RESEARCH ARTICLE OPEN ACCESS

Treatment of Sugarcane Industry Effluents: Science & Technology issues

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Abstract
The consumption of large volumes of water and the generation of organic compounds as liquid effluents are major environmental problems in sugarcane processing industry. The inadequate and indiscriminate disposal of this effluent in soils and water bodies has received much attention since decades ago, due to environmental problems associated to this practice. Because of the large quantities of effluent produced, alternative treatments have been developed. The low pH, electric conductivity, and chemical elements present in sugarcane effluent may cause changes in the chemical and physical–chemical properties of soils, rivers, and lakes with frequent discharges over a long period of time, and also have adverse effects on agricultural soils and biota in general. The sugar cane industry is among those industries with the largest water demands and, in addition, is an important source of non-toxic organic pollution combined with the fact that India it is second largest producer and largest consumer makes it all the more important. This paper examines the present status of sugarcane effluent, its characteristics and chemical composition. Keeping in view the relevant policy scenario in India, various available treatment technologies are discussed.
Key words- Sugarcane industry, effluent management, treatment

I. Introduction

Increased demand for food and the need to sustain the ever increasing world population have led to massive increase in both agricultural and industrial activities. Agriculture is one of the most significant sectors of the Indian Economy. Agriculture is the only means of living for almost two thirds of the workers in India. The agriculture sector of India has occupied 43% of India's geographical area, and is contributing 16.1% of India's GDP. Agriculture still contributes significantly to India's GDP despite decline of its share in India's GDP. There are number of crops grown by farmers. These include different food crops, commercial crops, oil seeds etc., sugarcane is one of the important commercial crops grown in India. There are around 45 millions of sugar cane growers in India and a larger portion of rural laborers in the country largely rely upon this industry. Sugar Industry is one of the agricultural based industries. Today, India is one of the first ten industrialized countries of the world. India, like any other developing countries, is faced with problems arising from the negative impact of economic development due to water or industrial pollution. Rapid progress made in industrialization without adequate environmental safety measures lead to pollution of water, which in turn, results in lack of good quality water both for irrigation and drinking purposes. Every human society, whether urban, industrial and most technologically advanced, disposes of certain kinds of by-products and waste products into the biosphere in large quantities, ultimately affecting the normal functioning of the ecosystem and have adverse effect on plants, animals and human. Awareness of environmental problems and the potential hazards caused by industrial wastewater has promoted many countries to limit the discharge of polluting effluents[1].

In many developing countries, especially in Asia and South America, sugar cane industry is one of the most important agricultural industries. As a consequence, sugar cane industry has significant wastewater production. Unfortunately, due to the lack of know-how and financial support, most of sugar cane industries in developing countries discharge their wastewater without adequate treatment. Similar with other wastewater generated by food processing plants, wastewater from sugar cane industry generally contains organic materials such as carbohydrates and proteins[2]. Generally effluent generated from sugarcane industry is disposed off on land. While moving on land, part of pollutants in the effluent may be migrated and deposited between the gaps of soil stratum and adsorbed on the soil particles surface, resulting in pollution of soil. Furthermore, the migrated effluent flows through the gaps in the soil stratum and reaches the groundwater table, which may cause impact to the aquifer and thereby pose a potential risk to human health as well as the surrounding environment[3].

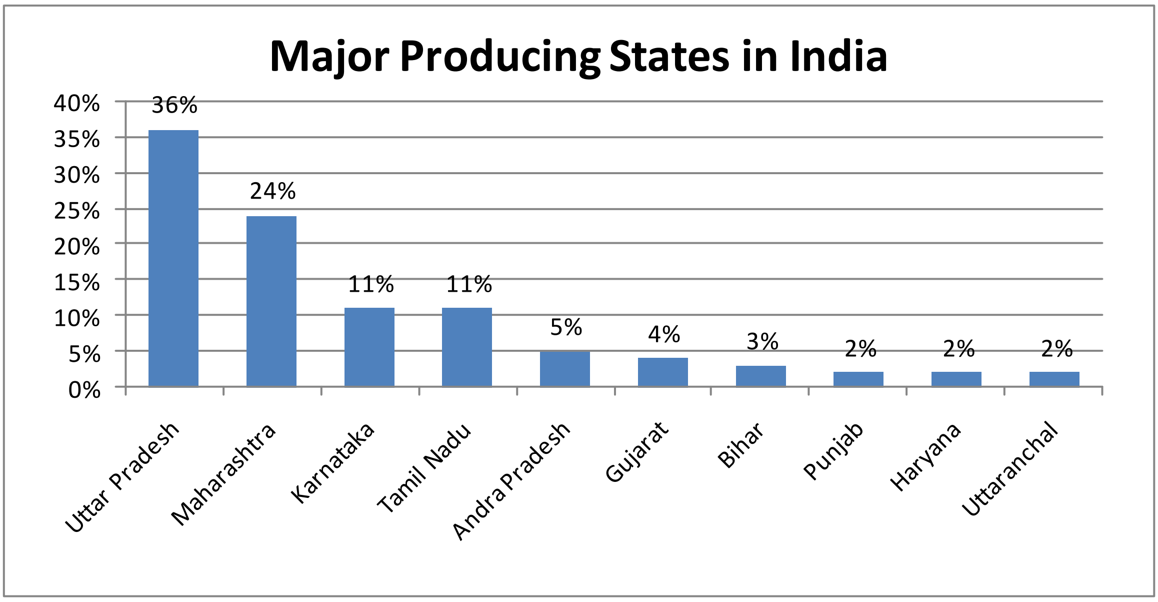

Figure 1: Total % share of the sugarcane production by major sugarcane producing states in India in 2012-201323

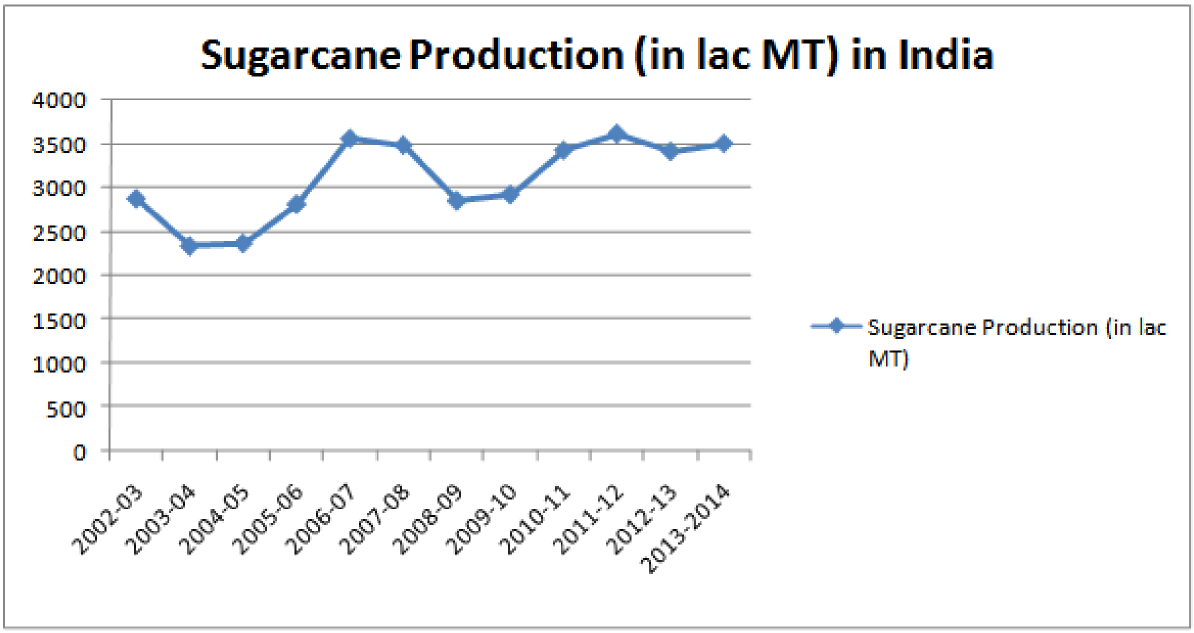

Figure 2: Production of sugarcane in India in last 10 years23

II. Sugar cane industry

In many developing countries, especially in Asia and South America, sugar cane industry is one of the most important agricultural industries. Sugar cane mill industry is one of the oldest industries in India, as in other parts of the world. In India, sugarcane industry is highly responsible for creating significant impact on rural economy after textiles[3]. India is the world's second largest sugarcane producer, with nearly 5 million hectares of cultivated area and provides direct employment to more than 3.6 lakes person Table 1.

The main final products of sugar cane industry are crystalline sugar and bio-ethanol. The latter is obtained from the fermentation and distillation of sugar cane juice and molasses. Quantitatively, the most significant by-product is bagasse, the solid residue from sugar cane after juice extraction and stillage (also called vinnasse or dunder), the liquid waste effluent after the distillation process of sugar cane juice. Sugar mill with annexed alcohol distilleries generally release an average of 155 L of stillage and 250 Kg bagasse per 1,000 Kg of sugar cane to obtain 12 L of alcohol and 95 Kg of sugar [5]. Alcohol distilleries are a major agro-based industry in India with around 300 units located mainly in rural, sugarcane growing regions. The total installed capacity is 3250 million L alcohol per annum with an estimated production of 2300.4 million L in 2006–2007. Most of the distilleries co-exist with sugar mills and utilize the molasses from cane sugar manufacture as the starting material for alcohol production. As per the Ministry of Environment & Forests (MoEF), Government of India, alcohol distilleries are listed at the top of "Red Category" industries having a high polluting potential. The industry generates large volumes (8–15 kL/kL alcohol) of dark brown colored wastewater ("spentwash") with high biochemical oxygen demand (BOD) and Chemical oxygen demand (COD).This poses a serious pollution threat; thus it is mandatory for distilleries to take appropriate measures to comply with the discharge standards set by the Central Pollution Control Board (CPCB), which is the national agency responsible for environmental compliance[6,7].

Table 1- Sugarcane production in major countries[4]

	Harvest area (million ha)	Annual production (million t)	Average income (t/ha)
Brazil	8.14	648	79.7
India	5.06	348	68.9
China	1.71	124	73.1
Pakistan	1.24	64	51.5
Thailand	1.05	73	69.7
Mexico	0.67	51	76.4
Colombia	0.38	39	100.4
Australia	0.39	34	87.1
South Africa	0.43	21	48.2
Cuba	0.38	16	41.3

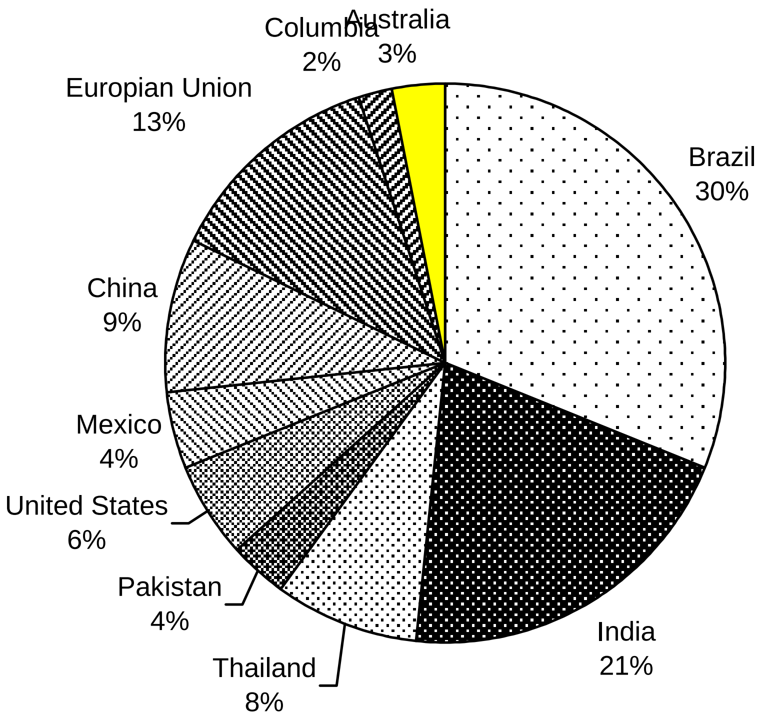

Fig. 3- Sugarcane worldwide distribution[24]

III. Sugarcane Processing

The main final products of sugar cane industry are crystalline sugar and bio-ethanol. The latter is obtained from the fermentation and distillation of sugar cane juice and molasses. Quantitatively, the most significant by-product is bagasse, the solid residue from sugar cane after juice extraction and stillage (also called vinnasse or dunder), the liquid waste effluent after the distillation process of sugar cane juice. Bagasse can be used in boilers during combustion, while stillage is mainly disposed to field crops, incorporating a risk for aquatic pollution. Surface water pollution potential is mainly due to the high contents of organic matters in stillage. Organic matters cause oxygen depletion by heterotrophic bio-degradation when enter in surface water. Stillage also contains high concentration of potassium which can accumulate at toxic levels in the soil[5].

