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Indian Sugar Industry: Towards Self-Reliance & Carbon Free Society for A Sustainable Future

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ABSTRACT

Sugar industry is an agro-based industry which impart significant contribution in the socio-economic development of the nations to fulfil one of the necessities of human survival.

India's sugar industry produces vast amounts of by-products such as molasses, press-mud, bagasse etc. To support the economic viability, predominant by-products of the sugar industry - molasses is utilized by distilleries and generate revenue from alcohol, where this process generates 10 -15 m3 distillery wastewater/m3 alcohol produced, and press-mud approximate 3-4% of the weight of the cane crushed [1]. Conversion of these by-products/ waste into valuable Biogas to Compressed Biogas (CBG) through bio-methanation and Fermented Organic manure (FOM) & Liquid Fermented Organic manure (LFOM) from press-mud digestate. Sugar and Distillery Industries can generate a significant additional income stream, improve waste management practices and contribute to a greener future. This not only stabilizes their financial health but also contributes to environmental sustainability.

This invention enables utilisation of indigenous greener fuel & potassic resource while addressing critical environmental concern to enhance the zero-waste economy for a sustainable future.

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Introduction

Sugarcane industry is one of the largest agri-based industry globally and contributes to approximate 80% of world's sugar production. Across India with the average press-mud production at 3.5 to 4% w/w of the crushing of about 350-400 MMT will stand at 12 to14 MMT per annum. Though the resulting press mud is highly organic in nature, with traces of sugar content & good proportion of nitrogen (C/N ratio of 14), the sugar Industry will pose a major disposal issue in the near future if not converted to a value-added co- product.

Press mud is an organic matter source that can be digested anaerobically and transformed into methane- rich biogas. It is also a good source of organic manure due to its high fiber and humus content. It generally contains 70-85% moisture (w/w); the chemical composition depends on cane variety, soil condition, nutrients applied in the field, process of clarification adopted and other environmental factors. It may be noted that, the press mud contains 25-30% organic matter, includes minor element like Fe, Zn, Mn, Cu, B & Mo as well as major nutrients like N, P, K, Ca, Mg and S for plants, which can minimize the use of inorganic fertilizer by 15-20% [2].

Biogas production through anaerobic digestions (AD) of organic wastes using microbes is a potential alternative to maintain the long term sustainability of the environment and also to full-fill the energy demands and waste management issues.

The Main Objective of this Work is to Devise a Process for

- Treatment of Press-mud for generation of Biogas with concomitant improvement of process effluent quality
- Purification of raw biogas for greener fuel
- Another objective of the invention on fruitful utilization of press-mud to recover organic fertilizer from Bio-methanated press-mud digestate to produce multi-nutrient potassic fertilizer, to enhance the profits, effective waste management and achieve a circular bio-economy approach.

Materials & Methods

A tremendous quantity of the waste generated from sugar industry, needs to be treated to avoid the disposal issues. Most common industrial practices for press-mud treatments are, (i) Composting, where the press-mud is mixed with other organic materials like animal manure to facilitate microbial decomposition and create a nutrient-rich compost (ii) Drying and palettization, Press-mud can be dried to reduce moisture content and then pelletized for easier storage and application (iii) Anaerobic Digestion, is the most widely used and accepted technology, where Microorganisms break down organic matter in the absence of oxygen to produces methane and the digestate containing FOM & LFOM.

Treatment Processes of Sugar and Distillery Industry Waste

Bio-Methanation Process

AD process proceeds continuously stirred activated sludge process (Continuous Stirred Tank Reactor
- CSTR) under normal temperature and pressure. Bio-methanation is composed of hydrolysis, acidogenesis, acetogenesis and methanogenesis.

Polysaccharides are decomposed to monosugars, proteins are to amino acids, and fats are to fatty acids and glycerol. Fermentative bacteria are for example Bactericides spp. and Clostridium spp. Sugars and amino acids are decomposed to acetate and propionate by acidogens. Finally, methanogens convert acetate or hydrogen and carbon dioxide to methane. Acetogenesis is a complex process in which micro flora of anaerobes collaboratively decomposes organic compounds to low molecular organic acids. Acetate, lactate, ethanol, butanol, acetone etc. can be produced from glucose by acidogens [3].

Press-mud can be converted into biogas through bio-methanation, but pre-treatment is crucial to improve the process's efficiency and biogas yield. The Press-mud, containing 25-30% (w/w) solids, has to be slushed in an agitated tank before feed to the bio-digester in order to bring down the solids content upto 10-12 %. This process requires dilution water to be added, which makes the press-mud suitable for efficient anaerobic digestion and high yield bio-methane production. Press mud is guided into the digester with the help of a pump and fully mixed by high quality submersible agitators and will be operated in a mesophilic (37-40°C) temperature range with a hydraulic retention time (HRT) of 26-30 days. This combination leads to a stable process with good homogenization results and a minimized effort as far as area requirements and digester volume are concerned.

