

## PAPER 87 – DEVELOPMENT OF FULLY BIOBASED MATERIALS FOR MEMBRANE INDUSTRY TRANSFORMATIONS IN THE LIGHT OF CIRCULAR ECONOMY

A.F. I. Akindele<sup>1\*</sup>, M. Ersöz<sup>2</sup>

<sup>1</sup>Department of Environmental Management and Toxicology, University of Medical Sciences, Ondo State

<sup>2</sup>Department of Chemistry, Secluk University, Konya, Turkey.

\*Email: fakindele@unimed.edu.ng

### ABSTRACT

Circular economy, a resource-efficient model emphasizes eliminating waste and making the entire economy more sustainable through waste reuse, reduction, and recycling. For economic and environmental concerns as well as to comply with the newly established reinforcements on green economy, circular strategies have been proposed in industrial sectors to realize the recovery of waste products that have potentials to be used as raw materials. The circular economy frameworks offer an opportunity for membrane technology innovation. Membrane technology has been applied across a broad spectrum of industrial and municipal installations and is currently popular for water treatment and reuse as well as water desalination, on account of its reliability, high-efficiency, and ease of operation. New membranes from renewable materials, including wood-based polymers (bio-based polymers) was innovated and it gave a membrane manufacturing by the green chemistry and green engineering principles and the life cycle analysis methodology realized green synthesis completely for membrane fabrications. This development solves seven out of seventeen of the sustainable development goal (SDG) No. 3, 6, 9, 12, 13, 14 and 15.

**KEYWORDS:** Circular economy, Green chemistry, Sustainable development goals, