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Production of Bioethanol from Agricultural Waste via Membrane Technology

Dr. Subash B. Magar[1], Sagar B. Kale[2], Paresh A. Chopade[3], Saurabh D. Nirmal[4], Hrishikesh D. Cholke

Faculty, Department of Chemical Engineering[1]

Students, Department of Chemical Engineering[2,3,4,5]

Pravara Rural Engineering College, Loni, Maharashtra, India

magarsb@pravaraengg.org.in, htcsagarkale@gmail.com, pareshchopade484@gmail.com

Abstract: *In the context of rapid industrialization and the increasing demand for sustainable energy sources, bioethanol presents a promising alternative to traditional fossil fuels. This research investigates the production of bioethanol from agricultural waste, specifically using bagasse, and employs membrane technology for purification. The fermentation of 1 kg of bagasse yielded approximately 800-850 ml of ethanol, demonstrating the efficiency of converting lignocellulosic biomass into bioethanol. The integration of membrane technology resulted in ethanol purity levels of 98-99%, highlighting its potential in achieving high-quality ethanol with reduced energy inputs. This study underscores the viability of utilizing agricultural waste as a feedstock for bioethanol production and emphasizes the role of membrane technology in enhancing both yield and purity. The findings support the potential for large-scale implementation, contributing to energy security and environmental sustainability*

Keywords: bioethanol, agricultural waste, bagasse, membrane technology, ethanol purification, renewable energy, lignocellulosic biomass, sustainable fuel, fermentation, energy efficiency

I. INTRODUCTION

Bioethanol, a renewable fuel, can be produced from a variety of raw materials such as sugar, starch, and lignocellulosic materials. Among these raw materials, lignocellulosic materials are considered the most promising feedstock for large-scale bioethanol production in the future. According to a report from the European Renewable Ethanol Association (ePURE) and the Biomass Ethanol Research Association (BERA), the use of lignocellulosic materials can not only improve the greenhouse gas balance of bioethanol but also not

compete with food and feed production. Every single ton of lignocellulosic materials can produce second generation bioethanol up to 500 liters. It is estimated that around 1.2 billion tons of lignocellulosic materials could be sustainably mobilized for energy purposes. However, up to now, the conversion of lignocellulosicmaterials to bioethanol is still at the research and development stage. Although there are only 4 commercial scale bioethanol plants based on lignocellulosic materials in the world, some advanced second-generation bioethanol technologies were built and demonstrated at an industrial scale. These technologies typically include pre-treatment of materials, hydrolysis of cellulose and hemicellulose to form sugar, fermentation of sugar into bioethanol, as well as the distillation of bioethanol and recovery of by-products. Many efforts have been put into improving the conversion of cellulose and hemicellulose to glucose, which is the limiting factorof the whole bioethanol production process. New methods for bioethanol are being sought, as the debateregarding large-scale food crop bioethanol and its impact on food prices and land use continues today. Forexample, the development of bioethanol with longer carbon chains such as biobutanol is being researched, and

it was reported that new genetically engineered bacteria have been generated to produce biobutanol. On the other hand, the development of bioethanol engines is pivotal for the future of bioethanol as a replacement for gasoline. It is because bioethanol has different properties from gasoline, and there were studies showing that if standard engines were using a high percentage of bioethanol blends, the efficiency of engines in terms of mileage per liter of bioethanol needs to be improved. This means that more bioethanol would have to be produced to match the energy output of gasoline. It is a catch-22 situation for the bioethanol proponents at the moment. However, the push for more energy efficiency of

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bioethanol engines is evident and promising, as research and development groups are tackling the fuel system and engine design, and one day, flex-fuel bioethanol engines could be widely seen in the vehicle market. In addition, to bring down the cost of bioethanol and the energy efficiency of the whole production process, the utilization of by-products from the bioethanol production such as lignin and yeast could not be neglected, and numerous research around the world has been carried out for the better usage of these by-products. For example, lignin is being used to demonstrate and produce steam and power to offset the energy requirement of the bioethanol plant, and some research is showing good indications of further developing lignin as a fuel for combined heat and power production. On the other hand, yeast from the fermentation process has found its way back to the healthcare products market as it was reported that yeast beta-glucan can be extracted for the use of some cholesterol loweringfood supplements. These efforts have shown a clear sign of improving the productivity of bioethanol.

