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PILOT-SCALE CONTINUOUS CONVEYOR DIFFUSION EXTRACTION SYSTEM FOR SWEET SORGHUM

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ABSTRACT

The purpose of this project is to design a pilot-scale, deployable sweet sorghum diffusion extractor to extract the juice from sweet sorghum stalks while simultaneously infiltrating the extracted juice and processing this juice to fuel grade ethanol. In essence, the system will work by running shredded sorghum through a conveyor with recirculating water running over the crop to extract the sugar through diffusion. The current design spans 30 feet of length, 3 feet of width, and 2 feet of height. The water to sorghum ratio is 0.4 to 35 ounces. The water will be kept at near boiling temperatures. A roller fixture will be placed at the end of the design. The pilot scale sweet sorghum diffusion continuous conveyor diffusion extraction is being constructed and when completed, will be capable of processing at least 5 tons of sorghum an hour with a minimum sugar extraction of 60%.

INTRODUCTION

Biofuels are necessary to offset the importation of oil and to preserve oil reserves. Growers in the United States have focused on the conversion of corn into ethanol; however, this is an expensive and energy intensive process with low yields, particularly when compared to fossil fuels. Additionally, using corn as a biofuel diverts crops from food and livestock production. This increase in the demand for corn can cause food prices to increase. This issue also applies when using sugar cane, another popular conversion crop, as a biofuel.

Sweet sorghum is an arid land grass with high sugar content that is not commonly used for human consumption. It grows in a much wider climate range than sugar cane and more efficiently. In tropical areas, a farmer can grow three crops of sorghum for every one crop of sugar cane per unit area. Overall, the crop requires fewer resources to grow and has the potential to yield similar, if not improved, sugar extraction over sugar cane and corn.

Further, sorghum is desirable as a crop in Arizona because of its drought resistant and heat tolerant qualities. Sorghum stalks are usually between 10 and 15 feet tall. Of the whole stalks, about 75% is moisture while the remaining 25% is dry weight. That moisture contains about 10-25% sugar.

Sorghum extraction efficiency is calculated differently than corn or sugar cane extraction. The main method to measure sorghum extraction in terms of grams is to multiply the amount of dry weight of sorghum by the 75% moisture and brix to determine the maximum sugar yield. Then, to multiply the brix by the final amount of water (the water from which you are determining the brix) to determine grams extracted. Both numbers are then divided to define the percent of the maximum possible sugar that was extracted.

$$\%\ \text{Extracted} = \frac{\text{Final Amount of Water}}{\text{Dry Weight} \times \%\ \text{Moisture}} \qquad (1)$$

The problem is that the technology for the extraction of juice from sweet sorghum is still at the 1-acre farm level. The team realizes that an effective and cost-efficient technique to extract the juice from sweet sorghum with a reasonable throughput is essential to make sweet sorghum a viable crop for the production of ethanol.

Current methods of sugar extraction from sorghum include roller mills and screw presses which have extraction yields of 35-45%. A new, more efficient method for obtaining sugar is desired. This method is diffusion extraction. Extraction by diffusion was first introduced in the 1960's in the South African cane sugar industry. The first installations were bagasse diffusers and they were preceded by a mill. Cane diffusion, which is the extraction of sugar from cane in the absence of a first mill, was coined by Payne. It began in Hawaii in 1968. This method has been adopted around the world ever since. Moving bed diffusers are counter current extraction devices that operate on a staged basis. According to PW Rein, the drive power required on a moving screen diffuser is generally 102,364 BTU/hr for a 300 ton/hr (Rein, 2). Moving bed type diffusers have captured the attention of the cane diffusion market because they have a relatively low cost, ease of operation, and ability to extract high yields of juice.