The overflow will contain around 5-6% TS in the slurry. The suspended solids out of this slurry will be removed with a solid liquid separator. The solid-liquid separation of AD digestate after the bio- methanation will be taking place with the help of decanter. The solid part of the digestate is called FOM and the separated liquid is mentioned as LFOM will contain approximately 1.5-2% TS can be directly used as fertilizer to the farm and some part used to adjust the daily water mass for the anaerobic digestion.

Compressed Biogas (CBG)

CBG is a clean renewable fuel, that has calorific value and other properties similar to CNG, and hence it can replace CNG in automotive, industrial and commercial areas, given the abundance availability of biodegradable organic waste. The biogas is purified to remove hydrogen sulfide (H_2S), carbon dioxide (CO_2), water vapor and there after compressed as CBG, which contains more than 90% methane (CH_4), a combustible gas and clean fuel.

There are several technologies used to produce and purify biogas, but in this study, the purification technology we are proposing are viable & moderately economical for very high H2S content, as the spentwash contains very high H2S content, are Bio-chemical Scrubber for desulfurization followed by Chilled water scrubbing for CO_2 removal.

Bio-Chemical Scrubber Technology for H2S Removal

In the Bio-Chemical Process, the raw biogas is fed to the absorber, where a lean solution containing NaOH is spread from top. The H_2S gets absorbed in the lean solution and gets converted into Sodium Hydro sulphide. The H_2S rich solution that goes to a biological reactor where the Bacteria oxidizes the sulphide into elemental sulphur and caustic soda is regenerated. The elemental sulphur generated is recovered as a by-product. The desulfurization limit achieved to maximum 100-150 ppm in the generated gas and the remaining H_2S can be removed by further polishing by catalytic adsorber bed to give less than <10-12 ppm H2S % (v/v) level.

Schematic Diagram for Bio-Chemical Scrubber Illustrated in Figure 1.

Figure 1: Schematic Diagram for Bio-Chemical Scrubber

Chilled Water Technology for CO_2 Removal

Chilled water technology, or water scrubbing technology, effectively removes CO_2 from desulfurized biogas by leveraging the higher solubility of these gases in water compared to methane, resulting in a cleaner, higher methane biogas stream. Biogas, containing CO_2, is fed into a water scrubber column at high pressure, where chilled water is sprayed from the top, CO_2 dissolve in the water due to their higher solubility compared to methane and the purified biogas, enriched with methane, exits the scrubber.

The spent water, now containing dissolved CO_2, is then sent to a stripping column where the dissolved gases are removed, allowing the water to be reused in the scrubber. Figure 2 demonstrate Chilled water Scrubber (schematic diagram).

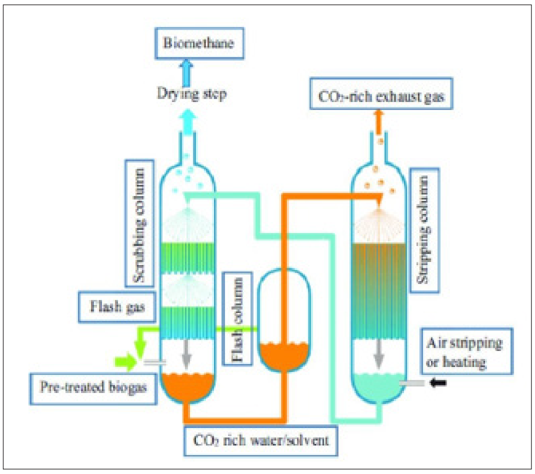


Figure 2: Schematic Diagram for Chilled Water Scrubber

Decanter Centrifuge Plant

Decanter centrifuge is a very common technology used for digestate separation in biogas plants. A centrifuge operates on the principle of applying a strong centrifugal force to separate components of a mixture, typically based on their density. This force causes heavier components to move outward, away from the axis of rotation, while lighter components remain closer to the centre. This separation is often used to isolate solid particles from a liquid or to separate different liquids with varying densities.