With the support from countries around the world to commit significant investment and targets of biofuels used in transportation fuel, as well as extensive research on biofuels, it is believed that bioethanol, especially lignocellulosic bioethanol production, will play a major role in the future renewable energy market.

II. LITERATURE SURVEY

Current numerous research studies have explored the integration of membrane technology in bioethanol production. Researchers have been investigated membrane materials, module designs, and process parameters to optimize the efficiency and productivity. Case studies on utilizing various agricultural waste feed stocks, such as bagasse, corn stover, rice straw, weat straw, have been conducted to evaluate the feasibility of membrane-assisted bioethanol production (1) Due to increasing oil price environmental concerns, current European & Asian initiatives are aiming torise the share of biofuel used for transportation from approx. Global biofuel demand is expected to 6% or9,100 million liter per year (MLPY) higher in 2022 than 2021. India is actively encouraging the setting up ofboth traditional and second generation (2G) ethanol plants to meet the anticipated rise in demand in 2025 whenit expects to launch 20% ethanol –blended gasoline across the country. The Indian government launched 20%ethanol-blended gasoline at select outlets in 11 states in **February 2023**, two months ahead of scheduled 1April & expects to launch it across the country by financial year 2025-26.The government expects to see a 25% increase in the country's total ethanol production capacity by endof calendar year 2023 said SangeetSingla, director, Ministry of Consumer Affairs, Food & PublicDistribution. "India currently has the capacity to produce nearly 10 billion liters. We should be able toincrease it to 12.5 billion liters by late 2023," he added.(3)Sugarcane is used to produce nearly 70% of the current capacity, while grains like rice and maizecontribute the remaining 30%. As Per official government records, India's current ethanol production capacitystands at around 9.5 billion liters of which 6.2 billion liters are produced using sugarcane feedstock while 3.3billion liters come from grain feedstock. As per the roadmap prepared by government think tank NITI Aayog,the estimated requirement of ethanol for blending with gasoline is 5.42 billion liters for ESY 2022-23 and 6.98billion liters for ESY 2023-24(2).Second generation biofuels, also known as advanced biofuels, are fuels can be manufactured from various types of non-food biomass. Biofuel is made from different feedstocks and therefore may require different technology to extract useful energy from them. Second generation feedstocks include lignocellulosicbiomass or woody crops, agricultural residue waste, as well as dedicatednon food energy crops grown on marginal land unsutaible for food production. Ethanol production from three distinct sources, namely sugarcane bagasse, rice straw, and wheat straw, was investigated using Saccharomyces cerevisiae in a submerged fermentation process conducted at a temperature of 30°C over a four-day incubation period. The findings of this research revealed that the highest ethanol output was achieved when employing sugarcane bagasse as the substrate, yielding 66 g/L of ethanol with an ethanol yield of 0.41. In comparison, both rice straw and wheat straw were capable of ethanol production, although their yields fell short of those obtained with sugarcane bagasse. The discrepancy in ethanol production levels was attributed to variations in the availability of fermentable sugars originating from cellulose within these biomass sources. In a separate study, Jalil et al. (2010) employed commercial enzymesfor saccharification and documented enhanced ethanol production from treated rice straw, which yielded 85 g/L, in contrast to untreated rice straw, which produced 70 g/L. Uma et al. (2010) conducted a pretreatment process on sugarcane bagasse using 1 N NaOH, leading to a 48% ethanol production rate by C. cladosporoidesafter 48 hours of fermentation conducted under static conditions. Additionally, Sasikumar and Viruthagiri

