each consisting of two rollers is used to extract the juice from the cane.

About 70% of the juice is extracted. After passing through the mill, the fibrous residue, called bagasse, is collected in a waste bin where it is dried and utilized as fuel. The extracted juice is then stored in a tank.

3.2.2 Fermentation

The sucrose from the storage tank is charged continuously into the chemostat which is essentially CSTR that contains the desired culture medium with associated monitoring equipment and pH controller. 5%wt/wt yeast of available sucrose is also fed to the chemostat where the sucrose is subjected to stoichiometric conversion into ethanol by yeast (Fogler, 2004)

3.2.3 Microfiltration

Continuous membrane filtration is employed to separate the yeast completely from the broth. The retentate which is essentially yeast is collected and either recycled or used as feed for agricultural purposes, while the permeate is pumped into a beer wall for storage.

3.2.4 Distillation

Here the ethanol is further concentrated from 8%wt/wt to 81%wt/wt.

3.2.5 Adsorption

The hydrous ethanol is superheated to about 100⁰C and passed through a fixed bed packed with activated carbon to absorb the water vapor thus producing anhydrous ethanol(99.98% wt/wt purity).The adsorption bed operates in two phases: adsorption followed by regeneration, however for continuous operation extra units are added so that the adsorption step is performed continuously. Regeneration of the activated carbon is carried out using steam to vaporizes the adsorbed water (thermal swing).(Alley,1990)

3.3 Equipment list

The equipment list is presented according to the process step list as follows in Table 3.1 on the next page.

Table 3.1: Equipment list.

S/N	NAME	TYPE	DESCRIPTION
1	V-101	Fermentor	Stoichiometric fermentation
2	MF-101	Micro filter	Microfiltration
3	PM-101	Centrifugal pump	Fluid flow
4	V-102	Flat bottom tank	Beer wall
5	PM-102	Centrifugal pump	Fluid flow
6	HX-102	Heat exchange	Heat exchanging
7	C-101	Distillation column	Distillation
8	HX-102	Heat exchanger	Heat exchanging
9	V-103	Flat bottom tank	Storage
10	PM-103	Centrifugal pump	Fluid flow
11	PBA-101	PB Adsorber	PB Adsorption
12	HX-103	Heat exchanger	Cooling
13	V-104	Flat bottom tank	Storage
14	n/a	None	Truck
15	HX-104	Heat exchanger	Heating
16	EH-101	Electric heater	Electric heating

Source: superpro designer data base

3.4 Process Block Diagram

The process block diagram is as shown in Fig 3.1 below.

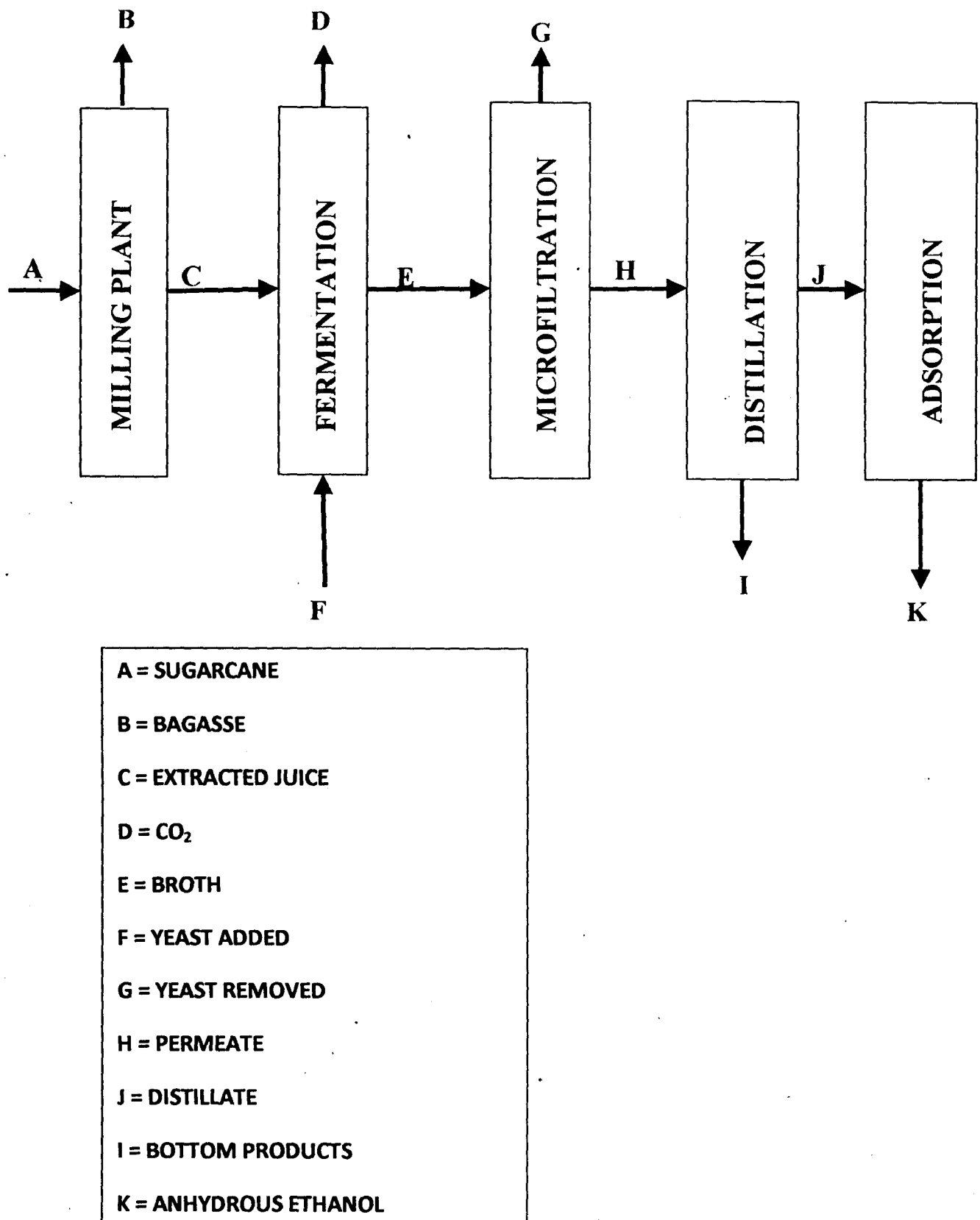


Fig 3.1: Process block diagram for the production of ethanol from sugarcane

3.5 Process Flow Sheet

The process flow sheet for the production of bio-ethanol as determined by superpro designer is shown

