CEER - 8.069: THE USE OF HIGH-TEST MOLASSES DISTILLERY WASTES

Prepared For: THE UPR CENTER FOR ENERGY AND ENVIRONMENT RESEARCH BIOMASS ENERGY PROGRAM & CENTER FOR ENERGY AND ENVIRONMENT RESEARCH

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Prepared For: THE UPR CENTER FOR ENERGY AND ENVIRONMENT RESEARCH BIOMASS ENERGY PROGRAM

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ABSTRACT:

The Puerto Rican rum industry earns revenues of more than $200 million yearly. A by-product of the rum production is distillery stillage, a muddy brown liquid, a waste effluent from the making of alcohol. It has a high biological oxygen demand (BOD), equivalent to that of raw sewage. Normally, Puerto Rican rum distilleries dump this material into land and coastal waters. Federal regulations starting in 1983 will prevent this. The present rum distillery and its future expansion for rum or gasohol production is threatened by proper disposal of the stillage. This paper presents possible solutions to this problem. The stillage is an organic liquid (8-10% total solids) with a high content of inorganic salts, especially potassium (6% K_2O, dry-weight basis).

The three rum distillers in Puerto Rico produce about 710,000 gallons of stillage daily. The pollutant value of this material is equivalent to the daily sewage of a city of over one million inhabitants. There exists a potential to produce 730 million gallons of stillage yearly if the 70,000 acres of sugarcane lands are put into high-test molasses production for alcohol. There are available methods for the utilization of stillage to minimize its organic content, and therefore, its ability to pollute. Possible products and uses from stillage are fertilizer, animal feed supplement, fuel, glycerol, ammonium sulfate, activated carbon, cement additive, corrosion inhibitor and agglutinating agent for animal feeds. They all present various advantages or economic factors. The choice favored by the Puerto Rican rum distillers for stillage utilization will vary, according to distillery site, from irrigation as a fertilizer to cane fields, to a bio-gas fuel source by anaerobic digestion, followed by aerobic digestion to lower the BOD level sufficiently to be dumped into the ocean. Yet, uses of stillage as a fertilizer and animal ration can supply needed materials and reduce imports. Economic considerations are discussed.

INTRODUCTION

Distillery waste (or stillage) is an amber to muddy brown liquid with a characteristic odor. It is the effluent from the first distillation column in the making of alcohol. This valuable product is an aqueous suspension of organic solids and minerals which has a high biological oxygen demand (BOD) content equivalent to that of raw sewage. For every gallon of anhydrous alcohol made, approximately 12-17 gallons of distillery waste are produced. The rum industry of Puerto Rico earns revenues of more than $200 million yearly. It is presently threatened by the industry's inability to dispose properly of its stillage. A total of 200 million gallons of stillage, with a BOD of 30,000-40,000 ppm, are dumped into land and coastal waters. The Environment Protection Agency (EPA)

The ruling states that the dumping of coastal water must stop unless the stillage is properly treated before 1983 (1). A sugar mill energy project submitted to the Office of the Governor of Puerto Rico by CEER-UPR (2) proposes the production of high-test molasses and boiler fuel. The high-test molasses will be used by the rum industry, which currently imports over 80% of its supply (3). If implemented in full-scale by the Puerto Rican sugar industry on its 70,000 acres, it could produce

122 million gallons of high-test molasses. This could yield 56 million gallons of alcohol for rum and gasohol and leave a residual 734 million gallons of stillage. The present rum industry and its future expansion for rum or gasohol production is threatened by the proper disposal of the stillage. The aim of this paper is to present possible solutions to this problem. The waste effluent, referred to as stillage in this paper, is also known as distillery slops, distillery spent wash, distillery wastes, and Vinasse (mosto in Spanish and vinhoto or vinhaca in Portuguese).

Spillage, Source: Stillage is derived as a residual product in the production of alcohol by fermentation. Its source is the effluent from the bottom of the first distillation column in the making of alcohol. Alcohol is made by fermenting a dilute solution of cane molasses with yeast for one or two days and then distilling the fermentation "beer" to recover the ethyl alcohol. The fermentation process begins as the yeast first converts the sucrose into equal parts of glucose and fructose. These in turn are converted into alcohol and carbon dioxide. The resulting fermentation product, known as "beer" or "wine" or mash (8 to 12% alcohol), is then fed continuously through a multi-column distillation process to separate the ethyl alcohol from the spent molasses and fermentation by-products (stillage). The first distillation or alcohol stripping column separates the alcohol from the fermentation mash. This stripping process yields the major waste component of the