Sweet Ethanol is a company that works with the University of Arizona to research the viability of sweet sorghum as a commercial crop and an alternative to corn for the production of ethanol. In attempt to efficiently and economically extract the juice out of sweet sorghum stalks, Sweet Ethanol has used roller mills and screw presses. The sugar extraction from these technologies; however, have maximum extractions of 35-45%; yields are too low to claim crop viability or technological efficiency. Hence, an improved method is needed to make sweet sorghum a viable source of ethanol.

The team advocates a system that will produce higher yields. By rectifying these weaknesses, our offered design will improve the extraction rates and quality of extracted juice from sweet sorghum by using a diffusion extractor rather than rollers.

METHODS

Diffusion is the process by which molecules move from a region of higher concentration to an area of lower concentration. The random molecular motion in diffusion is caused by energy that molecules possess. Kinetic energy makes them to constantly collide with each other. Diffusion dictates increased output with countercurrent flow, but to ensure a significant increase in percent extracted to make the complication statistically worth the effort, experiments were performed. The results, when compared, showed an increased extraction from the backward process (from high concentration to low concentration) as opposed to the forward reaction (from low concentration to high concentration) with a minimum extraction difference of 9.5% and a maximum difference of 16.3% (See Figure 1). Thus, in accordance with the principles of diffusion, to increase the extraction efficiency of the final design, the process works using the countercurrent flow of water over the sorghum. High sugar concentration water runs over the beginning section of the conveyor, where the sugar concentration is highest, and low sugar concentration water runs over the end of the conveyor, to extract the maximum remaining sugar from the shredded crop. Thus, water concentrations are added to crops in the opposite direction from which crops are moving. Fresh sorghum is first introduced to water of high sugar concentrations, followed by lower sugar concentrations, and finally, fresh water.

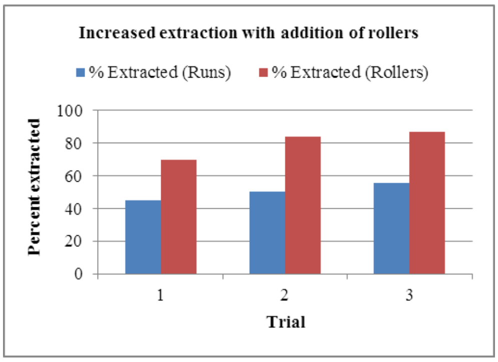

Fig.1. Percent Extraction of Sugar during forward and backward reactions.

Temperature affects the rate of diffusion. Heating a solution increases the rate of diffusion. This is because heat is the total amount of kinetic energy in a solution, which causes the movement of molecules. The water will thus be heated to almost boiling before running over the sorghum, increasing the rate of diffusion and the extraction of sugar.

The design is a portable, pilot-scale diffusion unit with a capacity to process a minimum of 5 tons per hour of sweet sorghum stalk while extracting a minimum of 60% of juice from the stalks.

The system will function using optimal parameters specific to sweet sorghum including a batch time of between 11 and 15 minutes, to ensure sufficient diffusion and desired output; a single batch of sorghum which has shown sufficient for optimal extraction; a final set of rollers which increases final sugar yields by at least 5%; water of about 200˚F, which experimentally increases sugar extraction by a minimum of 10%; and an unaltered pH.

The system will be mounted on a trailer and will be easily assembled and disassembled, allowing it to be moved to various harvest sites during the season. The system will be further optimized to decrease water use and increase efficiency by making the water circulate over the crop. The water will be heated in the collection tanks using propane gas burners. The conveyor will completely circulate in approximately 12 minutes and have a rate of 2.5 feet per minute.

40% water to sorghum will be used to produce optimal extraction rates. Thus, the design uses 9 gallons per hour total or 3 gallons/hour per tank (there are three tanks). Each gallon requires 195,156 BTU/hr. Using 54,000 BTU/hr propane burners, each tank requires 4 propane burners.

The diffusion system will have an automatic spray position control system installed and will require no virtual supervision once running. The hammer mill will produce 6 tons of sorghum per hour in tune with the conveyor speed. The conveyer belt motor will have a power of 205 BTU/hr. The conveyer belt will utilize a variable speed motor allowing for changes to the speed as necessary during operation.