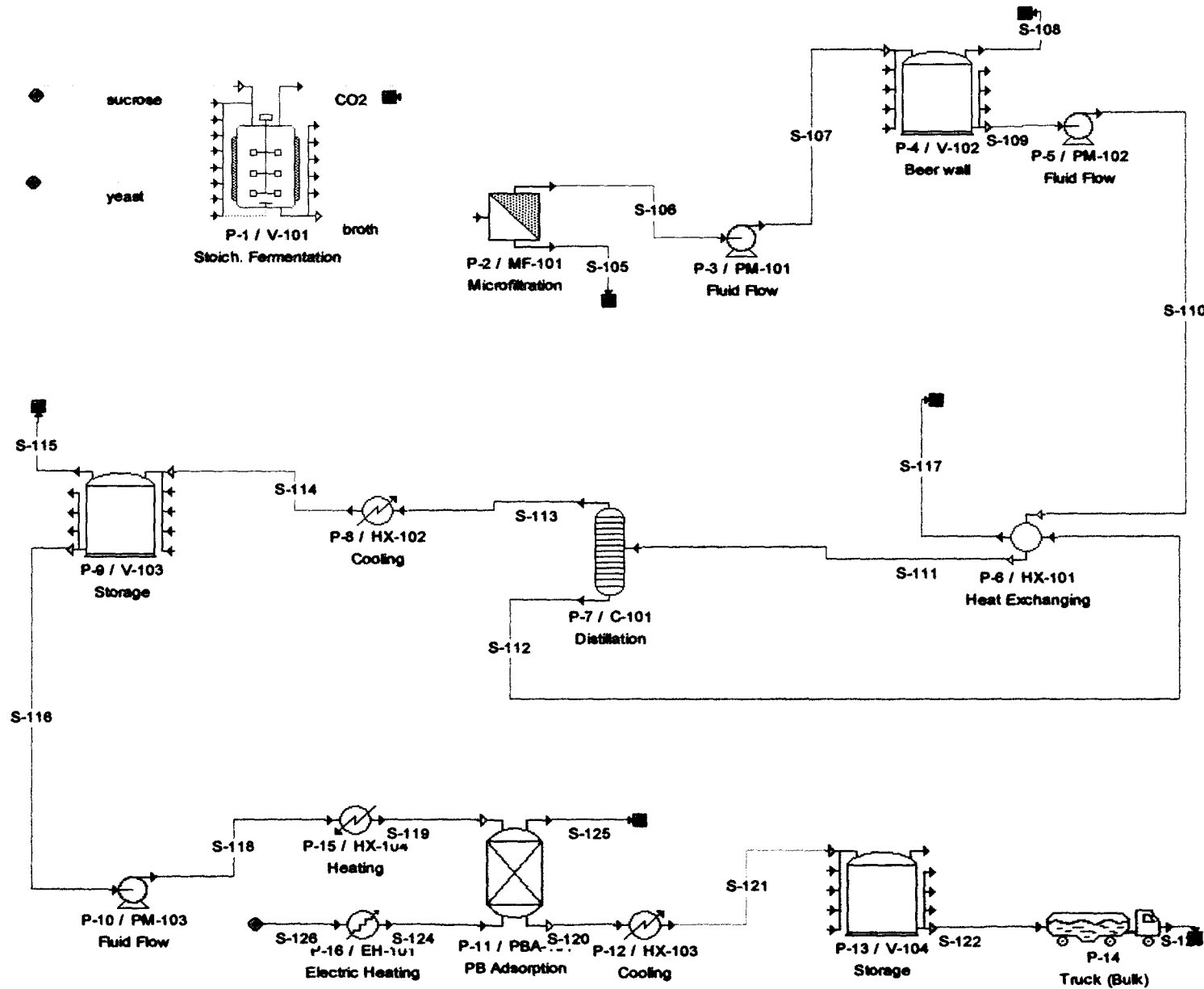


Fig 3.2 process Flow Sheet.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter presents the results obtained from the Superpro Designer software which involves the stream report, economic evaluation and equipment design. The manual calculations over the crusher for the mass balance and design of the crusher using MathCAD are also presented. The results are then discussed.

4.1 Results

A Summary of the material balance for the units of the plant is shown in table 4.1 (a, b, c) which is determined using superpro designer software. The mass balance across the crusher was determined manually and is shown separately in table 4.2. Detailed calculations are shown in appendix A.

Table 4.1: summary of material balance across units of the plant

(a) OVERALL PROCESS DATA

Annual Operating Time	=	7920.00 h
Annual Throughput	=	7162943.07 kg MP
Operating Days Per Year	=	330.00

MP = Main Product = Total Flow in S-123

(b) STARTING MATERIAL REQUIREMENTS

Section Name	Starting Material	Active Product	Gross Yield (%)	Amt Needed kg Sin/kg MP
FERMENTATION	Sucrose	Ethyl Alcohol	45.600	2.4151
FILTRATION	Ethyl Alcohol	Ethyl Alcohol	95.559	1.1013
DISTILLATION	Ethyl Alcohol	Ethyl Alcohol	116.671	1.0524
ABSORPTION	Ethyl Alcohol	Ethyl Alcohol	81.444	0.9998
TRANSPORT	S-122	S-123	100.000	1.0000

A_{in} = Section Starting Material , A_{out} = Section Active Product.

(c) Material flow across the unit of the plant (kg/h).

COMPONENTS	CRUSHER		FERMENTER		FILTER		DISTILLATION		ADSORPTION	
	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT	INPUT	OUTPUT
ASH	538	538								
SUCROSE	3,120.4	3,120.4	2,184.28	109.21	109.21	109.21	104.36	104.36		
FIBER	2,797.6	2,797.6								
WATER	15,064	15,064	10,792.28	10,792.28	10,792.28	10,792.28	10,312.97	10,312.97	206.26	0.21
YEAST			109.21	316.72	316.72	316.72				
ETHANOL				996.03	996.03	996.03	951.80	951.80	904.21	904.21
CARBON(IV)OXIDE				871.53						
TOTAL	21,520	21,520	13,085.77	13,086.46	12,214.24	12,214.24	11,369.13	11,369.13	1,110.47	904.42

Table 4.2: Summary of material flow across the crusher.

Input	Quantity(kg/h)	
Sugarcane	21520.00	
Output	Stream 3	Stream 4
Crucose	936.12	2184.28
Water	4271.72	10792.28
Fiber	2797.60	
Ash/impurities	538.00	

4.2 Equipment Design

A summary of the crusher design using MathCAD is shown in table 4.3 while the remaining units as determined by Superpro Designer software is shown in table 4.4. Appendix 'A' gives details of the calculations.

