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Sugarcane Vinasse Treatment and Utilisation in India

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ABSTRACT

The aim of this study was to assess the literature regarding the sugarcane industrial water effluent characteristics and evaluate wastewater treatment methods and possibilities to minimize the effluent environmental burden and extract high value products. As oxygen demand is the priority, anaerobic treatments, membranes etc. should be used in old plants. For new plants, bioconversion into high-added value products and energy or the use of bio refineries for the integrated sugar ethanol mills should be used.

Introduction

In 2019-2020 India produced 28.9 million metric tonnes of sugar and is the second largest exporter of sugarcane (Walton, 2022). Due to the large amounts of sugar produced and the high energy density of the crop, sugarcane has become an important source of biofuels. This combined with the Indian government's plans to increase ethanol blending in petrol / gasoline by 2030 to 20% has made integrated sugar ethanol mills increasingly popular (Chattopadhyay, 2021).

The sugar industry generates large volumes of organic, liquid effluents which if left untreated, may cause chemical and physical-chemical changes in properties of soil, lakes, rivers and other biota, thus necessitating an efficient and accessible method for wastewater treatment (Carillho, Labuto, & Kamogawa, 2016).

In these integrated mills bioethanol is produced from the wastewater of normal sugar production, where yeast feeds on the remaining carbohydrates and sugars. However the bioethanol production process creates wastewater called vinasse, which is the final by-product from bioethanol production (Carillho, Labuto, & Kamogawa, 2016). Sugarcane vinasse has a high concentration of organic matter and is characterized by being an acidic suspension, having high chemical oxygen demand values, unpleasant odours, and a dark brown colour (Reis & Hu, 2017). For each litre of alcohol produced, 15 litres of vinasse may be generated (Carillho, Labuto, & Kamogawa, 2016).

To address the potential environmental impact of vinasse, it must either be treated or recycled. While there is extensive research on treatment and alternative utilization methods both currently have significant drawbacks and require further research and implementation.

This paper will analyse the efficiency, cost and scalability of different approaches, and propose a suitable method for vinasse treatment.

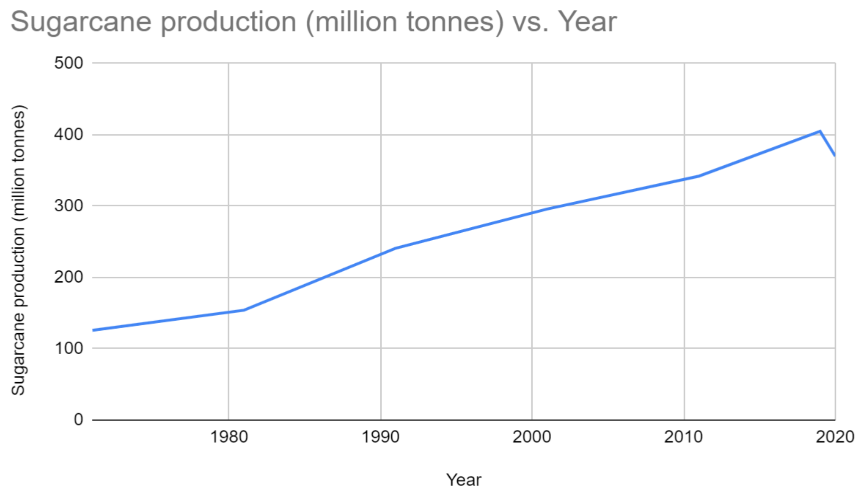

Fig 1- ("India- Sugar cane production quantity", n.d.)