(2010) reported the highest ethanol production levels, reaching 3.36 g/L, from pretreated sugarcane bagasse, employing optimized process conditions within an aerobic batch fermentation framework. (fig.2) . The sugars generated through enzymatic hydrolysis underwent efficient conversion into ethanol through the utilization of
Saccharomyces cerevisiae in a submerged fermentation process conducted at a temperature of 30°C over a four-day incubation period. Notably, sugarcane bagasse emerged as an exceptionally proficient substrate for thanol production. This observation carries significant implications for potential up scaling of the process,
promising enhanced cost-effectiveness.(4)

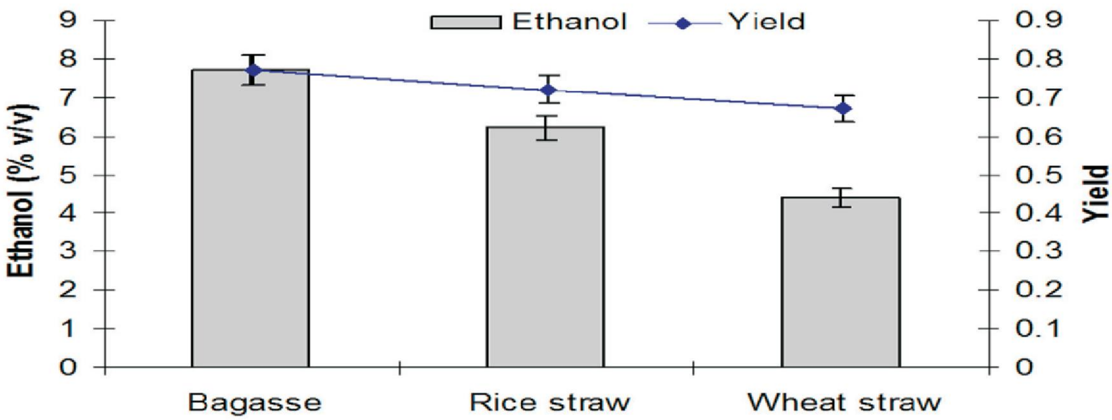

Figure 2 - Ethanol production from different lignocellulosic biomasses.

Membrane technology offers several advantages over the conditions mentioned in the previous discussion, which involved enzymatic hydrolysis and submerged fermentation for ethanol production from agricultural residues like sugarcane bagasse, rice straw, and wheat straw. Membrane technology allows for precise separation of components, such as the separation of ethanol from the fermentation broth. Thisseparation is often more efficient and selective compared to traditional methods. Membrane processes are typically energy-efficient as they operate at lower temperatures and pressures compared to traditional distillation methods used for ethanol separation. This can result in reduced energy consumption and operational costs. Membrane processes often produce less waste and have a smaller environmental footprint compared to traditional separation methods. They can contribute to more sustainable production practices. Membrane systems can be easily scaled up or down to meet production requirements. This scalability isvaluable for both small-scale and large-scale ethanol production facilities. Membrane processes can be designed for continuous operation, which can improve process efficiency and reduce downtime associated with batch processing. In some cases, membrane processes may require fewer chemicals for separation, reducing the need for additional processing steps and minimizing chemical waste. Membrane technology can produce high-purity ethanol and other products, which is important for industries requiring specific product quality standards. Membrane processes offer better control over separation parameters, allowing for fine-tuning of the process to optimize yields and product quality. Membrane technology can be applied to a wide range of separation processes beyond ethanol production, making it a versatile choice for various industries.

Membrane technology allows us to separate very small size of particles down to the molecular and ionic level this is the comparison to what may be the most familiar with the conventional separation systems which are also called as dead-end filtration where we may use filtration to separate ethanol and water. For separation of these mixture PV membrane system is used (pervaporation& vapor permeation is aenergy systematic combination for membrane permeation and evaporation. It is considered as a interesting alternative for other separation methods like extractive distillation. Pervaporation process is used for the dehydration of organic solvent and removal of organics from aqueous streams.