Table 4.3: Crusher Design

Type	Roll crusher
Materials of construction	Steel
Length of Roll(L)	0.012m
Diameter of crusher	2.539m
Length of crusher(h)	3.173m
Area of crusher	35.429m ²
Volume of crusher	16.06m ³ /h
Power requirement	39.547W

Table 4.4 Equipment Design in Superpro Designer

(a) Fermenter (V-101)

Operational data (input)

Power consumption for agitation	3kw/m ³
Pressure	1.013bar
Heat transfer agent	Cooling water
Cooling rate	518861.87kcal/h
Cooling agent inlet temperature	25 ⁰ C
Cooling agent outlet temp.	30 ⁰ C

Equipment Data obtained

Height	9.812m
Diameter	3.271m
Volume	8244.37L
Design pressure	1.5bar
Number of units	1

(b) Strainer (MF-101)

Operation Data input

Filtration time	4.0h
Max. particle concentration in retentate	1000g/L
Filtrate flux	50L/m ² .h
Recovery (permeate/feed)	94%

Equipment Data Obtained

Membrane area	77.897m ²
Number of units	24

(c) Beer Wall (V-102)

Equipment data obtained

Type	Flat bottom tank
Height	5.299m
Diameter	1.766m
Volume	12985.01L
Design pressure	1.5bar
Number of units	1

(d) Distillation column (C-101)

Operational Data (input)

Duty	Component separation
Distillate	95%ethanol,5%water
Column pressure	1.03bar
Stage efficiency	80%
Vapor linear velocity	3.00m/s
R/R _{min}	1.25
Condenser	
Temperature	90°C
Cooling agent	Cooling water
Inlet temperature	25°C

Outlet temperature	30 ⁰ C
Cooling rate	11084041.0kcal/h
Mass flow rate	2218050.8kg/h
Heating agent	Steam

Filter

Temperature	100 ⁰ C
Inlet temperature	152 ⁰ C
Outlet temperature	152 ⁰ C
Mass flow rate	24164.5kg/h

Equipment Data obtained

Stage height	0.4m
Column height	14m
Column diameter	1.428m
Actual stages	35
Design pressure	1.5bar
Number of units	2

(e) Adsorption Column

Operation data(input)

Breakthrough time	2h
Regeneration time	1h
Adsorption capacity	500mg adsorbate/g.pkg

	40%
eter	5.00mm
nsity	1030g/L
iscosity	0.018cp
erall binding efficiency	99.9%

Equipment Data obtained

Bed diameter	1.366m
Dept	1.366m
Max. volume	50.00m ³
Number of units	2

4.3 Economic Analysis and Project Evaluation

The results of the economic analysis are shown below. Detail calculations are shown in appendix 'B'.

Table 4.5: Economic Analysis

Project Totals	
Revenue	\$36,883,504/yr

	\$28,770,510/yr
	7,162,943.073kg/yr
Production cost	\$4.0166/kg
Indices	
Profit Margin	22.00%
ROI	23.15%
Payback time	4.32yr
IRR(after tax)	12.89%
NPV at 7% interest	\$12,083,199

4.4 Discussion of Results

The bioethanol plant is designed using Superpro Designer to produce 9millions liters of ethanol per annum(99.98%wt/wt purity) from sugarcane via the selected route and has a full capacity of 9,114,003.36 liters of ethanol per annum .When operating at full capacity, 21.52tons/h of sugarcane feedstock is required. The mode of operation of the plant is continuous, operating at 330 days per year. The mode of transportation is by use of trucks since ethanol has a high affinity for water, thus will absorb water when flowing in pipes.

Results of the material balance, it was observed that out of the 12,976.56kg/h feedstock, 8,543.44kg/h was removed as waste (bagasse) in 8,543.44kg/h from the milling plant while 12,976.56kg/h flowing through stream is the active product. This is due to the performance of the crusher operating at 70% efficiency. The simulation result at the filtration step showed a loss of 44.24kg/h of ethanol coming out in the retentate out of the total amount, 996.032kg/h entering as feed. Also in the packed distillation column the total amount of ethanol was reduced to 904.21kg/h in the distillate due to loss as bottom product. Finally, the result of the economic analysis shows that plant gross margin is 22%.its Net Present Value (NPV) is \$12,083,199 and has a payback period of 4.32years.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

From the results of this project, conclusions and recommendations are drawn in this chapter.

Conclusion

1. The plant has a full capacity of 9,114,003.36 liters of ethanol per annum (99.98%wt/wt purity) which can be blended with gasoline to produce E10
2. It requires 21,520kg/h of sugarcane feedstock when operating at full capacity.
3. The profitability analysis shows a Net Present Value(NPV) of \$12,083,199, gross margin of 22% and a payback period of 4.32 years.

5.2 Recommendations

- With the availability of data, the fermentation of sucrose should be carried out using the kinetic model rather than the stoichiometric model as used in this project.
- Other methods of primary product recovery should be adopted to compare the loss of ethanol at this stage.
- An improved version of the superpro Designer should be used such as version 7.0 to obtain flexibility of using different currencies and other improvements that comes with new versions of the software.
- This project should be used for academic purpose at this stage. For commercial purpose, detailed mechanical design, safety, process control and instrumentation, should be carried out.

REFERENCES

1. Johnson K. (2005): Ethanol fuel: Journeytoforever. Retrieved October 15, 2006 from Journeytoforever. Web site: <http://journeytoforever.org>.
2. Bailey F.C & Cooper C.D (1990): "Air pollution control: A design approach", McGraw-Hill.
3. Baasel W.D (1974): "preliminary chemical engineering plant design". New York, Oxford.
4. Backhurst J.R & Harker J.H(1990): "process plant design", London, Heinemann educational books
5. Bailey J.E & Ollis D.F (1987): "Biochemical engineering fundamentals", McGraw-Hill international edition.
6. Fogler H.S (2004): "Element of chemical reaction engineering", pp 394-407, prentice-Hall of India.
7. Gilliland E.R (1940): "Indian engineering program" ,32, pp1101.
8. Hayes F.W (1980): production of ethanol from sugarcane. Retrieved April 20, 1982, from United States patents.
Website: <http://www.freepatentsonline.com/4326036.html>
9. McGregor W.C (1986): "Membrane separation in biotechnology", New York, Marcel Dekker inc.
10. Richardson J.F& Peacock D.G (1991): "chemical & biochemical reaction engineering, and control", volume 3, third edition, India, Elsevier.
11. Richardson J.F& Harker J.H (1983): "Particle technology& separation processes", volume 2, fifth edition, India, Elsevier.
12. Sinnott R.K (1999); "Chemical engineering design", volume 6, third edition, Great Britain, BTCV.

..., (1976): "A guide to chemical engineering process design & economics", New York.

APPENDIX A

AL MATERIAL BALANCE OVER THE MILLING PLANT

1,520kg/h of sugarcane.