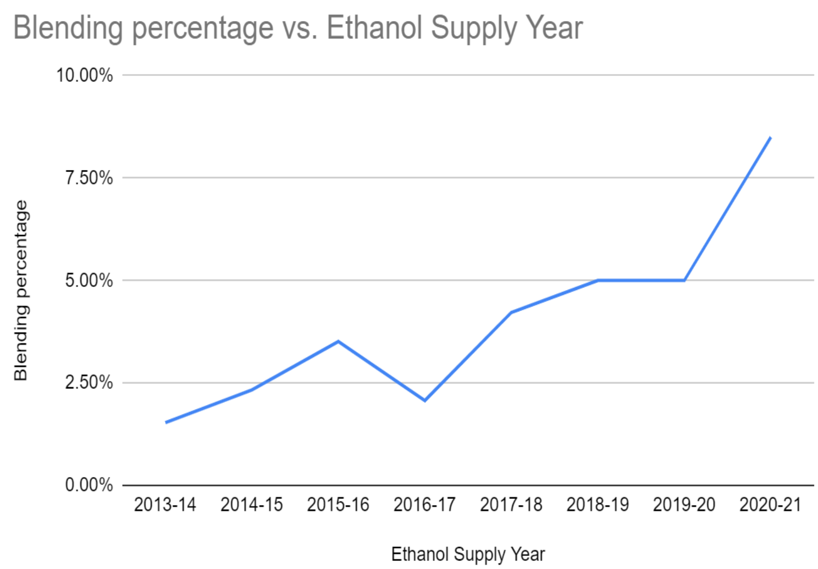

Fig 2- (NITI Ayog, 2021)

Case study of Brazil

Brazil is the largest sugarcane producer (Walton, 2021) and a majority of its sugar processing plants are already integrated sugar ethanol mills. While India does not yet have the same density of integrated sugar ethanol mills, the government's energy policy is causing an increase in bioethanol production from sugar. Brazil has faced numerous environmental and ecological problems from the large amounts of wastewater produced by this process. In this paper, we will review the extensive research done on sugarcane ethanol mills, the wastewater produced, and their treatment methods for vinasse. As India increases its production of bioethanol, it is important to evaluate the strengths and weaknesses of already implemented wastewater recycling techniques and accordingly adopt competent techniques.

Clean Water Regulations

We have evaluated the acceptable limits for components of vinasse in the Gazette of India. These guidelines form a metric to judge the success of different treatment methods and the scope of the environmental concerns.

To understand the scope of the problem it is necessary to analyse the components of vinasse. To facilitate this discussion, the components of vinasse have been broken down into the following groups: pH, oxygen demand, medium to large metals, and small ions. These groups have been divided up because they have similar environmental impacts and treatment strategies. (In table 1)

Table 1- components of vinasse and their concentrations (Government of India, 2016), (Christofoletti, Escher, Correia, Marinho, & Fontanetti, 2013)

Components	Mean concentration	Acceptable concentration (mg/L)- according to the Gazette of India
pH	3.9	5.5-8.5
Biochemical oxygen demand	5046	100 (for disposal on land) 30 (for disposal in surface waters)
Chemical oxygen demand	13380	NA
Potassium	2056	NA
Sodium	50.2	NA
Sulfate	710	NA
Calcium	719	NA

- pH- Vinasse's acidity modifies environmental conditions in soil and water ecosystems. This may disturb the flora and fauna present. Acidic wastewater may strip soil of essential nutrients for plant growth and exceed the tolerable range of certain species (United States Environmental Protection Agency, 2021).
- Oxygen Demand- Biological oxygen demand (BOD) is the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic conditions at a specific temperature (Tuser, 2020). Chemical oxygen demand (COD) is the amount of oxygen consumed in the chemical oxidation of organic matter in the water (Hu & Grasso, 2005).
  Releasing waste water with high oxygen demand rapidly depletes oxygen in a water body and affects the environment by introducing competition for biologically available oxygen which may outcompete native organisms. High biological oxygen demand has the same consequences as low levels of dissolved oxygen (United States Environmental Protection Agency, 2012).
- Potassium- High concentrations harm the environment by damaging germinating seedlings, inhibiting the uptake of other minerals and reducing the quality of crops (Lenntech, n.d.).
- Sulphates- In the environment, high levels contribute to acidification of surface water and soil and acid precipitation that damages ecosystems, forests and plants (California Air Resources Board, n.d.).

India generates 45 billion litres of spent wash annually which on proper treatment has the potential to produce 1200 million cubic metres of bio gas, 85000 tons of biomass annually. It is estimated that utilisation of spent wash may provide 5 trillion KCals energy and post methylated effluents can provide 245,000 tons of Potassium, 12,500 tons of Nitrogen and 2100 tons of phosphorus annually (Singh, 2021).

Treatment methods

Traditional sugarcane industrial wastewater management

Traditional practices of wastewater management are fertigation, concentration by evaporation (incineration) and bio-compost.

Fertigation:

Fertigation is the use of soil as a medium for treatment and disposal of industrial wastewater (Fito, Tefara, & Hulle, 2019). Vinasse can be used as a fertiliser due to its high level of organic matter and nutrients like phosphorus needed to supplement plant growth. It is a traditional method used by sugarcane refineries to utilise vinasse, the liquid residual, as fertiliser. Its advantages are its low capital cost, that it decreases the cost involved in chemical fertiliser and completely supplies phosphorus to the soil. However, according to a paper by the University of Minnesota, fertigation practises have been linked with increase in eutrophication of water bodies and the formation of dead aquatic bodies in Brazil and in other countries (Reis & Hu, 2017).

