Energy Recovery from byproduct of sugar cane processing plant: Review Articles

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Abstract

The energy crisis necessitates studying and discovering new processes involved in the production of utilizable compounds as alternative energy sources among which fermentation to ethanol represents a significant strategy. The aim of this material was to assist processors to understand and apply the energy generation from sugar processing plant by products*;* to address that, there exists an increased unit production cost of sugar unless otherwise simultaneous production of diversified products stipulated from the same sugar cane source and the redetermination of the initial sugar concentration and amount of yeast to optimize the molasses medium. Sugarcane resource can be used to produce a variety of commercial products that can be marketed domestically, regionally and internationally. In economic and environmental terms, the three products that have special significance area sugar, ethanol, and electricity. Ethiopia through its potential in developing large sugarcane production can play a pro-active role in mitigating the same. Molasses the non-crystallizable residue remaining after crystallizing sucrose, has additional advantage; it is relatively inexpensive raw material, readily available and already in use for industrial ethanol production. Along with sugar production, diversification was considered to include ethanol production and electric cogenerations.

Key words: Cane, Ethanol Processing, Fermentation, Molasses, Yeast.

Background

Major problems facing modern society include the provision of energy with the minimum generation of pollution, and the environmentally friendly disposal of waste. Ethanol is being widely investigated as a renewable fuel source because in many respects it is superior to gasoline fuel (**Jones and Ingledew, 1993).** This situation has led many countries including Ethiopia to develop and prepare preconditions for the use of ethanol as a fuel from cane sources. Sugarcane resource can be used to produce a variety of commercial products that can be marketed domestically, regionally and internationally. In economic and environmental terms, the three products that have special significance are sugar, ethanol, and electricity. Ethiopia through its potential in developing large sugarcane production can play a pro-active role in mitigating the same. Molasses the non-crystallizable residue remaining after crystallizing sucrose, has additional advantage; it is relatively inexpensive raw material, readily available and already in use for industrial ethanol production. As per the Ethiopian sugar sector strategic plan **ESDA (2005)** the country's sugar consumption has risen from 144,000 tons in 1985 to 300,000 tons in 2003 and the per capita consumption reached 4.2 kilograms per head. In USA in the year 2003, each person consumed about 142 pounds of sugar per year (**OSN, 2005).** The potential growing trend of local market for sugar, export opportunities in EU, COMESA and neighboring countries were the fertile and reliable conditions for expanding and developing sugar factories in the country. This review is to address that, there exists an increased unit production cost of sugar unless otherwise simultaneous production of diversified products stipulated from the same sugar cane source and to redetermination of the initial sugar concentration and amount of yeast to optimize the molasses medium are another point of attention.

Methods

This literature review was formulated through literature searches using Science direct. The following keywords were used:" Cane, Ethanol Processing, Fermentation, Molasses, Yeast ". The logical term operant and was used in the search of items to match keywords.

Molasses Types and its Utilization

The name molasses is derived from Latin word mel, meaning honey **Paturau (1969)** and can be defined as the final effluent obtained in the manufacture of sugar in the repeated crystallization from various raw materials. It is a residual substance from which no crystalline sucrose can be obtained by simple means. Cane molasses is a major byproduct of the sugar industry **(Yansong et. al. 2000).**There are various types of molasses which depends on the source from which they are obtained **Rao (1997);** beet molasses, cane molasses, black strap molasses, refinery molasses and high test molasses are among the common once. Molasses can be converted into many value-added products by application of modern technologies. Many products can be made theoretically **Rao (1997) and Paturau (1989),** but in actual practice, the production of only a few products is commercially viable and hence, commercial scale plants are working in different countries to produce; ethyl alcohol, bakers yeast, torula yeast protein molasses, L-lysine, acetone-butanol, citric acid, lactic acid, glutamic acid and mono sodium glutamate. The industrial use of molasses arises from its sugar constituents. When compared to others, there was less molasses utilization in Ethiopia at present mainly due to low technological development and low market availability. The use of power alcohol from molasses source for vehicles increases the demand of molasses in most other countries and there is a promising move towards production and use of power alcohol in Ethiopia also. This review is insight to indicate the opportunities of ethanol production from sugar cane intermediate molasses for alternative energy utilization.