6.1 : Composition of sugarcane.

Components	Composition(%wt/wt)
Fiber	13
Sucrose	14.5
Water	70
Ash & other impurities	2.5
Total	100

Source: Blanch, 2006.

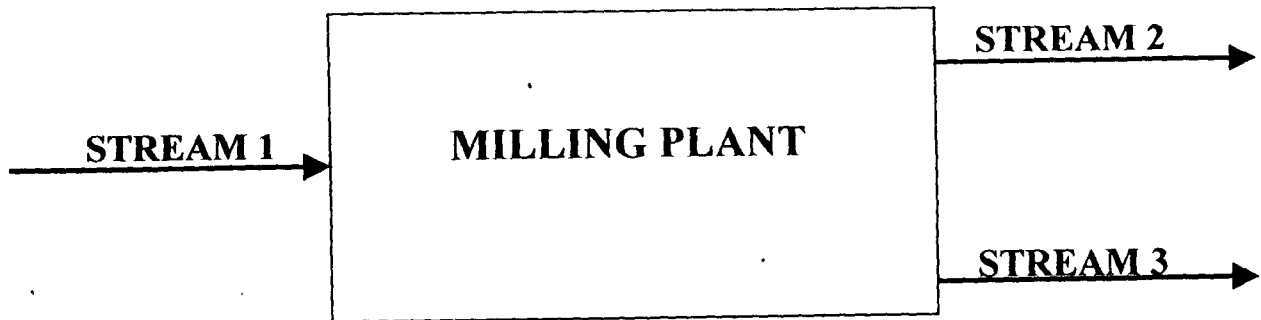


Fig.6.1 :Milling plant.

Hence, composition of stream 1 is as follows:

Fiber 2,797.6kg/h
Water 15,064kg/h
Sucrose 3,120kg/h
Ash 538kg/h

IONS

...ing efficiency is 70 % (i.e. 70% of sucrose is extracted).

...nal moisture content of bagasse (fiber) is 50%wt/wt.

No ash content in the juice extracted.

BALANCE OVER STREAM 2

Since 70% of sucrose is extracted, therefore

$$\text{Amount of sucrose in stream 2} = 0.3 * 3,120 = 936.12 \text{ kg/h}$$

$$\text{Amount of ash} = 538 \text{ kg/h}$$

$$\text{Amount of fiber} = 2,797.6 \text{ kg/h}$$

$$\text{Total} = 936.12 + 538 + 2,797.6 = 4,271.72 \text{ kg/h}$$

$$\text{Moisture content} = 50\%$$

Let A = Amount of Water

$$A / (A + 4,271.72) = 0.5$$

$$A = 4,271.72 \text{ kg/h}$$

Hence composition of stream 2 is as follows;

Ash	538kg/h
Sucrose	936.12kg/h
Fiber	2,797.6kg/h
Water	4,271.72kg/h

OVER STREAM 3

stream 3 = amount in stream 1 – amount in stream 2

Amount of sucrose = $3,120.4 - 936.12 = 2,184.28\text{kg/h}$.

Amount of water = $1,5064 - 4,271.72 = 10,792.28\text{kg/h}$.

Therefore stream 3 composition is as follows;

Sucrose	2,184.38kg/h
Water	10,792.28kg/h

Design of Crusher

Roll Crusher

Material of construction: Steel

Roll crusher is used to squeeze the juice out of the sugarcane.

The crushing ability of the crusher is carried by the rolls inside the crusher. Therefore, the design of the crusher will take the space of the rolls into account so as not to underestimate the capacity of the crusher.

Given the amount of materials in the crusher to be:

$$M' := 21520 \frac{\text{kg}}{\text{hr}}$$

The average density of the sugarcane is:

$$\rho_{\text{av}} := 1340 \frac{\text{kg}}{\text{m}^3}$$

So, the volume is calculated to be

$$V_{\text{crusher}} := \frac{M'}{\rho_{\text{av}}} \quad V_{\text{crusher}} = 16.06 \frac{\text{m}^3}{\text{hr}}$$

The volume occupied by the rolls can be given as

$$Q = \frac{d \cdot L \cdot s}{2.96}$$

where

Q is the capacity of the crusher occupied by the rolls in

d is the distance between the rolls

length of rolls

peripheral speed

then that,

$$d := 1.5 \text{ cm}$$

$$d = 0.015 \text{ m}$$

$$L := 1.20 \text{ cm}$$

$$L = 0.012 \text{ m}$$

$$s' := 10 \frac{\text{cm}}{\text{min}}$$

$$s' = 1.667 \times 10^{-3} \frac{\text{m}}{\text{s}}$$

$$Q_{\text{crusher}} := \frac{(d \cdot L \cdot s')}{2.96}$$

$$Q_{\text{crusher}} = 3.649 \times 10^{-4} \frac{\text{m}^3}{\text{hr}}$$

The total volume of the pre-crusher is thus

$$Q_{\text{crusher}} := Q_{\text{crusher}}$$

$$V_{\text{Tcrusher}} := V_{\text{crusher}} + Q_{\text{crusher}}$$

$$V_{\text{Tcrusher}} = 16.06 \frac{\text{m}^3}{\text{hr}}$$

The volume of the pre-crusher is given as:

$$V = \pi \cdot r^2 \cdot h$$

and, since

$$r = \frac{d}{2}$$

$$V = \pi \cdot \left(\frac{d}{2}\right)^2 \cdot h$$

$$V = \pi \cdot \frac{d^2}{4} \cdot h$$

Let $h = kd$, where k is a constant

substituting for h ,

$$V = \pi \cdot \frac{d^2}{4} \cdot (k \cdot d)$$

$$4 \cdot V = k \cdot \pi \cdot d^3$$

Making d the subject of the formula

$$d = \left(\frac{4 \cdot V}{k \cdot \pi}\right)^{\frac{1}{3}}$$

assuming that $k := 1.2$

$$V_{\text{Tcrusher}} := V_{\text{Tcrusher}} \cdot \text{hr}$$

From

$$d_{\text{crusher}} := \left(\frac{4 \cdot V_{\text{Tcrusher}}}{k \cdot \pi}\right)^{\frac{1}{3}}$$

$$d_{\text{crusher}} = 2.539\text{m}$$

$$h_{\text{crusher}} := k \cdot d_{\text{crusher}}$$

$$h_{\text{crusher}} = 3.173\text{m}$$

The area of the pre-crusher is therefore,

$$A := 2\pi \cdot \frac{d_{\text{crusher}}}{2} \cdot h_{\text{crusher}} + 2\pi \cdot \left(\frac{d_{\text{crusher}}}{2}\right)^2 \quad A = 35.429\text{m}^2$$