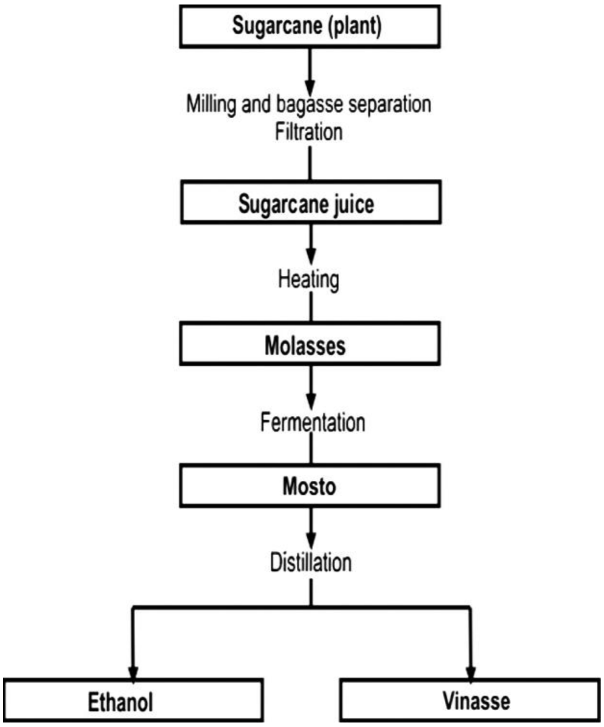

Fig. 4- Flowchart of ethanol production process and underproduction of sugar cane vinasse

IV. Characteristics of sugar cane industry wastewater

The wastewater or spillage products from such distilleries contain huge quantity of dissolved organic matter, heavy metals, dyes etc., along with other pollutants. These discharge into water bodies, somber the aquatic life in consonance with decrease in the quality of water and irrigation land. Table 2 shows the analyzed composition of molasses stillage coming from the bottom of the stripper column of the ethanol production plant.

Table 2- Characteristics of sugar cane vinnasse /Molasses stillage[8]

Sr. No.	Parameter	Range
1	pH	3.8-4.4
2	Total solids	60,000-90,000
3	Total suspended solids	2,000-14,000
4	Total dissolved solids	6,70,000- 73,000
5	Total volatile solids	45,000-65,000
6	Chemical oxygen demand	70,00,000- 98,000
7	Biochemical oxygen demand	45,000-60,000
8	Total nitrogen as N	1000-1,200
9	Potash as K	2,05,000-12,000
10	Phosphate as PO4	5,000-1,500
11	Sodium as Na	150--200
12	Chlorides as CI	5,000-8,000
13	Sulphates as SO4	2,000-5,000
14	Acidity as CaCO3	8,000—16,000
15	Temperature (after heat exchanger)	70-80^{o}C

Samuel and Muthukkaruppan (2011) conducted experiment on the effluent and contaminated soil from a sugar mill located at Cuddalore district, India and reported that there was a gradual decrease in the percentage seed germination and germination value with sugar industry effluent concentration. The untreated sugar industry effluent could possibly lead to soil deterioration and low productivity. Terrestrial and aquatic environmental pollution could be averted by proper treatment of the effluents using suitable conventional methods. In conclusion, sugar industry effluent concentration governs seed germination. The effects vary from crop to crop because each plant species has its own tolerance of the different effluent concentrations.

V. Treatment of Effluents from Sugar Cane Industry

Effective handling and disposal of the generated effluent is a major concern in all Indian distilleries since the units are required to meet the discharge standards (Table 3) laid down by CPCB. To comply with the disposal norms, it is recommended one or a combination of the following schemes to treat the generated wastewater.

Table 3- Distillery effluent composition limits ISI Standards (IS: 506-1980)

Characteristics	For discharge into water Course	For discharge into public sewers	For discharge on land
pH	5.5–9.0	5.5–9.0	5.5–9.0
BOD (mg/L)	100	500	500
Total suspended solids (mg/L)	100	600	–
Oil and grease (mg/L)	10	100	6–10
Temperature (°C) outlet	Shall not exceed 40 ◦C in any section of the stream within 15m from effluent		