Pretreatment processes

The pretreatment stage of lignocellulosic biomass, a crucial step in bioethanol production. Pretreatment aims to break down the lignin structure and disrupt the crystalline structure of cellulose, enhancing enzyme accessibility during hydrolysis. Various pretreatment methods exist, including biological, chemical, and physical processes, each offering

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unique advantages and challenges. For instance, chemical pretreatment methods like dilute acid and alkali pretreatment have been extensively studied for their effectiveness in degrading hemicellulose and increasing biomass porosity. Dilute acid pretreatment, for example, utilizes acids like sulfuric acid or phosphoric acid to hydrolyze hemicellulose and lignin bonds, thus improving enzymatic hydrolysis efficiency. Alkali pretreatment, on the other hand, employs bases such as sodium hydroxide or calcium hydroxide to selectively remove lignin and enhance cellulose accessibility. Among physical pretreatment methods, steam explosion is widely recognized for its efficiency in deconstructing plant cell wall organization. By subjecting biomass to high temperatures and pressures in the presence of steam, steam explosion breaks down lignocellulosic materials, increasing enzyme accessibility to\ cellulose. Similarly, liquid hot water (LHW) pretreatment, conducted at elevated temperatures with water, maximizes hemicellulose solubilization and partial removal of lignin, making cellulose more accessible to enzymes. LHW offers advantages such as no additional catalysts or chemicals, moderate operating temperatures, and high hemicellulose recovery. Biological pretreatment, utilizing cellulolytic and hemicellulolytic microorganisms, presents an ecofriendlyand cost-effective alternative. Filamentous fungi, particularly white-rot fungi, are commonly employed for their ability to degrade lignin using lignin-degrading enzymes. Despite longer incubation times and space constraints, biological pretreatment offers low capital and energy requirements, with no chemicalinputs necessary. Overall, exploring and understanding the diverse pretreatment methods is essential for optimizing bioethanol production from lignocellulosic biomass, addressing challenges such as biomass recalcitrance and enzymatic hydrolysis efficiency.[7]

III. MEMBRENE PREPARATION

To prepare the polyvinyl alcohol (PVA) membrane, begin by gathering the necessary materials. Obtain PVA with a purity of 98.5% and an alcoholysis degree of 99%, with a molecular weight ranging from 73,900 to 82,700 g/mol. Acquire glycerol (GC) with a purity of 99.5%, lithium fluoride (LiF) with a purity of 99.99%, hydrochloric acid (HCl) with a concentration of 36–38%, and ethanol of analytical reagent (AR) grade. Use a PTFE support with a width of 220 mm, a length of 15 m, and a mean pore size of 0.22 µm. Additionally, obtain MAX (Ti_3AlC_2) powder with a mesh size of 400 and prepare deionized water (DI water) in the laboratory.

For the preparation of $Ti_3C_2T_x$-based MXenenanosheets, utilize the in situ etching method as described in previous studies. Mix 2.4 g of LiF, 35 mL of HCl (12 M), and 2 g of MAX powder. Stir the mixture for 48 hours at a temperature of 40°C. Afterward, dilute and sonicate the mixture in DI water for 3 hours, followed by filtration and freeze-drying to obtain MXenenanosheets. To prepare the composite membranes, combine a specified amount of PVA and GC in boiling DI water, stirring until the PVA is completely dissolved. Allow the mixture to cool to room temperature to obtain the PVA/GC solution. Disperse a specified amount of MXene powder in DI water at room temperature and sonicate for 20 minutes to achieve a uniform MXene dispersion. Mix the MXenedispersion with the PVA/GC solution and stir at room temperature for 24 hours to obtain a PVA/GC/MXene mixed solution. After defoaming for 24 hours, heat the PVA/GC/MXene casting solution to 40°C. Add the solution into an ultrasonic spraying system with a flow rate of 10 mL/min, nitrogen pressure of 0.05 MPa, and ultrasonic power of 15W. Set the winding rate of the PTFE support at 0.5 m/min, with a heating roll temperature of 110°C and a heating furnace temperature of 150°C. Using these parameters, obtain fresh PVA/GC/MXene composite membranes. Following these steps will ensure the successful preparation of polyvinyl alcohol membranes embedded with MXenenanosheets for further characterization and application in various fields.