The agricultural plan of Puerto Rico (5) is to be used to produce high-test molasses and bagasse as advocated by CEER (2). The alcohol produced from this acreage would be 56 million gallons, which would yield 734 million gallons of stillage to be disposed of yearly. Such large quantities of stillage, more than three times the amount now produced, will pose a challenge of how to dispose of it properly, considering both environmental and economic considerations. Stillage can be a pollutant if not disposed of properly. It does not contain viruses or pathogenic bacteria. However, its most prominent pollution problem is due to its organic matter content, which gives it a high biological oxygen demand (BOD) equivalent to raw sewage. In Brazil, human sewage production per day is estimated to have a BOD value of 54,000 ppa (6). Stillage from the Puerto Rican rum industry has a BOD of 30,000 to 40,000 ppa (4, p. 21). Therefore, one gallon of stillage has a BOD equivalent to the sewage produced daily by 1.5 people. The dumping of 360,000 gallons of stillage daily into the coastal waters by the Bacardi distilleries in Cataño has a BOD equivalent to the sewage of a city of about 540,000 inhabitants. Stillage also contains several compounds included in the list of toxic materials (priority pollutants) identified by Congress in the Clean Water Act (Table 4). It is believed that the high BOD of the effluent is the cause of significant damage to marine organisms in the coastal waters where the stillage is discharged (4). The Environmental Protection Agency (EPA) has ruled, after a study of the rum distillery effluent discharges into the coastal waters of Puerto Rico and the Virgin Islands, that these effluents are harmful to the marine environment. This dumping must stop unless the stillage is properly treated before 1983 (1). Therefore, the present rum industry and its future expansion for rum or ethanol production is threatened by improper disposal of the stillage. The reduction of the pollutant effect of stillage can be

The text can be corrected as follows:

Accomplished by:

1. Degradation of the stillage into inert forms in relation to the environment. For the organic residues present, this can be achieved by chemical or biological oxidation, which eventually produces CO_2 and water as the non-pollutant residues.

2. Processing the stillage, transforming it into commercial products (recycling) such as fertilizer salts or animal feeds.

The amount of BOD reduction by treatment of stillage is as follows:

Process % BOD Reduction

- Anaerobic fermentation: 80%
- Aerobic fermentation: 90%
- Evaporation to 60% total solids: 95%
- Incineration: 295%
- Reverse osmosis (15% total solids): 9%

Suggested processes for reducing the BOD of the stillage and/or recycling the stillage into commercial products will be presented in the following sections of this report.

UTILIZATION

Stillage should not be considered as waste material, but rather as a raw material with possibilities for conversion into useful products with potential economic value. Even if the money generated by the product utilization just covers its conversion costs or usage, it should be considered of beneficial value as it eliminates a pollutant from the environment. The possible processes and products for the utilization of stillage are shown in Fig. 4.

A. Fertilizer

Stillage can be classified as a dilute liquid organic fertilizer with a high content of K. It contains about 90-93% water and 7-10% solids of which 75% is organic. The 25% inorganic solids have about 63% K_2O on a dry-weight basis. However, stillage should not be regarded merely as a K fertilizer. Its N is mostly organic in colloidal form, available over a longer range of time than most inorganic N sources. The P is about two-thirds in organic form, thus making it much more available than inorganic P sources. Also, it contains large amounts of such important secondary elements as Ca, S, and Mg as well as needed trace elements such as Mo, Cu, and Zn. In its natural state, as it comes from...

The distillery (at about 70°C), stillage offers the most immediate and economic use as a fertilizer if it can be used directly for land application. It is being used as fertilizer on a large commercial scale by the Brazilian sugarcane growers. Faced with huge quantities of this material, about 34 billion gallons per year by 1985, the Brazilian sugar-alcohol industry has made rapid strides in applying stillage as a fertilizer for their sugarcane, decreasing the use of commercial fertilizers.

(a) Influence on Soils and Production: Stillage applied to the soil raises soil pH, mostly by virtue of its Ca content, for 30 to 40 days after application. The soil returns to its original pH value six months after application (7). The cation exchange capacity on light-textured soil is increased by large applications of stillage (6). This action is short-lived if not repeated, but annual applications tend to keep this value elevated. Levels of K, Ca, and Mg are increased in the cation-exchange complex by stillage application. The physical properties of the soil concerning resistance to erosion (9) and water-infiltration capacity (10) have been improved by stillage application. Numerous experiments in Brazil have shown increases in cane tonnage per acre with the use of stillage (12, 12). Increases up to 30% in cane production have been obtained. Also noted is the increase in the number of ratoons per field when stillage is used on sandy soils. Increases in cane tonnage of up to 38% using stillage on partially reclaimed saline soil were obtained in Puerto Rico (13). In Trinidad, increases of up to 45% in cane tonnage were shown on first ratoon application of stillage to a sandy loam (14). Adverse effects on cane quality have been reported when using large quantities of stillage per acre, up to 10,000 gallons. The principal effects of high rates of stillage application on cane quality is to retard maturation (probably due to excess N), lower the sucrose-percent-juice and increase the level of ash in the juice.