Ethanol Processing

The common process for ethanol production from any biomass source consists of two steps: Converting polysaccharides into monosaccharide through acid hydrolysis or enzymatic process and then converting the monosaccharide into ethanol by fermentation. The major problem encountered here is that the biomass source contains not only fermentable sugars, but also a wide spectrum of compounds having inhibitory effect on fermentation microorganisms. These inhibitions significantly reduce the ethanol production **(Luo et.al 2002).** The inhibitory nature of molasses arise from its composition which depend on variety of cane, composition of soil, climatic conditions, harvesting practice, and the sugar manufacturing process, handling and storage practices **(Godbole, 2002).**

Fermentation is one of the oldest methods of producing ethyl alcohol, mainly meant for potable purposes. The two main operations are fermentation and distillation. Fermentation is a biological process, whereas distillation is a chemical engineering unit operation. Ethanol respiration is the form of fermentation used to make alcohol and bread. The raw materials used for fermentation are those containing carbohydrates, in one form or the other. According to **Rao (1997),** these are sacchariferous materials (those containing sugar) like cane and beet molasses, cane and beet juice, fruits etc.; amylaceous materials (those containing starch) like grains, potatoes, other roots etc.; Cellulose, like wood, agricultural residues, waste sulphite liquor from pulp and paper mills, waste paper etc.

Molasses contains about 45-50% total sugars, of which 30-33% are cane sugar and the rest are reducing sugars. During the fermentation process, yeast strains of the species saccharomyces cerevisiae, a living microorganism belonging to class fungi converts sugar present in the molasses such as sucrose or glucose to alcohol. As the fermentation starts and the yeast multiply, a part of the fermentable sugars content in the wort is consumed by the yeast for its own survival and multiplication. Then, anaerobic fermentation takes place **(FSFP, 1997).** When the enzyme ‘’Invertase’’ contained in the yeast converts the di- saccharides like sugar in the molasses into mono-saccharides like glucose and fructose subsequently, the enzymes ‘’Zymase’’ contained inthe yeast converts the mono-saccharides into ethyl alcohol and carbon dioxide **(Rao, 1997).** Fermentation is a process by which a chemical changes are brought about in an organic substrate through the action of biochemical catalysts, called enzymes, elaborated by specific types of living microorganisms. It is a metabolic process characterized by: incomplete oxidation, and the transformation of large amounts of substances by comparatively small amounts of organisms **(Paturau, 1989).**

The carbon substrate concentration has a significant effect on ethanol production. Increasing sugar concentration was an advantage because it led to higher final ethanol concentration and, subsequently to reduction of distillation costs. At the same time, the growth of osmotic sensitive contaminants was suppressed. However, at sugar concentration greater than 14%, plasmolysis of yeast cells begins. In addition, the initial rate of fermentation starts to decline before the ethanol concentration reaches a significant value **(Ullmann’s, 1987).**Although biomass produced under

aerobic, anaerobic conditions favor production of ethanol, oxygen found to be essential for good fermentation. Oxygen is especially necessary when batch fermentation is carried out at high sugar levels requiring prolonged growth of yeast, or in continuous processes, because the yeast is unable to grow for more than four to five generations under fully anaerobic conditions (**Bassapa, 1989).** Ethanol is toxic to yeast. The general effect is most noticeable on the cell membrane; the major toxic effect has been postulated as membrane damage of a change in membrane properties. Ethanol inhibits both growth and ethanol production in a non-competitive manner. When ethanol is present in concentrations of up to 2%, the observed inhibition is almost negligible for most yeast. Ethanol tolerance is a desirable trait in industrial yeast strain; however, slow fermenting sake yeast (sacchromyces sake) can tolerate ethanol concentration around 25 % w/v at low temperature as it contains lipoproteins **(Pina et.al, 2004).** Ethanol inhibition is directly related to the inhibition and denaturation of important glycolytic enzymes as well as modification of membrane Hydrogen ions (H+) in a fermentation broth affect yeast growth, ethanol production rate, byproduct formation, and bacterial contamination control. If the pH value is less than five during fermentation, bacterial growth is severely repressed. The pH value range for growth of most strains of sacharomyces cerevisiae is 2.4-8.6, with an optimum of 4.5. Yeast sugar fermentation rates are relatively insensitive to pH values between 3.5 and 6. Most brewer's yeasts have a maximum growth temperature around 39-400C. The maximum growth temperature reported for any species of yeast was 490C for kluyveromyces marxiamus. Mesophilic strains of saccharomyces have optimum cell yields and growth rates between 28 and 350. The optimum and maximum temperature for growth of thermophilic yeast are ca. 40 and 500C respectively; these strains have a high maintenance requirement and more complicated nutritional requirements **(Ullmann's, 1987).**