IV. MEMBRANE TECHNOLOGY IN BIOETHANOL PRODUCTION

4.1 Process characteristics of PV/VP :

o Low energy consumption, less running cost.
o No entrainer required, no contamination to product.
o Easy operation and less maintenance.
o Functions independent of vapor/liquid equilibrium.
o Reliable treated solvent quality.
o Less labor cost.
o Less waste discharge.

4.2 Procedure

Membrane technology is a versatile and increasingly important field that involves the use of semipermeable membranes to separate, purify, and concentrate various substances in a wide range of applications. The principles of membrane technology are based on the selective permeation of different components through the membrane, which can be used to achieve separation and purification objectives. Here are some key principles and various applications of membrane technology: Following figure shows the systemic diagram of production of bioethanol from agricultural waste by membrane technology. It shows how to produce bioethanol by using MF/UF/PV membrane.(1)

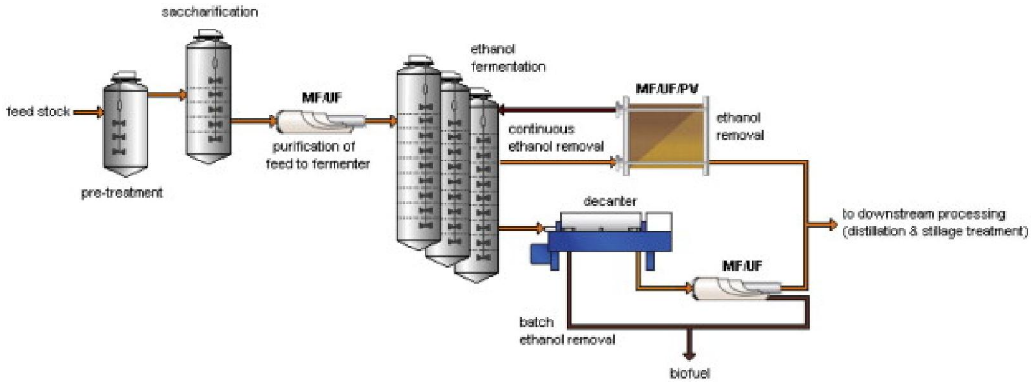

Fig – process for production of ethanol Principles of Membrane Technology:

Membranes are designed to allow the passage of certain substances (permeate) while restricting the passage of others (retentate). This selectivity is achieved based on the size, charge, and solubility of the molecules or ions. Different types of membranes are used, including microfiltration, ultrafiltration, Nano filtration, and reverse osmosis membranes. These membranes have different pore sizes and properties, making them suitable for specific applications. Membrane processes often involve the application of pressure to drive the separation. For example, reverse osmosis uses high pressure to separate solutes from water. During membrane processes, a concentration gradient can develop at the membrane surface, which can reduce permeate flux and increase fouling. Strategies to mitigate concentration polarization are essential for efficient operation. The versatility of membrane technology, along with ongoing advancements in membrane materials and processes, continues to expand its range of applications across various industries. It offers sustainable and energy-efficient solutions for separation and purification challenges. Membrane technology can significantly enhance the production of bioethanol, a renewable and environmentally friendly alternative to fossil fuels. It is used in various stages of the bioethanol production process, including separation, purification, and concentration, to improve efficiency, reduce energy consumption, and increase the overall yield. Here's how membrane technology can enhance bioethanol production.

4.3 Fermentation Separation and Clarification:

The first step in the production of bioethanol from agricultural waste via membrane technology is the collection and preparation of the agricultural feedstock. This can include various agricultural residues such as\ corn stover, sugarcane bagasse, or other lignocellulosic materials. These feedstocks are typically ground or chopped into smaller particles to increase their surface area and facilitate subsequent processing. Next, the prepared agricultural waste is subjected to a pretreatment step. Pretreatment is essential to break down the lignocellulosic structure of the feedstock, making the cellulose and hemicellulose components more accessible for enzymatic hydrolysis. Common pretreatment methods include steam explosion, acid hydrolysis, or alkaline