The net power to drive a roll ball was found to be

$$E = [(1.64L - 1) \cdot K + 1](1.64D)^{2.5} \cdot E_2$$

where

E is the net power to drive a roll

L is the inside length of the crusher, m

D is the mean inside diameter of the crusher, m

E_2 is the net power used by a 0.6 - 0.6-m roll under similar operating conditions K is a constant which is 0.9 for rolls less than 1.5m long and 0.85 for crushers over 1.5m long

Now, choosing

$$L = 0.012\text{m}$$

$$K_r := 0.9$$

$$D := d_{\text{crusher}}$$

$$E_2 := 9.5\text{W}$$

(Ernest, 1995)

So, the net power used by the roll is

$$E_{\text{roll}} := [(1.64L - 1) \cdot K_r + 1](1.64D)^{2.5} \cdot E_2 \cdot m^{-3.5}$$

$$E_{\text{roll}} = 39.547\text{W}$$

Stream report
 RESULT OBTAINED FROM SUPERPRO DESIGNER

PROCESS DATA

Operating Time = 7920.00 h
 Throughput = 7162943.07 kg MP
 Operating Days Per Year = 330.00

Main Product = Total Flow in S-123

STARTING MATERIAL REQUIREMENTS

Section Name	Starting Material	Active Product	Gross Yield (%)	Amt Needed kg Sin/kg MP
Main Section	(none)	(none)	Unknown	0.0000
FERMENTATION	Sucrose	Ethyl Alcoho	45.600	2.4151
MICROFILTRATION	Ethyl Alcohol	Ethyl Alcoho	95.559	1.1013
DISTILLATION	Ethyl Alcohol	Ethyl Alcoho	116.671	1.0524
ADSORPTION	Ethyl Alcohol	Ethyl Alcoho	81.444	0.9998
TRANSPORT	S-122	S-123	100.000	1.0000

Sin = Section Starting Material
 Aout = Section Active Product

BULK RAW MATERIAL REQUIREMENTS PER SECTION

SECTIONS IN: Main Branch

Main Section

Raw Material	kg/Year	kg/Hour	kg/kg MP

FERMENTATION

Raw Material	kg/Year	kg/Hour	kg/kg MP
Water	85474857.60	10792.280	11.933
Sucrose	17299497.60	2184.280	2.415
Yeast	864974.88	109.214	0.121
Section Total	103639330.08	13085.774	14.469

ATION

Raw Material	kg/Year	kg/Hour	kg/kg MP

LLATION

Raw Material	kg/Year	kg/Hour	kg/kg MP

ADSORPTION

Raw Material	kg/Year	kg/Hour	kg/kg MP
Water	8159703.52	1030.266	1.139
Section Total	8159703.52	1030.266	1.139

TRANSPORT

Raw Material	kg/Year	kg/Hour	kg/kg MP

SUMMARY (Entire Flowsheet)

Raw Material	kg/Year	kg/Hour	kg/kg MP
Water	93634561.12	11822.546	13.072
Sucrose	17299497.60	2184.280	2.415
Yeast	864974.88	109.214	0.121
Flowsheet Total	111799033.60	14116.040	15.608

BULK RAW MATERIAL REQUIREMENTS BREAKDOWN PER PROCEDURE

Water	kg/Year	kg/Hour	kg/kg MP
Total	93634561.12	11822.546	13.072

Stream report

(Total)				
ION				
h)	91.29	85474857.60	10792.280	11.933
	91.29	85474857.60	10792.280	11.933
PTION				
Branch)	8.71	8159703.52	1030.266	1.139
16	8.71	8159703.52	1030.266	1.139

Sucrose	kg/Year	kg/Hour	kg/kg MP
Total	17299497.60	2184.280	2.415

(%Total)				
FERMENTATION				
(Main Branch)	100.00	17299497.60	2184.280	2.415
P-1	100.00	17299497.60	2184.280	2.415

Yeast	kg/Year	kg/Hour	kg/kg MP
Total	864974.88	109.214	0.121

(%Total)				
FERMENTATION				
(Main Branch)	100.00	864974.88	109.214	0.121
P-1	100.00	864974.88	109.214	0.121

BREAKDOWN PER RAW MATERIAL AND SECTION (kg/kg MP)

Raw Material	Main Section	FERMENTATION	MICROFILTRATION	DISTILLATION	ADSORPTION
TRANSPORT	Subtotal				
Water	0.000	11.933		0.000	1.139
	13.072				
Sucrose	0.000	2.415		0.000	0.000
	2.415				
Yeast	0.000	0.121		0.000	0.000
	0.121				

Stream report

	0.000	14.469	0.000	0.000	1.139
	15.608				

BREAKDOWN PER RAW MATERIAL AND SECTION (kg/h)

Material TRANSPORT	Main Section Subtotal	FERMENTATION	MICROFILTRATION	DISTILLATION	ADSORPTION
Water 0.000	11822.546	0.000	10792.280	0.000	1030.266
Sucrose 0.000	2184.280	0.000	2184.280	0.000	0.000
Yeast 0.000	109.214	0.000	109.214	0.000	0.000
TOTAL 0.000	14116.040	0.000	13085.774	0.000	1030.266

BREAKDOWN PER RAW MATERIAL AND SECTION (kg/year)

Raw Material TRANSPORT	Main Section Subtotal	FERMENTATION	MICROFILTRATION	DISTILLATION	ADSORPTION
Water 8159703.5	0.0	85474857.6	0.0	0.0	
Sucrose 0.0	93634561.1	17299497.6	0.0	0.0	0.0
Yeast 0.0	17299497.6	864974.9	0.0	0.0	0.0
TOTAL 8159703.5	0.0	103639330.1	0.0	0.0	

COMPONENT BALANCE AND STREAM REPORT

STREAM NAME	sucrose	yeast	CO2	broth	S-105
SOURCE	INPUT	INPUT	P-1	P-1	P-2
DESTINATION	P-1	P-1	OUTPUT	P-2	OUTPUT

Stream report

PROPERTIES

U/ml	0.0	0.0	0.0	0.0	0.0
deg C	25.0	25.0	20.0	32.0	32.4
bar	1.0	1.0	1.0	1.0	1.0
g/L	1055.311	1562.000	1.829	982.608	1133.000

COMPONENT FLOWRATES (kg/h averaged)

Carbon Dioxide	0.0000	0.0000	871.5277	0.0000	0.0000
Ethyl Alcohol	0.0000	0.0000	0.0000	996.0317	44.2362
Sucrose	2184.2800	0.0000	0.0000	109.2140	4.8505
Water	10792.2800	0.0000	0.0000	10792.2800	479.3111
Yeast	0.0000	109.2140	0.0000	316.7206	316.7206