Juice (15). High levels of ash in the cane juice interfere with the crystallization of the sugar. Research has shown that varieties differ greatly in their uptake of K from applied stillage and the resultant 'ash in juice' and influence on maturity (16). Proper selection of varieties can diminish the adverse influence of high stillage applications on juice quality. Rates up to 750 gallons per acre of stillage from molasses do not appear to influence cane quality adversely.

Application and Rates: In Brazil, stillage is applied by tank trucks and irrigation. The tank truck transports the stillage from the distillery to the field and applies it. Another method uses a tank truck to transport the stillage to the field where it is transferred to a tractor-powered tank for infield application. In general, the tanks are constructed of stainless steel or fiberglass, due to the corrosive nature of the stillage to ordinary steel or other metals.

Irrigation with stillage, called "ferti-irrigation", normally consists of pumping the stillage, in its natural form or diluted with residual wash water from the sugar mill or distillery, to reservoirs at high points in the field. By gravity, the stillage is distributed via canals and furrows to the field. Overhead portable irrigation equipment has also been used to apply diluted stillage. The advantages and disadvantages of the various systems used for fertilization with stillage are given in Table 5.

It should be remembered that whatever system is used, all of the daily stillage production of the distillery has to be applied in about 26 hours or it begins to ferment. The economics of stillage application for fertilizing sugarcane depend on such factors as distance to area to be applied, rate of application, source of stillage, and type of application equipment. An excellent study of the economics of stillage application by various systems has been made by Copersucar in Brazil (17). A comparative study of all systems showed the relative costs of the various systems.

The corrected text is as follows:

System Relative Application Costs are as follows: Tank truck, gravity flow, Tank truck, motor pump, Tank truck pump powered by take-off, Tank truck delivering to tractor-tank.

Irrigation, overhead, Irrigation, furrow, Mineral fertilizer. Normally, stillage is applied to the ratoon crop in Brazil after the cane is harvested but before the germination of the new ratoon takes place. This coincides with the availability of the stillage from the distillery and ratoon field operations. The plant crop rarely receives stillage as new plantings occur when stillage is not available. However, some field experience has shown good results from applying the stillage to the field after the last harvest, before preparing the next field planting. Limited experiments in Brazil have shown that herbicides may be applied with the stillage in tank-truck application for weed control (18).

On a limited scale in Brazil, stillage has been composted with filter press cake or mud and/or bagasse to make an organic fertilizer. Experiments are being evaluated as to the value of these composts for below the seed application in plant crops. The rates of stillage application depend on its source, because its composition is somewhat variable. Inasmuch as stillage is used primarily as a potash fertilizer, rates are based on the amount of K needed by the crop for the particular soil. Bittencourt (19) has devised equations to determine application rates for various stillage sources using K analyses.

Stillage is applied normally at rates of about 750 to 2000 gallons per acre when derived from molasses fermentation and up to 4,000 gallons per acre when derived from cane juice. Of course, amounts of %, Ca, § and other fertilizer elements are also supplied by the stillage (Table 6).

Concentrated Stillage Fertilizers: The concentration of stillage for fertilizer usage by removal of water decreases handling, storage, and transportation costs. The removal of water from stillage requires energy, and thus raises the

Cost of the concentrated product. At present, there exist two commercial processes developed in Europe for the beet stillage industry, but now being used in Brazil for sugarcane stillage. The "Borag" process concentrates the stillage to 60% total solids by use of multiple evaporators in the distillery (no outside energy source is needed) and then concentrates the material to a powder by use of chimney gases (20). "Conger" uses two processes to convert stillage to a concentrate of 50-60% total solids and then to a powder - one being a spray drier, the other a turbo-homogenizer (21). The powdered stillage is hygroscopic except with the turbo-homogenizer process which mixes the stillage with bagasse. No experience exists in Brazil for the use of concentrated stillage as a 60% total solid syrup or powder. In Europe, especially France, concentrated stillage, primarily from sugar beet-alcohol distilleries, is used with good results as a fertilizer for grapes, citrus, tobacco, and asparagus. In Australia, a patent has been granted to mix the powdered, hygroscopic stillage with 15% superphosphate to make a granulated fertilizer (22). The use of the ash from incinerating stillage for fertilizer had been practiced in the 1930's in Brazil (23). A vegetable potash made from distillery waste and containing 33% K2O was listed on the U.S. fertilizer market in the 1940's. Several processes exist today to produce potash-rich fertilizer by incineration of concentrated stillage (24, 25). The combustion of concentrated stillage provides sufficient heat to carry out the evaporation of the natural stillage to 50-60% total solids as well as give a potash-rich ash for fertilizer.