In this study, the digestate contains approximately 6% solid, is feed to the decanter centrifuge. Depending on the feedstock material, decanter centrifuge can achieve approximately 25 % (w/w) dry matter content of the separated solid fraction with the separation efficiency of approximately 50-55%. Schematic diagram of decanter centrifuge is demonstrated in Figure 3

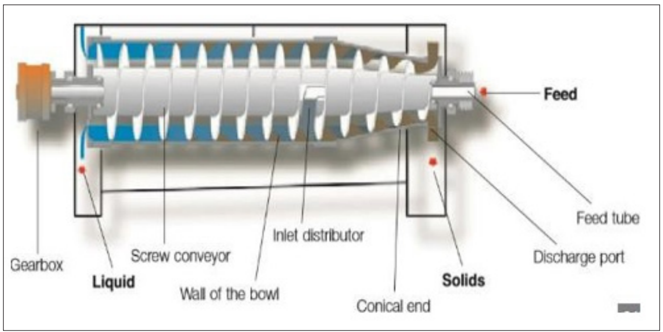


Figure 3: Schematic Diagram for Decanter Centrifuge

Paddle Dryer Plant

Figure 4: Paddle Dryer Plant

Drying is usually the last stage of the system and involves final removal of effluent from the material to convert it in a solid material.

The FOM 25% (w/w), then fed to the paddle dryer to get the dried product with 25% (w/w) moisture by removing the excess water in it.

In Paddle Dryer, steam with pressure @ 3.5 Kg/cm^2 pressure & 135 deg C is introduced to paddle wings through rotary joint and with the rotation and adequate slope of dryer the feed travels from feed end to product end. Maintaining travel speed and steam through wing paddles feed get vaporized to get required final dry product. The dried product entrained with the exhaust air is separated in a high efficiency cyclone separator and discharged through the rotary air lock valve. Clean air is then vented to the atmosphere through Exhaust Duct. The process air is handled by means of one centrifugal fan. A Paddle dryer plant is illustrated in Figure 4.

Granulation Plant

Dried FOM of 25% (w/w) moisture with few value adding components, is granulated in the Granulation Plant. Depending upon application we decide the recipe and quantity of other ingredients. We mix spent wash powder, dried FOM with other ingredients (eg. Bentonite, Rock phosphate, Boiler ash etc.) in blender and after blending we feed this mixture into granulator, where binding of fine powder particles together, typically through wetting and drying processes at 440-450 deg C, and then cool the granules through rotary cooler to create more desirable properties like improved flowability, compressibility, and dust resistance.

Results & Discussion

The result and discussion pertaining to treatment of the Sugar industry waste, i.e., press-mud. Table 1 given below describes typical characteristics of Press-mud. The moisture content in the samples varied from 75 to 78 % (averaging 76.5 %). The press mud used for generation of biogas contained about 77% volatile solids. The C/N ratio was ~14. The organic matter present in the press mud consisted mainly of cellulose 11.4%, hemicellulose 10%, lignin 9.3%, protein 15.1%, wax 8.4% and sugar 5.7% (Table I) [4].

Table 1: Typical Characteristics of Press-Mud

Compound	%	Component
Total solids	26-30	Simple sugar, Cellulose, Hemi cellulose, Protein, wax & Lignin
Total Volatile Solids w.r.t TS	75-77	
Ash	6-7	

AD offers potential energy recovery through the generation of biogas and relatively a potash rich organic manure. The composition of raw biogas produced from press-mud feedstocks is tabulated in Table 2.

Table 2: Composition of Raw Biogas

Particular	Unit	Source: Press-Mud
CH4	%(v/v)	55-60
CO2	%(v/v)	35-40
H2S	ppm	1500-4000
Moisture	%(v/v)	Saturated
Raw Biogas Pressure	mmWC (g) max.	2500-3000

The press -mud either treated or utilized profitably. In this work, the biogas generated was Purified and upgraded to CBG. When the economics and the profitability of the end use of the biogas was investigated, it was found that BioCNG when generated and replaced the fossil fuels is more economical. Biogas can be effectively utilized in production plant boilers thus saving about 50 to 60 % fuel/steam or can be desulfurized and utilized in combined heat and power (CHP) or upgraded to compressed biomethane gas (CBG) a greener transportation fuel.

The raw biogas has to be upgraded and H2S content has to be scrubbed and removed which ranges from 0.2-0.4% (2000 ppm – 4000 ppm) and after removing the H2S content the same gas is then passed through the CO_2 scrubbers to removes the CO_2 and the highly pure methane is formed which is then pressurized to 200-250 bars with the help of high-pressure compressor and is directly filled into the cylinders designed for BioCNG/CNG. The characteristics of the CBG tabulated in table 3.

Table 3: Characteristics of Pure Methane

Parameter	Composition	Units
CH_4	97-98	%(v/v)
CO_2	< 0.2-0.4	%(v/v)
H_2S	<10-12	PPM
DP	-65°	i.e. < 5 mg/m3
Bio CNG Pressure (250 Bar design)	160 to 250 (operational Permission)	Bar (g) max.