TOTAL (kg/h)	12976.5600	109.2140	871.5277	12214.2463	845.1183
TOTAL (L/h)	12296.4362	69.9193	476453.2675	12430.4423	745.9118

STREAM NAME	S-106	S-107	S-109	S-110	S-111
SOURCE	P-2	P-3	P-4	P-5	P-6
DESTINATION	P-3	P-4	P-5	P-6	P-7

STREAM PROPERTIES

ACTIVITY U/ml	0.0	0.0	0.0	0.0	0.0
TEMP deg C	32.4	32.4	32.4	32.4	79.5
PRES bar	1.0	2.0	1.0	2.0	2.0
DENSITY g/L	972.847	972.842	972.842	972.837	36.488

COMPONENT FLOWRATES (kg/h averaged)

Ethyl Alcohol	951.7955	951.7955	951.7955	951.7955	951.7955
Sucrose	104.3635	104.3635	104.3635	104.3635	104.3635
Water	10312.9689	10312.9689	10312.9689	10312.9689	10312.9689

TOTAL (kg/h)	11369.1280	11369.1280	11369.1280	11369.1280	11369.1280
TOTAL (L/h)	11686.4509	11686.5086	11686.5086	11686.5662	311588.6748

STREAM NAME	S-112	S-113	S-114	S-117	S-116
SOURCE	P-7	P-7	P-8	P-6	P-9
DESTINATION	P-6	P-8	P-9	OUTPUT	P-10

STREAM PROPERTIES

Stream report

ACTIVITY U/ml	0.0	0.0	0.0	0.0	0.0
TEMP deg C	100.0	90.0	25.0	49.4	25.0
PRES bar	1.0	1.0	1.0	1.0	1.0
DENSITY g/L	243.360	1.898	817.777	987.928	817.777

COMPONENT FLOWRATES (kg/h averaged)

Ethyl Alcohol	47.5898	904.2057	904.2057	47.5898	904.2057
Sucrose	104.3635	0.0000	0.0000	104.3635	0.0000
Water	10106.7095	206.2594	206.2594	10106.7095	206.2594

TOTAL (kg/h)	10258.6629	1110.4651	1110.4651	10258.6629	1110.4651
TOTAL (L/h)	42154.3048	585185.2173	1357.9077	10384.0168	1357.9077

STREAM NAME	S-118	S-119	S-120	S-121	S-122
SOURCE	P-10	P-15	P-11	P-12	P-13
DESTINATION	P-15	P-11	P-12	P-13	P-14

STREAM PROPERTIES

ACTIVITY U/ml	0.0	0.0	0.0	0.0	0.0
TEMP deg C	25.0	100.0	100.0	25.0	25.0
PRES bar	2.0	2.0	2.0	2.0	2.0
DENSITY g/L	817.761	3.669	2.990	785.927	785.927

COMPONENT FLOWRATES (kg/h averaged)

Ethyl Alcohol	904.2057	904.2057	904.2057	904.2057	904.2057
Water	206.2594	206.2594	0.2063	0.2063	0.2063

TOTAL (kg/h)	1110.4651	1110.4651	904.4120	904.4120	904.4120
TOTAL (L/h)	1357.9338	302694.6637	302481.6595	1150.7576	1150.7576

STREAM NAME	S-123	S-125	S-124	S-126
SOURCE	P-14	P-11	P-16	INPUT
DESTINATION	OUTPUT	OUTPUT	P-11	P-16

STREAM PROPERTIES

ACTIVITY U/ml	0.0	0.0	0.0	0.0
TEMP deg C	25.0	141.7	150.0	25.0
PRES bar	2.0	1.0	1.0	1.0
DENSITY g/L	785.927	0.529	0.519	994.704

COMPONENT FLOWRATES (kg/h averaged)

Stream report

Ethyl Alcohol 904.2057 0.0000 0.0000 0.0000
 Water 0.2063 1236.3187 1030.2656 1030.2656

TOTAL (kg/h) 904.4120 1236.3187 1030.2656 1030.2656
 TOTAL (L/h) 1150.75762335782.65361985588.8743 1035.7506

OVERALL COMPONENT BALANCE (kg/h averaged)

COMPONENT	IN	OUT	(OUT-IN)
Carb. Dioxide	0.000000	871.527720	871.527720
Ethyl Alcohol	0.000000	996.031680	996.031680
Sucrose	2184.280000	109.214000	-2075.066000
Water	11822.545596	11822.545596	0.000000
Yeast	109.214000	316.720600	207.506600
TOTAL	14116.039596	14116.039596	0.000000

EQUIPMENT CONTENTS

This section will be skipped (overall process is continuous)

Stream report

STREAM NAME	S-106	S-107	S-109	S-110	S-111
SOURCE	P-2	P-3	P-4	P-5	P-6
DESTINATION	P-3	P-4	P-5	P-6	P-7

STREAM PROPERTIES

ACTIVITY U/ml	0.0	0.0	0.0	0.0	0.0
TEMP deg C	32.4	32.4	32.4	32.4	79.5
PRES bar	1.0	2.0	1.0	2.0	2.0
DENSITY g/L	972.847	972.842	972.842	972.837	36.488

COMPONENT FLOWRATES (kg/h averaged)

Ethyl Alcohol	951.7955	951.7955	951.7955	951.7955	951.7955
Sucrose	104.3635	104.3635	104.3635	104.3635	104.3635
Water	10312.9689	10312.9689	10312.9689	10312.9689	10312.9689

TOTAL (kg/h)	11369.1280	11369.1280	11369.1280	11369.1280	11369.1280
TOTAL (L/h)	11686.4509	11686.5086	11686.5086	11686.5662	311588.6748

Stream report

TOTAL (kg/h)	10258.6629	1110.4651	1110.4651	10258.6629	1110.4651
TOTAL (L/h)	42154.3048	585185.2173	1357.9077	10384.0168	1357.9077

STREAM NAME	S-118	S-119	S-120	S-121	S-122
SOURCE	P-10	P-15	P-11	P-12	P-13
DESTINATION	P-15	P-11	P-12	P-13	P-14

STREAM PROPERTIES

ACTIVITY U/ml	0.0	0.0	0.0	0.0	0.0
TEMP deg C	25.0	100.0	100.0	25.0	25.0
PRES bar	2.0	2.0	2.0	2.0	2.0
DENSITY g/L	817.761	3.669	2.990	785.927	785.927

COMPONENT FLOWRATES (kg/h averaged)

Ethyl Alcohol	904.2057	904.2057	904.2057	904.2057	904.2057
Water	206.2594	206.2594	0.2063	0.2063	0.2063

TOTAL (kg/h)	1110.4651	1110.4651	904.4120	904.4120	904.4120
TOTAL (L/h)	1357.9338	302694.6637	302481.6595	1150.7576	1150.7576