In batch processing, the optimum temperature for the complete utilization of glucose and the highest final ethanol concentration is generally slightly below the optimum growth temperature. This is attributed to enhanced ethanol inhibition at higher temperature. At higher temperature, the ethanol production rate through the cell membrane. The difference in these rates results in an increase of ethanol concentration in the cells, a subsequent inhibition of some enzymes, and cells, a subsequent inhibition of some enzymes, and cell death. Some yeast has an optimum fermentation temperature of 40-420C. They produce up to 12% of ethanol with yields greater

than 90% of theoretical. Because sugar fermentation is exothermic (586 J of heat produced per gram of glucose consumed), using yeasts that ferment at higher temperature substantially reduces cooling costs of fomenters **(Ullmann's, 1987).**

Glucose and sucrose (molasses) generally well fermented to ethanol by majority of yeasts especially by species of saccharomyces (**Bassapa, 1989).** Generally, distiller's yeasts show a broad pH optimum from 4 - 6. This range is lower than that of typical bacteria. Further, yeastscan tolerate as low pH as two without permanent damage can. As heat, energy liberated during fermentation of sugar by yeasts there is always an increase in temperature and cooling of fermentor is required, and, therefore, it is desirable to use temperature tolerant strains. Most strains have a temperature growth optimum to 30-350C. It has found that trace amounts of oxygen may greatly stimulate yeast fermentation, which used as a building block for synthesis of polyunsaturated fats and lipids required in mitochondria and plasma membrane. High sugar concentration is adequate to repress sugar consumption by yeasts, which show the Crabtree effect. For other yeasts or at low sugar concentrations, the oxygen supply should be limited. In addition to sugar the fermentation broth must provided by additional nutrients for cell growth and maintenance. Glucose medium supplemented with ammonium salts, calcium chloride and yeast extract support rapid growth and ethanol production **((Bassapa, 1989)**

Theoretical Yields and Productivity

In the anaerobic pathway, every mole of glucose converted into two moles of ethanol, two moles of CO2 and two moles of ATP along with 56 Kcals of heat. The ATP produced used in biosynthesis or maintenance via this pathway, every gram of glucose converted yield 0.511-gram ethanol. Molasses contains about 40-45% total sugars, of which 30-33% is sucrose and the rest are reducing sugars. During the fermentation, yeast strains of the species saccharomyces cerevisiae, a living microorganism belonging to class fungi converts sugar present in the molasses such as sucrose or glucose to alcohol.

Glucose $\rightarrow$ Ethyl alcohol + Carbon dioxide

Thus, 180 gm of sugars on reaction give 92 gm of alcohol. Therefore, one tone of sugar gives 511.1 Kg of alcohol. The specific gravity of alcohol is 0.7934. Therefore, 511.1 Kg of alcohol is equivalent to 644 liters of alcohol. During fermentation other by-products like glycerin,

succinine acid etc. are also formed from sugars. Therefore, actually 94.5% total fermentable sugars are available for alcohol conversion. Thus, one tone of sugar will give only 644 x 0.945 = 608.6 liters of alcohol, under ideal condition theoretically. Normally only 80-82% efficiencies are realized on plant. One tone molasses containing about 45% fermentable sugars gives an alcoholic yield of 230 liters per tones (**FSFP, 1997**).

Yeast Strain Selections

Yeasts are the most commonly used organisms in the industrial production of ethanol. Some widely used, high-productivity strains are saccharomyces cerevisiae, S.uvarum (formerly S.carlsbergensis), and candidautilis. Saccharomyces anamensis and Schizosaccharomyces pombe are also used in some instances. Kluyveromyces species, which ferment lactose, are good producers of ethanol from whey. Ethanol production by yeast is characterized by high selectivity, low accumulation of byproducts, high ethanol yield, high fermentation rate, good tolerance toward both increased ethanol and substrate concentrations, and lower pH value. Viability and genetic stability of yeast cells under process conditions and at high temperature are also desirable. Although finding a strain that has all these characteristics is difficult, some yeast strains can fulfill them largely. Yeasts are single-cell fungi organisms. The most important ones used for making ethanol are members of the saccharomyces genus, bred to give uniform, rapid fermentation and high ethanol yields, and be tolerant to wide ranges of, temperature, pH levels, and high ethanol concentrations. Yeasts are facultative organisms-which mean that they can live with or without oxygen. In a normal fermentation cycle, they use oxygen at the start, and then continue to thrive once it has all been used up. It is only during the anaerobic (without oxygen) period that they produce ethanol **(Basappa, 1989).**

The process implies two distinct fermentation phases. The primary fermentation takes place as the yeast breeds rapidly in the initially aerobic environment and the colony comes up to strength.Then, the secondary fermentation takes place in the anaerobic environment thus generated, as the yeast strips oxygen from the sugar molecules in order to avoid suffocating. The influence of the yeast depends on the sugar concentration in the fermentation broth and the pitching temperature **Kelsall (1989),** there are three phases to fermentation once the yeast has been added:

An **initial lag phase**, where little appears to be happening, but the yeast is adjusting to its new environment, and beginning to grow in size **After about 30 minutes,** the yeast begins to reproduce rapidly and the number of yeast cells increases exponentially (thus known as the exponential growth phase).Carbon dioxide is released in large quantities, bubbling through the liquor. As the fermentation proceeds, the yeast cells tend to cluster together (flocculate). The **last phase** is a stationary phase during which nutrients are becoming scarce, and the growth rates slow down. The evolution of carbondioxide slows down, and the yeast settles to the bottom of the fomenter. While making the ethanol, the yeasts will also make very small amounts of other organic compounds–including other alcohols, aldehydes, esters, etc. These are known as the "congeners" or the "fusel oils". It is the presence of these, which give the alcohol its flavor. So when trying to make a neutral spirit, one would try to minimize their presence, but if making a rum, brandy etc, and then one need a very small proportion of them present **(HD, 2000).**

Ethanol and Sugar Production in Ethiopia

The worldwide recent awareness for the use of ethanol to replace petroleum and generation of power along with sugar mill plants should have led to setting up of number of ethanol plants and co-generations. There is only one sugar mill producing ethanol & few distilleries participating in down stream chemicals from alcohol in the country at present due to poor economy of scales. Among molasses derived products ethanol takes the largest part, but its utilization must attract the attention of the government policy makers in order to utilize as a bioethanol. Bioethanol or biofuel is ethanol-based products that can processed into liquid fuels for either transport or heating purposes. With the coming into being of the sugar sector expansion and modernization in the country, implementation of the different domestic measures for bioethanol fuels utilization has to take place. At present there was about 8000 cubic meter annual production of ethanol, but there are projects towards increasing the product to over 142000 cubic meter (**ESDA, 2005).**

Engineering Principles Involved in Sugar and Ethanol Production

Principles Involved in Sugar Crystallization

In Ethiopia sugar cane is processed to sugar and molasses products after successive operationsunder exaggerated equipments capacity utilization and energy intensive processes. Both sugar and molasses product qualities are dependent on the manufacturing process and raw material. In practice not all of the sugar in the syrup comes out in one go, therefore the sugar is extracted in stages: taking out some sugar from the syrup, then taking more from the resultant molasses and finally a third boiling occurs to remove more. Each stage takes approximately twice as long as the previous one, as there is less sugar available in the resultant molasses. The crystallization of sugar from impure sugar cane syrup necessitates good planning of the crystallization stages in order to crystallize out the sucrose in original material and it commonly termed "Boiling Scheme" **(Made and Chen, 1974; Jenkins, 1966).** The ultimate is to crystallize the sugar starting with the raw material, the syrup, in a minimum number of boiling of descending purity, to final molasses. The increased number of boiling necessitates high energy consumption and increased equipment utilizations. Boiling Scheme will be determined by sucrose content of input syrup and, it could be classified as four stages, three stages and two stages of boiling. When the syrup purity range is over 85%, it follows four stages of boiling. When the input purity ranges is in between 80-85%, three stages finally, when the input purity falls below 80% can accomplished in two stages of boiling (**Made and Chen, 1974).** In sugar practice, letters A, B, C designates the different grades of strikes and after purging the separated sugar and molasses takes the same symbol as (A,B,C) sugar and molasses respectively. As the total quantity of processed sugar from cane increases, the quantity of molasses produced increases. On the average, the production of molasses in cane sugar factories is of the order of 35% on the production of sugar and in beet sugar factories, it is of the order of 25% on the production of beet sugar **(Rao, 1997).**

A-sugar: This is made by 'footing' a pan - under a vacuum a set amount of magma (a thick paste of small sugar crystal and water) is drawn into the pan. The footing is then fed with syrup until the crystals grow to the right size. The crystals are in a mix with molasses. This mix is called 'massecuite' (m/c). The m/c is dropped out of the bottom of the pan into receivers, to await separation. A-.m/c separates into A-sugar and A-molasses by centrifugal machines.

B-sugar: This is the same as A-sugar except the pan is fed on A-molasses and takes twice as long to grow the crystal, because B-sugar produces B-sugar crystal and B-molasses.

C-sugar: A set amount of A-molasses is drawn into a pan and boiled until it becomes very thick, this is then seeded with powdered sugar particles and allowed to grow and form C-m/c by feeding on B-molasses, until the crystal reaches the required size. On separation C-m/c gives C-sugar and final molasses which is usually used as raw material for alcohol and many other products.