Bio-methanation is a suitable technology and the current industrial standard for press-mud. Since only organic materials are decomposed in the process, the composition of the feedstocks plays a crucial role in the nutrient content of the digestate, which is produced after the biogas process and used as fertilizer. The advantage of using press mud is that the digestate is largely stabilised after sufficient anaerobic digestion and can be used as high-quality fertilizer or as a soil improver in agriculture, in soil works, and in horticulture and landscaping. With the appropriate application rate, the nutrients contained in the feedstock, such as nitrogen, phosphorus, potassium, sulphur etc. and other micronutrients will cover the nutrient demand for plant growth.

In a significant move toward sustainable agriculture, the Ministry of Agriculture and Farmers Welfare has amended the Fertiliser (Inorganic, Organic or Mixed) (Control) Order of 1985 to include 'Organic Carbon Enhancers' derived from CBG plants as a recognised category of fertilizers. This amendment is expected to encourage greater use of organic fertilizers, support the expansion of CBG plants, and drive sustainable development across India's agricultural sector [5]. The characteristics of press-mud digestate granules with potash powder is stipulated in (table 4).

Table 4: Analysis of Granules prepared from BMSW Powder & Press-Mud digestate

Sr. No	Parameter	Result
1.	C/N ratio	9.92
2.	pH	9.31
3.	Moisture	4.45 %
4.	Silica Content as SiO2	29.73 %
5.	Electrical Conductivity	10.5 mS/cm
6.	Organic Carbon	11.11 %
7.	Nitrogen as N	1.12 %
8.	Phosphorus as P2O5	0.68 %
9.	Potassium as K2O	18.75 %
10.	Calcium	0.66 %
11.	Magnesium	0.27%
12.	Sulphur	1.87%
13.	Iron	0.23 ppm
14.	Manganese	0.17 ppm
15.	Zinc	0.21 ppm
16.	Copper	0.07 ppm
17.	Boron	0.08 %
18.	Aluminium	0.11 ppm
19.	Fluoride as F	0.025 %
20.	Chloride	3.55 %
21.	Gross Calorific Value	480 cal/g

Digestate with the desired DM content (up to over 90%) have to dried depending on the residual moisture and converted into granules to stable in storage and transport and must be compacted further to avoid dust emissions and to decrease transport costs. This granule is rich in potash, organic carbon and other minerals. This granule is easily soluble in water and can be used for various crops as Organic Fertilizer. Potash Granules shown in Figure 5.

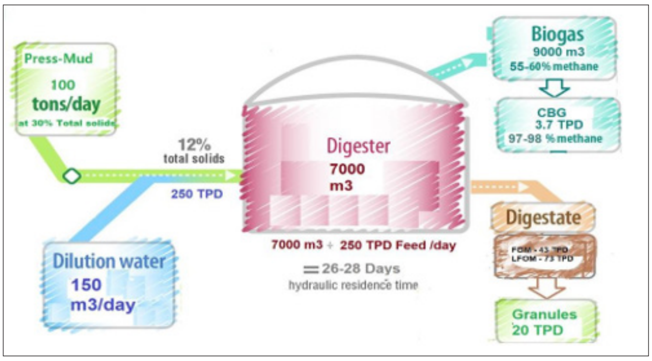
The liquid fraction with a DM content of 1.5-2% has high flowability and can, therefore, easily drip off the plant and enter the soil. Due to the enrichment of NH4, this fraction is a fast-acting nitrogen fertilizer that is immediately available to plants (e.g. maize, cereals, rape seed, grassland).

Figure 5: Image of Potash Granules

A Case Study

In this study, our technology focused on waste management with revenue generation and fruitful utilization of press-mud for agricultural applications. For better understanding of the technology, a mass balance for 100 Tons Press-mud is demonstrated in figure 6. For the treatment of 100 Tons of press-mud anaerobically, a 150 m3 of dilution water to be added to maintain a 11-12% feed slurry to the CSTR digester. For proper digestion and efficient biogas production we have considered an HRT of 26-28 days in a 7000 m3 volume closed tank. The biogas generated from the process is 9000 Nm3/day with the methane content of 55-60%, which is then further purified, upgraded, compressed and a revenue can be generated from the compressed biogas of 3.7 TPD with a selling price of Rs. 68/- per Kg.

The digestate from the AD, is then proceed for solid liquid separation, a FOM and LFOM of 43 TPD and 73 m3/d respectively, generated. The LFOM can directly use as fertilizer where the FOM is further process for granulation and a 20 Tons of granules can be produced per day with a selling price of Rs. 5/- per Kg.



This technology helps to earn revenue with zero waste management to the sugar industry.

Figure 5: Mass Balance for AD for 100 Tons Press-Mud

Conclusion

This study indicated the anaerobic digestion of sugar Industries waste produces biogas which then upgraded to the compressed biogas for sustainable green fuel with zero air pollution potential. After Drying, we achieved to produce a nutrient rich organic fertilizer from the post-methanated digestate by combining with few additional value adding nutrients, this practice will result in revenue generation with zero waste management approach.

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