Treatment After pretreatment, the hydrolyzed agricultural waste is enzymatically digested to convert the cellulose and hemicellulose into fermentable sugars. Enzymes such as cellulase and hemicellulase are added to the feedstock, and the mixture is allowed to react at controlled conditions to maximize sugar yield. Once the enzymatic hydrolysis is complete, the resulting sugar solution, known as the fermentation broth, is subjected to fermentation. Yeast or other microorganisms are introduced to ferment the sugars into ethanol. This fermentation step can occur in batch or continuous mode, depending on the specific process design Following fermentation, the ethanol-containing broth needs

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to be separated and clarified. Microfiltration (MF) membranes can be used at this stage to remove yeast cells and other solid particles from the broth, leaving behind a clear permeate enriched in ethanol. The clarified permeate is then processed further using ultrafiltration (UF) or nanofiltration (NF) membranes to concentrate the ethanol and remove impurities. Thesemembranes effectively separate ethanol from water and other undesirable components in the solution. Toachieve the desired ethanol concentration, reverse osmosis (RO) membranes can be employed in the concentration step. RO allows for the selective removal of water molecules, resulting in a highly concentrated ethanol solution. To achieve anhydrous (99% or higher) ethanol, a final dehydration step using pervaporation or other specialized membranes is performed. Pervaporation membranes selectively remove the remaining water from the concentrated ethanol, leaving behind a nearly pure bioethanol product. The produced bioethanol can then be further refined, if necessary, to meet quality standards, and it is ready for storage ordistribution as a sustainable and renewable fuel source. Throughout this process, membrane technology plays a critical role in separating, purifying, and concentrating the ethanol, contributing to improved efficiency and sustainability in the production of bioethanol from agricultural was.

4.4 Membrane material and configurations:-

In bioethanol production, there are generally three types of membranes commonly used: polymeric membranes, inorganic membranes, and mixed matrix membranes. Polymeric membranes are one type of membrane used for bioethanol production . These membranes are made of polymers and are known for their flexibility, cost-effectiveness, and ease of manufacturing. They can selectively separate ethanol from the fermentation broth, allowing for the concentration of ethanol. Polymeric membranes are widely used in pervaporation processes for bioethanol production. Inorganic membranes are another type of membrane used in bioethanol production . These membranes are made of inorganic materials, such as ceramics or metals. They offer excellent chemical resistance, high temperature stability, and durability. Inorganic membranes are often used in membrane distillation or gas separation processes for bioethanol production. Mixed matrix membranes combine both polymeric and inorganic materials, offering a combination of their respective advantages 1. These membranes are designed to provide enhanced separation performance, improved selectivity, and increased permeability. Mixed matrix membranes have shown potential in improving the efficiency of bioethanol production processes. These different types of membranes play a crucial role in bioethanol production by selectively separating ethanol from the fermentation broth and concentrating it, contributing to the overall efficiency of the process. Polymer membranes are commonly used for the separation of ethanol-water mixtures through a process called pervaporation. Pervaporation is a method that utilizes a membrane to selectively separate different components of a liquid mixture based on their vapor pressure differences. Hydrophobic polymers have been identified as versatile and prospective membrane materials for ethanol-water separation in pervaporationapplications . These membranes are designed to be water-repellent, allowing for the preferential transport of ethanol vapor through the membrane while rejecting water molecules. In a study, three synthetic polymer membranes containing an imide group were used for the pervaporation of aqueous ethanol solutions. These membranes demonstrated effective separation of water and ethanol . Similarly, other experimental studies have also been conducted to evaluate the separation of ethanol-water mixtures usingpervaporation, with a focus on optimizing the process parameters and membrane properties .Overall, polymer membranes offer a promising solution for the separation of ethanol-water mixtures through pervaporation. Their hydrophobic nature and selective permeability make them suitable for this application, enabling the extraction of ethanol from water with efficient separation efficiency. The separation of ethanol and water can be achieved using membrane technology. Two types of membrane materials commonly used for ethanol-water separation are organophilic membranes and hydrophobic membranes. Organophilic membranes are designed to be selective for ethanol, allowing it to pass through while blocking water molecules. These membranes are typically made from materials that have an affinity for organic solvents like ethanol. They can be polymer-based or composite membranes. On the other hand, hydrophobic membranes are designed to repel water molecules and selectively allow ethanol to permeate through. These membranes utilize hydrophobic materials that have a wide range of hydrophobicity, enabling the separation of ethanol from water. The configuration of the membrane system depends on the specific separation requirements and the desired separation performance. Various configurations such as flat sheet membranes, hollow fiber membranes, and spiral wound membranes can be used for ethanol-water separation. The choice of configuration depends on factors such as the desired separation efficiency, throughput, and scalability of the process. Research has shown that membrane technologies such as pervaporation and vacuum membrane distillation (VMD) can be effective for ethanol-water separation. Pervaporation involves the use of amembrane to selectively vaporize the more volatile ethanol from the liquid mixture, allowing it to pass through as a vapor and then condense for further separation. VMD, on the other hand, utilizes vacuum pressure to drive the vapor-phase ethanol through a membrane, separating it from the liquid phase. In summary, for ethanol-water separation, organophilic and hydrophobic membranes are used, and the configuration of the membrane system depends on the specific separation requirements. Pervaporation and VMD are two membrane technologies that have been investigated for ethanol-water separation.