Incineration:

The concentration of distillery spent wash by evaporation is an old method. This wastewater can be burned in special boilers generating energy and the condensate removed by evaporation can be treated and reused by the factory, decreasing water use in the facility (Fito, Tefara, & Hulle, 2019).

Bio Composting

In this method, vinasse is subjected primarily to anaerobic digestion (bio-methanation) treatment to decrease BOD and COD and other pollutants before combining with the press mud to produce bio compost. It is difficult to manage the huge volume of distillery spent wash through bio-composting process as it is a very slow process that can take about 15 days for a single treatment. In addition, it requires a large treatment space (Fito, Tefara, & Hulle, 2019).

Anaerobic Treatment

Vinasse's high oxygen demand makes it attractive for an anaerobic system. Anaerobic processes allow the valorisation of vinasse as an energy resource in an environmentally friendly way (López, Borzacconi, & Passegi, 2018).

High-rate Anaerobic Wastewater Treatment:

High-rate anaerobic reactors require much less volume and space due to the advantage of high-load system's capacity. The most commonly used high-rate anaerobic digesters in wastewater treatment areas are: up-flow anaerobic sludge blanket (UASB) reactors, fluidised beds, sequencing batch reactors and anaerobic filters (Fito, Tefara, & Hulle, 2019).

Secondary Wastewater Treatments

Different physicochemical treatment methods for vinasse such as nanofiltration, Reverse Osmosis, advanced oxidation processes and membrane technology have been applied after biological/ anaerobic treatment.

Membranes

A range of membrane types are available which offer new opportunities for construction of appropriate membrane processes to provide good salt transmission while rejecting organic matter (Haghighat, 2018).

Microfiltration and Ultrafiltration

These are processes which may be used in vinasse treatment. Microfiltration (MF) is a pressure-driven separation process, which is widely used in concentrating, purifying or separating macromolecules, colloids and suspended particles from solution (Basile & Charcosset, 2012). Ultrafiltration (UF) is a water purification process in which water is forced through a semipermeable membrane (Fluence, n.d.).

Nanofiltration

NF membranes are highly effective in removing COD, suspended solids and colour. However, they have drawbacks such as concentration polarisation and membrane fouling which lead to decline in permeate flux. There are two main ways that this is done. One is Reverse Osmosis- is a technique which can be used effectively as post treatment for other membranes. The second is by size exclusion with controlled pore sizes.

In the basic treatment which usually applied microfiltration or ultrafiltration, the quality of recovered water is not high, and it is usually suitable for heat exchangers or cooling towers.

In the advanced treatment which includes initial aerobic and anaerobic treatments followed by further treatments with nanofiltration and/or reverse osmosis, the quality of recovered water is high enough to use in domestic or industrial sectors (Haghighat, 2018).

In a study, a hybrid NF and RO pilot plant with thin film composite membranes in spiral wound configuration has been designed to remove the colour and contaminants from distillery spent wash (Nataraj, Hosamani, & Aminabhavi, 2006). It was found that a very high colour removal through the NF process and a high rejection of 99.80% TDS, 99.90% COD and 99.99% potassium through the subsequent RO process can be obtained. It was shown that NF membrane has high efficiency in removal of colour and larger species, while the smaller species such as potassium, calcium, magnesium and iron metals were removed effectively with RO membrane.

There are many suppliers of various types of membranes who are concentrated mainly in the USA such as Fisher Biotec Pty Ltd, Australia, Millipore (USA), Nitto-Denko, Hydration Technologies Inc. (HTI), Spectrum Labs (USA).

California based New Logic Research Inc has proprietary Vibratory Shear Enhanced Processing (VSEP) technology and has successfully implemented in industry. The VSEP technology oscillates stacked membranes a high number of times per second. The stacking system provides free movement of rejected solids while vibration keeps foulants from attaching to the membrane surface (Soberg, 2011).

Upcoming plants need to have integrated membrane systems to minimize costs and derive high value salts and reduce environmental effects.

Combination of Components / Real life case studies

In recent years, the above traditional techniques are being combined to create various vinasse wastewater management systems with higher efficiency.

Bioconversion into high-added value products and energy (Naspolini, Machado, Cravo Junior, Freire, & Cammarota, 2017).