Usage, products with up to 42% K2O content have been obtained with a production of 184 pounds K2O per 1,000 gallons of stillage.

2. Fuel

Stillage can be fermented anaerobically to produce biogas, a mixture of gas containing 50-80% methane, giving 5.3 cu.ft/gallon of stillage with a heating value of 1020 BTU's/cu.ft of methane. The mechanism of

The anaerobic fermentation occurs in two stages. In the first stage, simple carbohydrates serve as a substrate for a group of acetogenic bacteria which metabolize the compost producing organic acids, principally acetic acid. In the second stage, which is strictly anaerobic, the acids are transformed into CO_2 and methane (CH_4), principally by methanogenic bacteria. The anaerobic fermentation can occur at two temperature levels each favoring specific bacteria: mesophilic phase (35-40°C) and thermophilic phase (50-60°C). There is evidence that the thermophilic phase can occur twice as rapidly as the mesophilic. Although the process is rather simple, there are complicating factors of pH, temperature, and interfering ions in the substrate. The two ions causing problems when in excess are K and S, with strong inhibition occurring at 12,000 ppm for K and 200 ppm for S (26). The S, as SO_4, favors the formation of H_2S gas which inhibits the methanogenic bacteria. Thus, for stillage produced from molasses fermentation, it may be necessary for pretreatment of the molasses to reduce the S content. Dilution to lower S levels causes added load levels making for a more expensive anaerobic fermentation operation. The efficiency of methane production in an anaerobic fermentation can be increased by using two digesters instead of one. One digester gives approximately 54% volume of methane gas in the biogas mixture, while the second digester gives 77.4% methane volume in the biogas mixture. The caloric value of the biogas from one digester is 550 BTU's/cu. ft of gas and 790 BTU's/cu ft from the second digester, giving 645 BTU's/cu ft for a mixture of the two digesters (27). A schematic representation of how stillage can be converted into steam for energy use by the distillery is shown in Fig. 5. The wastes from the anaerobic-methane fermentation plant include stillage XI which has a BOD reduction of about 80% from the original stillage. However, further treatment to reduce BOD to acceptable EPA levels may be required. The sludge...

The byproduct from methane fermentation must be partly disposed of by recycling to the digestors, then thickened, dried, and incinerated. This material has a fertilizer value. The anaerobic conversion of stillage to methane gas provides energy (1000 gallons of stillage provides gas energy equivalent to 0.52 barrels of oil) and reduces the BOD to less than 80% of former values. As mentioned in the previous section on fertilizers, fuel energy is also obtained in the incineration of concentrated stillage to ash. However, the amount of energy obtained normally covers that needed for the concentration of the stillage.

Stillage can be used as part of the rations for animal feed by:
(a) Direct incorporation of concentrated stillage (60-80% total solids) into balanced rations as a substitute for molasses.
(b) Drying the concentrated stillage to a powder and using this powder as an agglutinant and feed ingredient.
(c) Producing unicellular protein from aerobic fermentation of the natural stillage and using this material for the protein fraction in conventional animal feed rations.

The high potassium content of the concentrated or powdered stillage can cause an imbalance of the Na/Cl balance and cause intestinal disturbances in the animals if large amounts are consumed. The laxative effect of the potassium content of the concentrated or powdered stillage can be overcome by mixing bagasse into the feed ration, thus allowing for higher levels of the stillage concentrate. In the feed ration, stillage concentrate is usually limited to 22% for poultry and swine, and 10% for ruminants. In Europe, concentrated and dried slops from beet and barley fermentation have been used for over 10 years for animal rations. South Africa and Australia are using molasses stillage as concentrate or powder in animal rations. Known as MDS (Molasses Distillers Solubles), the concentrated stillage (60-80% total solids) is sold for rations for ruminants. Research in Puerto Rico has shown that local concentrated stillage can be used as

The text should be corrected as follows:

Part of the feed ration for poultry, swine, and ruminants. The production of unicellular protein from stillage is accomplished by aerobic fermentation. The process is shown diagrammatically in Fig. 6. The cooled stillage (25°C) is fermented with agitation to ensure good industrial production and produce a homogeneous mass of Tortula yeast. The cellular mass formed is washed and centrifuged to 90% moisture content, then hot air-dried to 5% moisture content. Yields of 64 pounds of crude protein per 1000 gallons of stillage have been obtained. Reductions of up to 90% in BOD levels are also obtained in the residual stillage effluent from the process.

Also available from the alcohol-production process is Saccharomyces yeast produced during the fermentation process. The advantages of producing unicellular protein from stillage are that it is a product with good market value and acceptance. There is an additional benefit of reducing the BOD of the stillage by about 90%. The disadvantages for the process are the high cost of investment and operation, narrow operational limits which require care and control including instrumentation and aseptic conditions to avoid unwanted biological infections reducing or stopping production.