STREAM NAME	S-123	S-125	S-124	S-126
SOURCE	P-14	P-11	P-16	INPUT
DESTINATION	OUTPUT	OUTPUT	P-11	P-16

STREAM PROPERTIES

ACTIVITY U/ml	0.0	0.0	0.0	0.0
TEMP deg C	25.0	141.7	150.0	25.0
PRES bar	2.0	1.0	1.0	1.0
DENSITY g/L	785.927	0.529	0.519	994.704

COMPONENT FLOWRATES (kg/h averaged)

Ethyl Alcohol	904.2057	0.0000	0.0000	0.0000
---------------	----------	--------	--------	--------

Stream report

Water 0.2063 1236.3187 1030.2656 1030.2656

TOTAL (kg/h)	904.4120	1236.3187	1030.2656	1030.2656
TOTAL (L/h)	1150.7576	2335.7826	5361.9855	88.8743 1035.7506

OVERALL COMPONENT BALANCE (kg/h averaged)

COMPONENT	IN	OUT	(OUT-IN)
Carb. Dioxide	0.000000	871.527720	871.527720
Ethyl Alcohol	0.000000	996.031680	996.031680
Sucrose	2184.280000	109.214000	-2075.066000
Water	11822.545596	11822.545596	0.000000
Yeast	109.214000	316.720600	207.506600
TOTAL	14116.039596	14116.039596	0.000000

EQUIPMENT CONTENTS

This section will be skipped (overall process is continuous)

Economic Analysis

APPENDIX B

EXECUTIVE SUMMARY (2007 prices)

TOTAL CAPITAL INVESTMENT	33287000 \$
CAPITAL INV. CHARGED TO THIS PROJECT	33287000 \$
OPERATING COST	28771000 \$/year
PRODUCTION RATE	7162943 kg/year of S-123
UNIT PRODUCTION COST	4.017 \$/kg of S-123
TOTAL REVENUES	36884000 \$/year
GROSS MARGIN	22.00 %
RETURN ON INVESTMENT	23.15 %
PAYBACK TIME	4.32 years
IRR AFTER TAXES	12.89 %
NPV (at 7.0 % interest)	12083000 \$

MAJOR EQUIPMENT SPECIFICATION AND FOB COST (2007 prices)

Quantity/ Stand-by	Description	Unit Cost (\$)	Cost (\$)
1/0 V-101	Fermentor Volume = 82442.37 L Diameter = 3.27 m	662000	662000
24/0 MF-101	Microfilter Membrane Area = 77.90 m ²	112000	2688000
1/0 PM-101	CF Pump Power = 0.46 kW	11000	11000
1/0 V-102	Flat Bottom Tank Volume = 12985.01 L Diameter = 1.77 m	14000	14000
1/0 PM-102	CF Pump Power = 0.46 kW	11000	11000
1/0 HX-101	Heat Exchanger Area = 21.29 m ²	7000	7000
2/0 C-101	Distillation Column Number of Stages = 35	87000	174000
1/0 HX-102	Heat Exchanger	1000	1000

Economic Analysis

Area = 0.86 m ²			
1/0 V-103	Flat Bottom Tank Volume = 1508.79 L Diameter = 0.86 m	14000	14000
1/0 PM-103	CF Pump Power = 0.05 kW	8000	8000
2/0 PBA-101	PB Adsorber Bed Volume = 2.00 m ³	93000	186000
1/0 HX-103	Heat Exchanger Area = 0.66 m ²	1000	1000
1/0 V-104	Flat Bottom Tank Volume = 1278.62 L Diameter = 0.82 m	14000	14000
1/0 HX-104	Heat Exchanger Area = 0.51 m ²	1000	1000
1/0 EH-101	Electric Heater Power = 149.37 kW	0	0
Cost of Unlisted Equipment		946000	

TOTAL EQUIPMENT PURCHASE COST	4732000
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FIXED CAPITAL ESTIMATE SUMMARY (2007 prices)

A: TOTAL PLANT DIRECT COST (TPDC) (physical cost)

1. Equipment Purchase Cost	\$	4732000
2. Installation		2610000
3. Process Piping		1656000
4. Instrumentation		1893000
5. Insulation		142000
6. Electricals		473000
7. Buildings		2129000
8. Yard Improvement		710000
9. Auxiliary Facilities		1893000

TPDC = 16238000

B. TOTAL PLANT INDIRECT COST (TPIC)

10. Engineering	4059000
11. Construction	5683000

Economic Analysis

TPIC = 9743000

C. TOTAL PLANT COST (TPDC+TPIC) TPC = 25980000

12. Contractor's fee 1299000
 13. Contingency 2598000

(12+13) = 3897000

D. DIRECT FIXED CAPITAL (DFC) TPC+12+13 = 29878000

LABOR REQUIREMENT AND COST SUMMARY

Section Name	Labor Hours Per Year	Labor \$/year	Cost %
Main Section	0	0	0.00
FERMENTATION	3960	228000	10.70
MICROFILTRATION	18889	1086000	51.02
DISTILLATION	8791	505000	23.74
ADSORPTION	5386	310000	14.55
TRANSPORT	0	0	0.00
TOTAL	37026	2129000	100.00

RAW MATERIALS COST SUMMARY

Raw Material	Unit Cost (\$/kg)	Annual Amount (kg)	Cost (\$/yr)	Cost %
Water	0.000	93634561.12	0	0.00
Sucrose	0.800	17299497.60	13839598	87.43
Yeast	2.300	864974.88	1989442	12.57
TOTAL		111799033.60	15829000	100.00

VARIOUS CONSUMABLES (2007 prices)

MEMBRANE or FILTER CLOTH

Procedure Name	Equipment Name	Unit Cost (\$/m ²)	Annual Amount (m ²)	Cost (\$/yr)
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Economic Analysis

P-2 MF-101 200.00 7403.37 1481000

 SUBTOTAL 1481000

OTHER PACKING (Activated Carbon, etc.)