The various methods of treatment are as follows

VI. Biological Treatment

Anaerobic Process

The high organic content of wastewater from sugar cane industry makes anaerobic treatment attractive in comparison to direct aerobic treatment. Therefore, biomethanation is the primary treatment step and is often followed by two-stage aerobic treatment before discharge into a water body or on land for irrigation. Aerobic treatment alone is not feasible due to the high energy consumption for aeration, cooling, etc. Anaerobic treatment converts over half of the effluent COD into biogas. Anaerobic treatment can be successfully operated at high organic loading rates; also, the biogas thus generated can be utilized for steam generation in the boilers thereby meeting the energy demands of the unit. Further, low nutrient requirements and stabilized sludge production are other associated benefits. Anaerobic lagoons are the simplest option for the anaerobic treatment of distillery spentwash[9]. it was reported that employing two anaerobic lagoons in series resulted in final BOD levels up to 600 mg/l. However, large area requirement, odor problem and chances of ground water pollution restrict its usage. These reactors offer the advantage of separating the hydraulic retention time (HRT) from solids retention time (SRT) so that slow growing anaerobic microorganisms can remain in the reactor independent of wastewater flow[10].

Aerobic treatment

The post-anaerobic treatment stage effluent still has high organic loading and is dark brown in color, hence it is generally followed by a secondary, aerobic treatment. Solar drying of biomethanated spentwash is one option but the large land area requirement limits this practice. Further, in India, solar drying beds become non-functional during the rainy season (Nandy et al., 2002). The other treatment options that have been demonstrated for biomethanated distillery effluent are Aquaculture, Constructed wetlands (CWs), Biocomposting, Fungal Treatment, Bacterial treatment, and Algal treatment.

Physico-chemical treatment

Sugarcane molasses spentwash after biological treatment by both anaerobic and aerobic method can still have a BOD of 250–500 mg/l .Also, even though biological treatment results in significant COD removal, the effluent still retains the dark color .In this context, various physico-chemical treatment options have been explored[10].

Adsorption: Activated carbon is a widely used adsorbent for the removal of organic pollutants from wastewater but the relatively high cost restricts its usage. Decolorization of synthetic melanoidin using commercially available activated carbon as well as activated carbon produced from sugarcane bagasse was investigated[11].

Coagulation and flocculation: Coagulation studies on spentwash after anaerobic–aerobic treatment have also been conducted using bleaching powder followed by aluminum sulfate. The optimum dosage was 5 g/l bleaching powder followed by 3 g/l of aluminum sulfate that resulted in 96% removal in color, accompanied by up to 97% reduction in BOD and COD[12].

Oxidation process: Oxidation by ozone could achieve 80% decolorization for biologically treated spent wash with simultaneous 15–25% COD reduction. It also resulted in improved biodegradability of the effluent. However, ozone only transforms the chromophore groups but does not degrade the dark colored polymeric compounds in the effluent[13].

Membrane treatment: Pre-treatment of spentwash with ceramic membranes prior to anaerobic digestion is reported to halve the COD from 36,000 to 18,000 mg/l (Chang et al., 1994). The total membrane area was $0.2m^2$ and the system was operated at a fluid velocity of 6.08 m/s and 0.5 bar transmembrane pressure. In addition to COD reduction, the pre-treatment also improved the efficiency of the anaerobic process possibly due to the removal of inhibiting substances[14]. In addition, reverse osmosis (RO) has also been employed for distillery wastewater treatment.

Electrodialysis: Electrodialysis has been explored for desalting spentwash using cation and anion exchange membranes resulting in 50–60% reduction in potassium content (de Wilde, 1987). In another study, Vlyssides et al. (1997) reported the treatment of vinasse from beet molasses by electrodialysis using a stainless steel cathode, titanium alloy anode and 4% w/v NaCl as electrolytic agent. Up to 88% COD reduction at pH 9.5 was obtained; however, the COD removal percentage decreased at higher wastewater feeding rates[15,16].

Evaporation/combustion: Molasses spentwash containing 4% solids can be concentrated to a maximum of 40% solids in a quintuple- effect evaporation system with thermal vapor recompression[17]. The condensate with a COD of 280 mg/l can be used in fermenters. Combustion is also an effective method of on-site vinasse disposal as it is accompanied byproduction of potassium-rich ash that can be used for land application[18].

Discussion: A range of biological and physico-chemical methods have been investigated for the treatment of wastewater from sugar cane industry wastewater. Because of the very high COD, anaerobic treatment with biogas recovery is employed extensively as the first treatment step. this treatment method reduces the organic pollution load and brings down BOD to 80–95% of the original value; however, the biodigested effluent still contains BOD in the range of 5000–10,000 mg/l. further the problem of color associated with this effluent not only remains unsolved but actually gets aggravated since the color causing melanoidin pigment intensifies under anaerobic conditions[19]. Therefore anaerobically treated effluent is darker in color compared to untreated spentwash and needs several-fold dilution by fresh water prior to discharge.