Although major attention has been given to the use of stillage for fertilizer, animal food, or fuel, there are other possible uses for this waste effluent. At present, the other uses are minor compared with the aforementioned. Yet, proper development may give these other products economic status. The suggested other uses of stillage are: (a) Agglutinant for animal feeds can be provided by adding either concentrated stillage (60% total solids) or powder. The stillage aids in the forming of pelletized animal feeds and can be used up to 10% in weight as the concentrate and 30% in weight as the powder for grass and legume mixtures. (b) Retardation of the setting of cement and prevention of crusting on cement forms by addition of stillage in concentrate or powder. At present

The text should be corrected as follows:

It is used principally in the Soviet Union (31). Some builders in Sao Paulo, Brazil, are using it to prevent crusting on cement forms. (e) Inhibition of corrosion of metals by acids can be accomplished by stillage derived from molasses. Although stillage in the natural state is corrosive to cast iron and mild steel, in dilute form (up to 20% natural, concentrated at 55% total solids) it provides inhibition against acid solutions, prolonging the equipment life 6-20 times (32). The anticorrosive action is believed to be due to polymers, coloring matter, and reducing sugars present in the stillage. (f) Glycerol can be obtained from concentrated stillage by extraction with a solvent and then distillation (33). Preliminary trials in Brazil revealed that the content of glycerol in their stillage was too low to make such a recovery process economically viable. (g) Activated carbon and ammonium sulfate can be obtained by pyrolysis of the residue from the distillation of glycerol. (h)

An aggregating agent for soil stability can be obtained by use of stillage in treating heavy clay soils. This was done with salinized soil in Puerto Rico (34).

5. Intermediate Technology for Reduction of Stillage Volume

The possibility exists to reduce the volume of stillage obtained in the production of each gallon of alcohol. From the present 12 to 17 gallons of stillage for each gallon of alcohol, reductions up to 50% are possible. Such a concentration would prove of economic benefit, regardless of the resultant use of the stillage. Some of the methods to reduce stillage volume are as follows (27): (a) Raising the alcohol concentration in the fermentation "beer" or "wine" Normally, the fermented molasses mixture is distilled off when it reaches 7.5° GL and gives 13.3 gallons of stillage per gallon of alcohol. By raising the alcohol level in the fermentation mixture before distilling, the volume of stillage could be reduced up to 28%. To do this, strains of yeast more resistant to higher alcohol levels will be needed.

Control of temperature by refrigerated cooling towers and continuous fermentation will be used. Tate and Lyle (35) have developed a continuous fermentation process allowing alcohol concentrations up to 12% with a subsequent reduction in size of the distillery and stillage volume. (b) Elimination of stillage dilution by waste steam. Normally, distillation of the alcohol in the distillation column is done by using steam as the heat source directly into the column. By use of external heat sources or steam in serpentine heating tubes, the dilution of the stillage volume could be reduced by about 17%. (c) Recirculation of the stillage by using it for dilution of the molasses rather than using water can achieve reductions in stillage volume from 20 to 30%. To permit a greater recirculation of the stillage, the Alnothern process (24) of molasses purification can be utilized to remove non-fermentable materials. (d) Concentration of the stillage by external heat sources using multiple effect evaporators or by direct contact with chimney-flue gases. One problem that exists in the use of multiple-effect evaporators with stillage is the problem of encrustation primarily due to the high amounts of calcium sulfate present in the molasses. The purification of the molasses by Alnotherm or other processes greatly reduces the encrustation problems as well as increases alcohol yield in the fermentation by 10%. There are other intermediate technologies which can be used to improve the quality of the stillage for by-product utilization. Some of these are: (a) Magnetic separation consists of adding magnetite sands to the stillage as a precipitation aid and then removing the magnetite with the attached solids by means of high intensity magnetic fields. At present, problems of dilution and destabilization exist (36). (b) Reverse osmosis for treatment of cane juice or stillage to remove starches, dextrins, and other polysaccharides (37). The process has various applications in cleaning up industrial wastes such as cheese whey. It has

The text has been revised for clarity, grammar, and spelling:

The pilot-plant stage has been tried for beet-industry wastes. The current problem consists of the large surface area needed for the process, making it uneconomical.

(c) Using MgO instead of CaO for clarification of cane juice will result in a reduction of $CaSO_4$, which due to low solubility, causes incrustation of distillation columns and interferes with stillage concentration. The problem here is that MgO costs more than CaO.

(a) Continuous fermentation in a vacuum improves alcohol production and reduces stillage volume by 2%. The problem here is the high energy costs needed to maintain the vacuum.

(e) Centrifuging stillage can reduce total solids by 75% by weight and remove 90% of the suspended solids fraction, as well as decrease the BOD by 50%. This method works well with stillage from winemaking, but experience in Brazil shows only a 25% reduction in solids and 30% in BOD. The energy requirements are too high for the reduction achieved.