 Procedure Equipment Unit Cost Annual Amount Cost
 Name Name (\$/L) (L) (\$/yr)

 P-11 PBA-101 1.85 792.20 1000

 SUBTOTAL 1000

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TOTAL 1482000

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WASTE TREATMENT / DISPOSAL (2007 prices)

a. SOLID WASTE

 Stream Unit Cost Annual Amount Cost
 Name (\$/kg) (kg) (\$/yr)

 a. Subtotal (Solid Waste) 0

b. LIQUID WASTE

 Stream Unit Cost Annual Amount Cost
 Name (\$/kg) (kg) (\$/yr)

S-117 0.000e+000 81248609.90 0

S-125 0.000e+000 9791644.22 0

 b. Subtotal (Liquid Waste) 0

c. EMISSIONS

 Stream Unit Cost Annual Amount Cost
 Name (\$/kg) (kg) (\$/yr)

CO2 0.000e+000 6902499.54 0

 c. Subtotal (Emissions) 0

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WASTE TREATMENT/DISPOSAL TOTAL COST (a+b+c) 0

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Economic Analysis

UTILITY REQUIREMENTS (2007 prices)

ELECTRICITY

Procedure Name	Equipment Name	Annual Amount (kWh)	Cost (\$/yr)
P-1	V-101	1762948	176295
P-2	MF-101	370169	37017
P-3	PM-101	3673	367
P-5	PM-102	3673	367
P-10	PM-103	427	43
P-11	PBA-101	832	83
P-16	EH-101	1182976	118298
Unlisted Equipment		207794	20779
General Load		623381	62338
SUBTOTAL			415587

HEAT TRANSFER AGENT : Steam (4.2000 \$/1000 kg)

Procedure Name	Equipment Name	Annual Amount (kg)	Cost (\$/yr)
P-7	C-101	191382559	803807
P-15	HX-104	896811	3767
SUBTOTAL			807573

HEAT TRANSFER AGENT : Cooling Water (0.1000 \$/1000 kg)

Procedure Name	Equipment Name	Annual Amount (kg)	Cost (\$/yr)
P-1	V-101	822337907	82234
P-7	C-101	17566962732	1756696
SUBTOTAL			1838930

HEAT TRANSFER AGENT : Chilled Water (0.4000 \$/1000 kg)

Procedure Name	Equipment Name	Annual Amount (kg)	Cost (\$/yr)
P-8	HX-102	75435241	30174
P-12	HX-103	62719688	25088
SUBTOTAL			55262

Economic Analysis

TOTAL	3117353
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ANNUAL OPERATING COST - SUMMARY (2007 prices)

Cost Item	\$/Year	%
Raw Materials	15829000	55.02
Labor-Dependent	2129000	7.40
Equipment-Dependent	5607000	19.49
Laboratory/QC/QA	319000	1.11
Consumables	1482000	5.15
Waste Treatment/Disposal	0	0.00
Utilities	3117000	10.84
Transportation	287000	1.00
Miscellaneous	0	0.00
Advertising and Selling	0	0.00
Running Royalties	0	0.00
Failed Product Disposal	0	0.00
TOTAL	28771000	100.00

PROFITABILITY ANALYSIS (2007 prices)

A. DIRECT FIXED CAPITAL	\$ 29878000
B. WORKING CAPITAL	1916000
C. STARTUP COST	1494000
D. UP-FRONT R&D	0
E. UP-FRONT ROYALTIES	0
F. TOTAL INVESTMENT (A+B+C+D+E)	33287000
G. INVESTMENT CHARGED TO THIS PROJECT	33287000
H. REVENUE STREAM FLOWRATES	
kg/year of total flow (in S-105)	6693337
kg/year of total flow (in S-123)	7162943
I. PRODUCTION (UNIT) COST	
\$/kg of S-123	4.017
J. SELLING/PROCESSING PRICE	
\$/kg of total flow (in S-105)	2.300
\$/kg of total flow (in S-123)	3.000
K. REVENUES (\$/year)	
S-105	15395000
S-123	21489000
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Total Revenues	36884000

Economic Analysis

L. ANNUAL OPERATING COST	28771000
M. GROSS PROFIT (K-L)	8113000
N. TAXES (40 %)	3245000
O. NET PROFIT (M-N + Depreciation)	7706000

GROSS MARGIN	22.00 %
RETURN ON INVESTMENT	23.15 %
PAYBACK TIME (years)	4.32

CASH FLOW ANALYSIS (thousand US \$)

YR	CAPITAL NET INVESTM CASH FLOW	DEBT FINANCE	SALES	OPERAT. COST	GROSS PROFIT	LOAN PAYMENT	DEPREC.	TAXABLE INCOME	TAXES PROFIT	NET
1	-8963	0	0	0	0	0	0	0	0	0
	-8963									
2	-11951	0	0	0	0	0	0	0	0	0
	-11951									
3	-10879	0	18442	18253	188	0	2838	0	0	188
	-10691									
4	0	0	36884	28771	8113	0	2838	5275	2110	
6003	6003									
5	0	0	36884	28771	8113	0	2838	5275	2110	
6003	6003									
6	0	0	36884	28771	8113	0	2838	5275	2110	
6003	6003									
7	0	0	36884	28771	8113	0	2838	5275	2110	
6003	6003									
8	0	0	36884	28771	8113	0	2838	5275	2110	
6003	6003									
9	0	0	36884	28771	8113	0	2838	5275	2110	
6003	6003									
10	0	0	36884	28771	8113	0	2838	5275	2110	
6003	6003									
11	0	0	36884	28771	8113	0	2838	5275	2110	
6003	6003									
12	0	0	36884	28771	8113	0	2838	5275	2110	
6003	6003									
13	0	0	36884	28771	8113	0	0	8113	3245	
4868	4868									
14	0	0	36884	28771	8113	0	0	8113	3245	
4868	4868									
15	3410	0	36884	28771	8113	0	0	8113	3245	
4868	8278									

	Economic Analysis			
IRR BEFORE TAXES = 19.141 %	INTEREST	7.0%	9.0%	11.0%
IRR AFTER TAXES = 12.891 %	NPV	12083	7162	3137

Depreciation Method: Straight-Line
 DFC Salvage Fraction : 0.050

LOAN INFORMATION (thousand US \$)

	Direct Fixed Capital	Working Capital	Up Front R&D	Up Front Royalties
Amount	29878	1916	0	0
Equity (%)	100.0	100.0	100.0	100.0
Debt (%)	0.0	0.0	0.0	0.0
Interest (%)	9.0	12.0	12.0	12.0
Loan Time (yrs)	10.0	6.0	6.0	6.0

BREAKDOWN OF CAPITAL OUTLAY (US \$)

YEAR	DIRECT FIXED CAPITAL	WORKING CAPITAL	START-UP COST	UP FRONT R&D	UP FRONT ROYALTIES	TOTAL
1	-8963257	0	0	0	0	-8963257
2	-11951009	0	0	0	0	-11951009
3	-8963257	-1915944	-1493876	0	0	-10879201
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	1493876	1915944	0	0	0	3409821

BREAKDOWN OF LOAN PAYMENT (US \$)

YEAR	Economic Analysis				TOTAL
	DIRECT CAPITAL	FIXED CAPITAL	WORKING R&D	UP FRONT ROYALTIES	
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	0	0	0	0
15	0	0	0	0	0