Biological treatment using aerobic processes like activated sludge, biocomposting etc. is presently practiced by various molasses-based distilleries. Due to the large volumes generated, only a part of the total spentwash gets consumed in biocomposting. Biocomposting utilizes sugarcane pressmud as the filler material; thus it is typically employed by distilleries attached to sugar mills. Since sugar manufacturing is a seasonal operation, pressmud availability is often a constraint. Further, biocomposting requires large amount of land; also, it cannot be carried out during the rainy season.

Though aerobic treatment like the conventional activated sludge process leads to significant reduction in COD, the process is energy intensive and the color removal is still inadequate. Thus several pure cultures of fungi, bacteria and algae have been investigated specifically for their ability to decolorize the effluent as discussed earlier. In all instances, supplementation with either nitrogen or carbon source is almost always necessary because the microbial species are not able to utilize the spentwash as the sole carbon source. Further, high dilution (typically up to 1:10 fold for untreated spentwash and 1:16–1:2 fold for biomethanated spentwash) is required for optimal microbial activity. In addition, these studies are mostly limited to laboratory scale investigations and no pilot/commercial scale operations are reported as yet.

Physico-chemical treatment, viz. adsorption, coagulation/ flocculation, oxidation processes, membrane treatment have been examined with particular emphasis on effluent decolorization. Though these techniques are effective for both color removal as well as reduction in organic loading, sludge generation and disposal is a constraint in coagulation/flocculation and adsorption.

Also, the cost of chemicals, adsorbents and membranes is a deterrent to the adoption of these methods. Membrane operations like microfiltration/ ultra filtration for spent wash treatment are characterized by significant membrane fouling that limits its applicability. Decolorization through chemical treatment with ozone and chlorine leads to temporary color reduction because of transformation of the chromophore groups so these are not preferred solutions[20].

Table 4-Status of Effluent Treatment of Sugarcane Industry[7,21,22]

	Status of Effluent Treatment(Internationally)	Status of Effluent Treatment(India)
Anaerobic digestion	being used	being used
Aerobic treatment	being used	being used

Adsorption,	being used	being used
Coagulation/ flocculation,	being used	being used
Oxidation processes,	being used	being used
Membrane treatment(RO)	being used	being used

VII. Possibilities of Use of Byproducts of Sugarcane

The various possible uses of sugar can by products are given in table 5- and use of vinasse for various alternatives range from low capital cost options to high capital cost technologies are as follows:

- The simplest approach is the use of stillage as fertilizer which returns most of the minerals back into the soil for the next crop. Producing a feed from stillage, one requires less capital investment, since it consists of drying the outcoming effluent before direct use as a supplement. However, the main disadvantage of this approach is the high mineral content in the stillage, especially potassium, limiting the maximum percentage which can be added to a balanced feed.
- The recycling of stillage as substrate for the cultivation of *Candida* yeast as a high protein supplement
- Recycling of stillage as a source of energy by evaporating the residual stream to a solids content ranging from 50 to 60% prior to being injected into the stillage fired boiler.

Methane generation through anaerobic digestion has become one of the more convenient options, and many research groups have reported about its benefits

Table 5-Possibilities of Use of Byproducts of Sugarcane (Internationally and India)[7],[21]

Product	**Internationally**	**India**
Bagasse	Fuel, Paper and pulp industries	Fuel
Molasses	Ethanol ,dry yeast, Amino acids, and feed supplement	Ethanol
Stillage, also known as mosto, vinasse or rum slops	Fertilizer, Animal feed, Stillage fired boiler, Methane generation through anaerobic digestion	Methane generation through anaerobic digestion

VIII. Conclusions

The main conclusions which could be drawn from the above review are as follows:

The sugar cane industry employs various treatment sequences to save water and to meet regulatory norms. The combination of biomethanation and biocomposting is a popular choice for wastewater treatment and disposal. Reverse osmosis and drying of biomethanated effluent are emerging technologies for efficiently managing this effluent. Considerable water saving can be achieved by better house keeping, segregating, recycling and reusing of non-process wastewater. There are several initiatives being followed by Indian distilleries to minimize their water consumption and recycle the treated wastewater. However, in addition to this, research to address existing gaps is also necessary to provide a comprehensive and cost effective solution to enable the industries to become low water consuming and zero discharge units.

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