(f) Flocculation and flotation of the stillage to remove solids can be used. Flocculants such as aluminum sulfate or iron hydroxide or sulfate can potentially cause problems of residual toxicity to the soil if the raw stillage is applied as fertilizer. Non-conventional poly-electrolytes are being evaluated (38). At present, the process is not economical.

(g) Yeast can be eliminated from the fermenter "beer or wine" before distillation by centrifugation. The centrifuged yeast may then be recycled for reuse in the fermenters, sold for animal feedstuff, or land disposed. The Boinet technique can be used for yeast recovery (4, p- 23), shortening fermentation time by 40 to 80% with up to 5% increase in alcohol yield.

(h) Removal of the unfermentable solids and dead yeast cells, which settle at the bottom of the fermenters to form a sludge (fermenter bottoms), can reduce suspended inorganic and organic materials which could become part of the stillage. Instead of discharging into local sewer drains, the sludge can be removed by a pump to a holding tank.

Then comes land disposal.

POTENTIAL USES OF STILLAGE

There are many potential uses of stillage in Puerto Rico rather than mere dumping of this material into coastal waters, which will be prohibited by 1983. Technology exists for the development of most of the processes and products. Research is needed to adapt the technology for Puerto Rican stillage under its own particular legal conditions. Also, economic investment is needed to put the processes and products into being.

A. Fertilizer

Puerto Rico is a heavy user of commercial fertilizers, especially for sugarcane, pineapples, and vegetables. Yet, the use of stillage as a fertilizer is ignored except for the Serrallés rum distillery in Ponce which for years applies stillage to its own nearby sugarcane fields by mixing with irrigation water. The two largest rum distillers do not own agricultural land, and thus they have no direct fertilizer market for the stillage they produce. The Bacardi operation in Cataño has no agricultural lands nearby. However, the Puerto Rico Distillery operation, west of Arecibo, is located in a large agricultural area devoted to sugarcane, pineapples, and vegetable crops. Aside from sugarcane, the Serrallés operation in Ponce is in the center of a large agricultural area which extends east and west along the south coast and produces bananas, vegetables, and orchard fruits.

Tank truck application of stillage as a fertilizer has proven economical in Brazil for distances up to 15 miles from the stillage source. However, application of stillage by tank truck to areas beyond economical irrigation application range has not been tried on the Island. Where distance becomes an economical limitation, the concentrated or powdered stillage may be used; but problems in the ease of application of these two forms remain to be solved.

The most practical form to apply stillage as a fertilizer material is the ash when savings in transportation are important. The incinerated ash would not have any nitrogen and phosphorus content, only potassium. Yet,

The text could be fixed as follows:

"It could compete with imported potash fertilizer. About 11,000 tons of potash are imported annually for local fertilizer consumption. If all of the approximately 200 million gallons of stillage produced yearly by the Puerto Rican rum distillers were converted into potash, it would give about 18,000 tons of 42% K70 potash fertilizer. This amount is more than enough to supply all local needs of this costly material. The potential fertilizer production from stillage in Puerto Rico is given in Table 7.

An organic complex N-P-K fertilizer process has been developed by the Japanese using concentrated stillage as a raw ingredient. A dry granulated product is obtained through a series of chemical reactions involving concentrated stillage, sulfuric and phosphoric acids, and ammonia. It has been estimated that the stillage from the Puerto Rican rum distillers could produce about 54,000 tons annually of this fertilizer (4, p. 71).

As an alternative to the use of stillage for fertilizer, there is the possibility of establishing a land farm program which allows the stillage to be applied to the land purely to absorb the material. Such practices are used in Brazil where excessive amounts of stillage from large distilleries are piped onto very low fertility savannah soils. The feasibility of land farming was investigated for the three distilleries in Puerto Rico (4, p. 67).

Based on stillage transport by tanker trucks and pipeline using a maximum annual application rate, the land requirements for stillage disposal was 273 acres for Bacardi and 125 acres for Puerto Rico Distillers. Serrallés Distillery already disposes of its stillage by irrigation application. The site's life was estimated to be a minimum of 25 years based on copper concentrations. If copper was removed or reduced, the next limiting metal, zinc, would extend the site's life to 160 years.

It is interesting to note that the Tanquinho sugarcane mill in the state of Sao Paulo, Brazil, has applied stillage at rates of 100,000 gallons per acre yearly to sandy marginal land for over 15 years."

The distillery in Puerto Rico at Arecibo already recovers fusel and aldehyde heads and burns them as fuel. Bacardi expects to install a recovery system in 1980.