After being passing a set of evaporators, the concentrated juice (Syrup) is sent to a unit called pan to get crystallized. The primary function of a pan is to evaporate the remaining water and bring the brix of syrup from about 65% solid content to sugar crystals which are 100% solid. The pan is plate and tube type heat exchanger that encompasses; bottom cone for m/c discharging, large cylindrical space above heat exchanger part for vapour - sugar entrainment separation, central down take for syrup/masscuite circulation, steam admission and condensate drainage provisions. The fundamental process takes place is heat transfer from the heating media (steam) to the masscuite inside the pan **(Hugot, 1986).** The rate of sucrose deposition on the crystal surface depends on; syrup/molasses viscosity, degree of sugar solution super saturation, boiling temperature and quality of input syrup. The viscosity of a masscuite is inversely proportional to the temperature and purity of the boiling material. The viscosity is increased from A-masscuite to last boiled C-masscuite, which highly affects the rate of crystallization. Lowering the pan boiling temperature reduce the rate of crystallization, while boiling under elevated temperature affects quality by inducing colour and also incur sugar loss due inversion. The rate of deposition of sucrose over the sugar crystal is proportional to the square of super saturation (**Karmarkar, 2000).**

Principles Involved in Ethanol Production.

There are different types of fermentations among which the batch and continuous fermentation are the most common. The batch fermentation process is the oldest and conventional method used for the production of ethanol from molasses. In this process, several fomenters are usually

operated in staggered intervals to provide a continuous feed to the distillation columns. As this method is not only laborious, time-consuming (36-72 hrs) but also less efficient (80%) and yields less alcohol and productivity (2.2 g/t/h) Continuous fermentation is among the several processes that have been developed for improvement. The inherent problems in the batch process are, low cell density product and substrate inhibition. The productivity of continuous fermentation can be greatly enhanced by yeast cell recycle by the use of a centrifuge and the yeast cell density is increased to four-fold to 50% g/t in a laboratory trial. The residence time for completion of conversion of 10% glucose feed was reduced to 1.6 hr with a corresponding productivity of 30 g/t/h. Simple cell settling systems using flocculating yeasts with essentially no equipment (centrifuge) cost could be developed **(Bassapa ,1989).** No matter which process is chosen (free cells, flocculent cells, or immobilized cells); as a general solution to reduce production costs and improve process efficiency and ethanol yield; the continuous fermentation method is the most appropriate. When compared with processes using immobilized cells, alcoholic fermentation using free cells offers some advantages: the larger area of contact between cells and nutrient medium and the management of current technology. However, disadvantages include the higher costs of microbial recycling and installation, high contamination risks, susceptibility to environmental variations, and the limitations of the dilution rate in continuous fermentation due to wash out **(Vasconcelos et. al., 2004).**

Conclusion

The analysis of cane molasses and particularly of sugars in it may vary considerably depending on the variety of sugarcane, soil, climate, period of the crops, efficiency of the factory operations, system of sugar boiling, storage conditions, age etc. The presence of caramel, gums, pectin, organic acid and proteinous matter vary in different kind of molasses **(Meade, 1977).** Some of factors in molasses influencing fermentation are fermentable sugars; inorganic salts; volatile acidity and hygienic conditions. Yeast uses fermentable sugar for ethanol production and salts inhibits yeast activity due to osmotic pressure. Volatile acids reduce yeast growth and ethanol formation **(Godbole, 2002).** During clarification of the juice in the sugar factory; it is observed that lime and sulphur are added. These practice increases the calcium content of the molasses and increases volume of molasses in the storage tank because of entrapped gasses like CO2 and SO2. The increased calcium in the molasses retards the fermentation rate and creates

scaling in the analyzer column. Excess of sulphate also results in lower fermentation efficiency investments to incorporate ethanol plant and if required, the production of sugar can be suitably curtailed without affecting the economy of sugar mill or reducing any intake of sugar cane. The suggested options are; produce sugar from primary juice and divert secondary for the production of ethanol or divert part of syrup or divert intermediate molasses mB for the production of ethanol. In each of the cases, there shall be an additional savings in steam energy and power resulting in an increase in earnings through export of power **(STM, 2005).** There is no standard rule as such that limits the determination of number of boiling stages in a sugar factory. All the sugar factories in Ethiopia follow three stages of sugar crystallization system including Wonji-Shoa Sugar Factory (WSSF). This review clearly indicates that there can be significant technical potential for maximum economic use of sugar cane source through selective use of modification of sugar crystallization system. The modification from three to two crystallization system brought about process operational simplifications and efficiency improvements besides enormous economic advantages.

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