This method involves the use of vinasse as a raw material for bio-surfactant production in the stage prior to its treatment and disposal. Rhamnolipid, a type bio-surfactant, is produced through submerged fermentation of Pseudomonas aeruginosa PA1 with a vinasse based medium. This produces a fermented medium with lower Rhamnolipid concentration but with surface tension and critical micelle concentration (CMC) similar to bio-surfactants obtained by a conventional medium. After bio-surfactant extraction, the residual fermentation medium still has a high concentration of carbon and nutrients, which is required to be reduced before being discharged into the environment. Anaerobic digestion seems viable for this because of its low cost operations, reduced sludge production and methane formation which has high combustion heat. The bio-surfactant production reduces the organic matter concentration of vinasse and does not inhibit the subsequent anaerobic digestion process. After anaerobic digestion, the vinasse has less organic load but still contains nutrients and minerals that can be used as fertilizer.

To harness the energy produced by microorganisms from anaerobic oxidation of biodegradable organic compounds, microbial fuel cells (MFCs) are used. Bio-refineries integrate the process of biological production of fuels, bioenergy and biomass bio-products analogous to an oil refinery. This technology addresses the need to reduce the organic matter concentration of vinasse while maintaining nutrients and mineral content for use/disposal in soil, and optimizing the energy balance of sugarcane refineries. Biogas could replace up to 40% of the annual diesel supply in the agricultural operations of a sugarcane bio-refinery and still provide approximately 14MWh annually from cogeneration. Yeast drying is another use for biogas in a bio refinery.

This method of bioconversion (i) reduces the organic matter concentration introduced into the soil, (ii) produces a high value product with vast potential in industrial applications and (iii) optimises energy production.

Vinasse bio refinement for trans-aconitic acid-based biopolymer synthesis and bioenergy synthesis

(Montoya et al, 2021)

A multiproduct biorefinery scheme may be developed for vinasse valorisation. This study involved extraction and purification of trans-aconitic acid via liquid-liquid extraction. 90% pure trans-aconitic acid was obtained, in which pH and extraction time primarily influenced the yield. This was transformed into biopolymers (various crosslinking degrees can be synthesised) using microwave irradiation. Resultant raffinate-vinasse was used for biogas production. A circular economy centred on sugarcane vinasse may be achieved if the resultant digestate is used as fertiliser.

Conversion of vinasse into a protein ingredient for aqua culture feed (eniferBio, 2021)

Skretting ARC, eniferBio announced the successful completion of process piloting trials and the beginning of the next phase testing of its Pekilo mykoprotein at their R&D facility in Norway. Their desktop assessment verified the potential of this ingredient to be an alternative protein source to marine and soy proteins in aqua feeds. The process tested efficient conversion of vinasse from beet molasses into a valuable protein ingredient for aqua culture feed. The product can be used as a cost competitive sustainable alternative to soy protein concentrate.

Testing is required to evaluate whether a similar method may be used for sugarcane vinasse, considering the difference in composition of sugarcane and beet vinasse.

Table 2- (Christofoletti, Escher, Correia, Marinho, & Fontanetti, 2013)

Parameters:	Sugarcane vinasse	Beet vinasse
pH	3.9	5.1
BOD	5046	78300
COD	13380	NA
Potassium	2056	10.000-10.030
Sodium	50.2	3.79
Sulfate	710	0.62
Calcium	719	0.71
Magnesium	237	1.23
Phosphorus	190	91
Hardness	2493	NA

Vinasse as a medium for the production of Chlorella vulgaris

The use of microalgae for the removal of pollutants from wastewaters and their transformation into biomass allows (i) nutrient removal effluents with high organic load, (ii) treatment of industrial waste waters with trace metals and acids, (iii) CO2 sequestration, (iv) transformation and degradation of xenobiotics and (v) detection of toxic compounds by algae based sensors (Quintero-Dallos et al, 2019).

Chlorella vulgaris has been suggested for this because of its easy adaptability and rapid growth. A bio-refinery approach combining microalgae cultivation with the biological degradation of vinasse was studied in 2019 and can be a sustainable option for the production of value added compounds for the biofuel and other sectors (Quintero-Dallos et al, 2019).