V. RESULTS

The results of the project indicate that the utilization of 1 kg of bagasse yields approximately 800-850 ml of ethanol. This demonstrates the efficiency of the fermentation process in converting lignocellulosic biomass into bioethanol, providing a significant yield of the desired product. Moreover, the implementation of membrane technology in the ethanol purification process has led to remarkable outcomes. With the use of membranes, ethanol purity levels of 98-99% have been achieved. By using membrane technology we can produce absolute alcohol. This high level of purity is crucial for ensuring the quality and suitability of ethanol for various industrial applications and environment also, including as a fuel additive or in the production of pharmaceuticals and beverages. Overall, these results underscore the effectiveness of integrating membrane technology into the bioethanol production process from bagasse, enhancing both the yield and purity of ethanol obtained from this renewable feedstock.

VI. CONCLUSION

In conclusion, the production of bioethanol from agricultural waste via membrane technology presents a promising avenue for sustainable and efficient ethanol production. This review has highlighted the significance of bioethanol as a clean and renewable fuel source, emphasizing its growing importance in addressing energy needs while mitigating environmental concerns. The utilization of agricultural waste materials, such as rice straw and sugarcane bagasse, for bioethanolproduction represents an eco-friendly approach to waste management, reducing environmental pollution caused by burning these residues. The shift toward second-generation biofuels, including bioethanol from lignocellulosic feedstock's, holds great potential in meeting the rising demand for alternative fuels. The integration of membrane technology into the bioethanol production process offers several advantages, including enhanced separation efficiency, reduced energy consumption, and improved product purity. Membrane materials, such as polymeric and inorganic membranes, provide selective separation of ethanol from fermentation broths, contributing to the overall yield and quality of bioethanol. Furthermore, membrane configurations, such as pervaporation and vacuum membrane distillation (VMD), have demonstrated effectiveness in ethanol-water separation, offering versatility and scalability to meet production requirements.

The global demand for biofuels, including bioethanol, is on the rise due to environmental concerns andthe need for sustainable energy sources. Initiatives in countries like India underscore the significance of bioethanol in reducing fossil fuel dependency and promoting cleaner transportation options. The adoption of membrane technology in bioethanol production aligns with these objectives by enhancing efficiency, reducing costs, and minimizing environmental impact. As the bioethanol industry continues to evolve and expand, ongoing research and development efforts in membrane technology will play a crucial role in advancing the sustainability and feasibility of bioethanol production from agricultural waste. This comprehensive review provides valuable insights into the potential of membrane technology as a key enabler in the journey toward a more sustainable and environmentally friendly bioethanol industry.

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