Experiments performed by the team show that adding rollers at the discharge end of the diffusion extractor is essential to extract the remaining moisture and sugar content from the sorghum stalks.

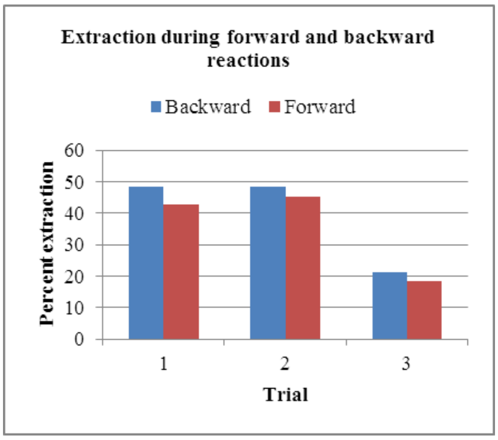

Fig.2. Increased Extraction with the Addition of Rollers to the Diffusion Extractor.

PROCESS

Sorghum goes into the hammer mill where it is shredded. A shaft is attached to the hammer mill. From there, gravity drives the sorghum to fall from the shaft to the conveyer belt. The conveyer belt transfers the sorghum the 30 feet conveyor length where the bagasse will go into a collection tank and re-used for heating the water.

This juice is moved forward one stage by pumping and the process is repeated until the juice reaches maximum concentration at the feed end of the diffuser. The diffuser may be conditioned either for single-flow or for parallel-flows juice circulation.

There are temperature control loops on the scalding juice heaters and direct injection heating. In addition, there is a pH control loop to limit corrosion and mold growth. The system has variable speed pumps to better control the water flow rate. Fresh water is provided by a hose to the first chamber with the float valve that operates on pressure and refills the chamber when more water is needed. This fresh water is pumped into the first nozzle that is located at the opposite end of sorghum flow. Water sprinkles and hits the moving sorghum and passes into the perforated belt and into the first chamber. That chamber has a pump that pumps that juice into a nozzle pipe that then drives the juice to the next nozzle head. Up to this point, the process is repeated two more times until the juice has flowed through a total of three chambers. The final juice flows from the sprinkler pipe into the collection chamber. Based on the float valve used, the chamber containing the fresh water is situated relative to the outlet or sprinkler heads. This is based on the pumping head needed for the water to reach the sprinkler head and on pressure losses that take place from inlet (chamber with fresh water) to outlet (nozzle heads) (See Figure 3).

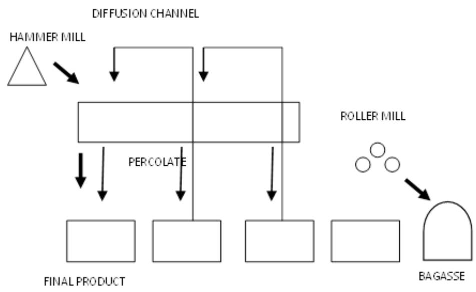

Fig.3. Illustration of the Diffusion Extraction Process

The system is currently being constructed. Testing and calibration will be performed after construction of the final sorghum diffusion extractor. The final system will process 6 tons per hour of sweet sorghum with 60% juice extraction, which will be greater than the current extractions offered by traditional rollers.

CONCLUSION

The final design will process at least 5 tons an hour with a minimum 60% extraction yield by exposing sweet sorghum to a constant diffusion gradient that will incite sugar to flow out from the sweet sorghum stalks. It will operate under extreme Arizona summer conditions, withstanding high temperatures and UV radiation. It will utilize optimized parameters. Furthermore, the final design will be portable and mounted on a trailer and taken to the field, capable of juicing harvested sorghum stalks. Most importantly, the system will provide an efficient source of renewable energy for ethanol production from sweet sorghum juice, from the farm level to EtOH.

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