3. Animal Feeds: The use of concentrated and dry stillage has been evaluated as rations for animal feeds for several years in Puerto Rico (28, 29). Results indicate that only small percentages (3-10%) can be used in a ration without causing nutritional problems. The Bacardi distillery in

Catano installed a pilot plant in 1977 to produce concentrated molasses stillage (CMS) to determine optimum operating conditions. Markets are limited in Puerto Rico. Assuming a 5% incorporation level into the feed ration, it was estimated that an annual theoretical maximum of 18% of the CMS produced by all three distillers could be utilized in Puerto Rico (4). The actual maximum may be significantly lower due to customer and manufacturer reluctance to accept a new product. Feeding tests suggest CMS is technically less adequate than molasses as a feed ration, and that to balance this disparity, CMS market prices would have to be about 50% lower than those for cane molasses.

The production of unicellular protein from stillage by aerobic fermentation has been tried in several countries, but at present, there are no large-scale commercial productions of this product. Production of protein from stillage has also been evaluated in Puerto Rico on a laboratory scale (39, 40). The limitations of this product have been economic rather than technological. The unicellular protein has to compete with low-priced protein feed sources. Puerto Rico has no large-scale production of low-priced protein feed sources such as corn or soybeans. These protein sources are imported, with 35,422 tons brought in for 1976 (41). The possibilities for animal feed protein production from stillage appear to be worth consideration. Based on an estimation of 60 pounds of unicellular protein from 1,000 gallons of stillage, the three distillers could produce 6,000 tons of protein.

Feed from the 200 million gallons of stillage they produce yearly. Moreover, there are other possible uses of stillage other than for fertilizer, fuel, or feed for animals. Some of these other uses have potential in Puerto Rico even though they may be considered minor in a global evaluation. A brief description of these uses as applied to the Island are as follows:

(a) Recovery of saline soils can be accomplished by use of stillage. It is estimated that there are about 10,000 acres of soils affected by salinity (10). It would require about 326 billion gallons of stillage to reclaim the 10,000 using 326,000 gallons per acre (1-acre foot) as determined for these soils (23). Most of the saline soils are located on the south coast of the Island where the Serrallés distillery is also located.

(b) Retarding of the setting of cement or prevention of crusting on forms condition of stillage concentrate or powder provides a potential market on the Island, inasmuch as cement is used almost exclusively in its construction program. Research is needed to determine rates and forms of stillage needed.

(c) Glycerol can be obtained from the extraction and distillation of concentrated stillage. The amount of glycerol used in Puerto Rico is not available in the literature. The residue from the distillation can be pyrolyzed to obtain activated carbon and ammonium sulfate, both of commercial value on the Island. The activated charcoal is used in the rum industry for producing "hive" rum, and the ammonium sulfate is a nitrogen fertilizer used in mixed fertilizers for most crops.

Economic Considerations: The rum industry is an important and growing source of government revenues contributing about $213 million or 12.7% of general fund receipts in Puerto Rico for 1978. The industry employed 1,463 individuals in 1977. The chief secondary contributions of the industry are its support of Puerto Rican sugarcane and molasses production and bottle and carton manufacturing. The entire rum industry is threatened by its inability to

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Here is the corrected text:

Break- a as. 16. a. a8. ww. 20. a. 22. 23. 2. 23. 26. 2. ~

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Table 1. Production of Anhydrous Alcohol and Stillage from Various Sources

1/ Fermentable Production, Volumetric relation,

Source materials, % gallons/ton _stillage/alcohol

Sweet potatoes 16 23 2

Cassava 25 a a

Cereal grain 38 145, a

Sugar beets 50 96 7

Sugarcane, juice 10 20 2

Sugarcane, blackstrap molasses 35 96 2

Sulfite Liquor 2 38 96

Wood 6 58 36

Derived from (42, 43)

2/ Gallon alcohol/gallon of sulfite Liquor

Table 2. The Chemical Composition (of Total Weight) of Stillage from RDI and Anhydrous Molasses

Cane juice ‘Total solids 8.55 (7.69-9.5) 8.15 (4.60-8.75)

Organic solids - 6.00 (3.70-6.59) 2.00

Crude protein 0.47 (0.38-.56) 0.75 (.38-.83)

Carbon (C) 2.89 (1.93-3.00)

Potassium (K) 0.65 (.68-.75)

Sulfur (SO_4) 0.66 (.37-.8)

Calcium (Ca) 0.26 (.26-.37)

Chlorine (Cl) 0.3 0

Nitrogen (N) 0.08 (.06-.09)

Magnesium (Mg) 0.06 (.06-.10)

Phosphorus (P) 0.012 (.012-.014) 0.008 (.009-.017)

All derived from (42, 43)

Table 3.