Incorporation of appropriate amounts of vinasse in culture media is an effective remediation strategy for the treatment of this effluent. It is an attractive alternative for the production of valuable metabolites such as carbohydrates and proteins from C.vulgaris. Vinasse is a suitable and effective medium for the growth of C.vulgaris UTEX 1803. The algal biomass can be used as a source of value added compounds for food, nutraceutical, cosmetic, and biofuel applications. It has the potential of being transferred to the industrial scale as the conditions necessary for the heterotrophic growth of microalgae are similar to those employed for the large-scale production of yeast and bacteria (Quintero-Dallos at al, 2019).

Vinasse as a medium for Chlorella vulgaris growth was further studied in 2021. The study showed a significant reduction of the toxicity and contamination potential of vinasse (lower BOD and COD values) after C. vulgaris growth. Serial microalgal cultures may remove BOD and COD further. Combination with physico-chemical treatments can further reduce vinasse's environmental burden. Also, algal biomass produced during vinasse fermentation can be used in the production of biofuels and pigments, and as a protein source for animal consumption. (Soto, Diaz, Zapata, & Higuita, 2021).

Concrete Production with Recycled Concrete Aggregate and Vinasse (Tamashiro et al, 2022)

A study on use of vinasse as a hydration agent in concretes, analysed the compressive strength of concrete manufactured with vinasse and recycled concrete aggregates (RCA), instead of water and sand. At the initial periods (7 and 14 days), the compressive strength of specimens hydrated with water was higher than those hydrated with vinasse due to sucrose present in vinasse. Strength of concrete cured by vinasse increased for longer periods- its strength was equal to the reference at 28 days and higher than the reference at 63 days.

This may have limited practical use due to the long curing period with vinasse. Moreover, transportation of vinasse to urban areas with intensive concrete use may not be cost effective.

Use of vinasse for sand dune stabilisation (Sabzi, Asgari, & Afzali, 2017)

Mulch is a common material for soil stabilisation to reduce wind erosion and dust formation. In a study by Sabzi, Asgari, and Afzali, combinations of waste press mud beet vinasse and clay were used as a stabiliser. Treatment with 25g compost, 100g vinasse, and 100g clay was identified as the best combination for stabilising sandy soils.

Sugarcane is a water-intensive crop- grown and processed in regions with abundant water resources like Uttar Pradesh and Maharashtra and at a distance from desert states. Transport of vinasse over such a distance is costly and, hence, this application may be unviable.

Discussion

In this paper, I have reviewed the environmental consequences of disposing inadequately treated vinasse and the different treatment techniques used to mitigate its effects. Due to the environmental impacts of the high oxygen demand of Vinasse, methods that perform well in removing these pollutants should be of high priority. Most of the literature in this field focuses on removal of the high oxygen demand, showing a consensus that this is the largest problem with Vinasse treatment. Due to the extremely high concentration of oxygen demand, vinasse disrupts the balance of an ecosystem by altering the chemical and biological properties of soil and water bodies. Other components of vinasse include pH that is already being addressed, medium to large metals that can be leveraged to use as high value products, and ions that are not an area of large concern for vinasse.

Fertigation should be avoided at all costs as it does not remove pollutants. It is essentially putting untreated vinasse into the ecosystem, resulting in the environmental consequences associated with vinasse. This has already been phased out, but it is important that it continues to remain a dead practice.

Old plants should be retro fitted with procedures such as anaerobic treatment, membranes etc to separate concentrates and water.

With oxygen demand as the priority, I recommend bioconversion into high-added value products and energy for new plants as this method effectively removes all the pollutants before disposal. There is an added benefit of recovering valuable products that can be used in the future. This has the potential to offset costs and can either mitigate the costs of recycling or potentially make them profitable.

Many treatment methods like using vinasse as a medium for Chlorella vulgaris growth and extraction of trans-aconitic acid are still at the lab level and require testing at the industrial level to assess their techno-eco feasibility.

Various designs of bio-refineries that incorporate anaerobic bioreactors followed by a concentration technology such as evaporation, reverse osmosis or forward osmosis, membrane distillation should be explored.

As the sugarcane bioethanol industry in India expands, a larger quantity of vinasse will be generated. We should be prepared to tackle this by adopting efficient treatment methods to prevent large-scale environmental consequences. I recommend bioconversion into high-added value products and energy or the use of bio-refineries as effective methods to remove the biological and chemical oxygen demand.

Conclusion

As India increases its sugarcane ethanol production, it is imperative to implement effective vinasse wastewater treatment methods. A two fold strategy may be implemented, in which old plants use anaerobic treatment and membranes, and upcoming plants follow bioconversion into high-added value products.

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