CHEMICAL COMPOSITION OF PUERTO RICAN MOLASSES, 1976-75
1) Sugar, % Ash, % Potassium (K), % Calcium (Ca), % Nitrogen (N), % Magnesium (Mg), % Sodium (Na), % Phosphorus (P), % Iron (Fe), ppm Manganese (Mn), ppm Nickel (Ni), ppm Copper (Cu), ppm Zinc (Zn), ppm. Derived from (45, table 2). Content in molasses: 58.6, 10.45, 3.33, 0.78, 32, 3, 0.8, 280, 50, 0.7.

TABLE 4, TOXIC POLLUTANTS (PARTS PER BILLION) IN PUERTO RICAN DISTILLERY SUBSTANCE
Beryllium (Be), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni), Silver (Ag), Cyanide, Phenol, Ethyl Benzene, Toluene, Benzene, Acetone (Ac).
2) With other waste waters from the distillery.

TABLE 5. COMPARISON OF STILLAGE-FERTILIZER APPLICATION SYSTEM
Advantages and Disadvantages
'Tank track': Easy operation and maintenance but poor control of application rates.
'Slow distribution time': Compacts cost, can't use in rainy weather for steep slopes.
'Uniform application': Can use in any weather or steep slopes but higher fuel consumption.
'Velocity comparable Irrigation': High investment and labor cost to prepare land, can be used in rainy weather, less soil erosion.
'High Tilted Beds': Low maintenance cost for soil irrigation, low labor cost to prepare land, less soil erosion, easy to install and remove from field.

TABLE 6. QUANTITIES OF FERTILIZER ELEMENTS SUPPLIED BY DIFFERENT RATES OF APPLICATION
Fertilizer applied, pounds/acre; Rate applied, in gallons/acre; N%, P%, K%.
500: 2, 1, 2;
750: 5, 2, 5;
1,000: 7, 2, 7;
2,000: 8, 4, 8;
3,000: 2, 3, 5;
4,000: 9, 10, 7;
5,000: 3, 5, 10;
10,000: 5, 15, 7.
Note: Based on average composition.

"On stillage from molasses with an average composition of 0.08% by O38 F05, 0.72% Kj0, 0.28% CaO, 0.17% MgO and 0.01% E5.

TABLE 7. POTENTIAL FERTILIZER PRODUCTION FROM STILLAGE IN PUERTO RICO

Fertilizer elements, consistent with suitable source products. Thousands of tons of N05 AP from rum distilleries. Natural 200 3/ 670 230 6,000. Natural quantities, to be concentrated and 6,000 rosters. 150,000 potash. Total alcohol - Natural 500,000. Concentrate 500,000. Potash ash - 22,000. MG 150,000 gallons. 60% coral solids 12. Based on average composition of stillage given in table 6, footnote 1.

MOLASSES. Wastes NC. Fermentation tank wastes. Alcohol, Aldehyde Rectifying column. Stripping column. Wines heads. Figure 1 is a flow diagram of a typical rum distillery (p. 15).

MOLASSES. Additive: Yeast. Fermentation tank waste. Alcohol, ATA / ALCOHOL / BENZENE Distillation. Rectifying column. Dehydration column. Benzene column. Recovery column. Figure 2 is a flow diagram of a typical anhydrous alcohol distillery.

Total solids: Dissolved (25), Suspended (25). Organic: Inorganic (26.5) (6.7), 5) (22.5) 20 (8.6) 2/. Glycerol (12.2) p20 (0.8). Gums, Sy (7.6) Sugars (11.6) F505 (0.7). Waxes, Frac (6.3) Phenol (2.2) Malt (0.6). Others, CaO (2.5) Nitrate (1.4). CaO (0.3). Fats, Fag (2.3) Igo (0.2). Proteins, Ae 7 Fete, (22.5). Figure 3. Distribution of stillage solids on a dry-weight basis 2/ 2/ Hypothetical composition based on stillage from anhydrous alcohol production (45). 2/ Numbers in parenthesis are percentages of total solids.

"Workstation eBetta@ SOS syrup pad. Purely aesthetic *y "9g e— Honeycomb s01Ty, + Aero Mousepad radius TT ergonomic design{ easy grip.

Stillage, cooling water. Cooling. Fermentation, Sugar extraction, Ethanol. Siphon, Soluble solids. Boiler, Process water. Figure 5. Process of steam."

Generation with biogas (methane) using anaerobic fermentation of tillage.

Sillage water footprint square for organization structure, where sustainability is a central theme. Fig. 6, Process for the production of unicellular protein by the use of aerobic fermentation.

Digestion surface (Extracted Subae) Fig. 7. Soluble acids forming enzymes. Aerobic step: organic acids + methane forming bacteria yield methane + carbon dioxide.

Anaerobic step: aerobic step with activated sludge results in cleaned waste water.

An efficient system for treating tillage using a combined anaerobic/aerobic process (4, p. 75).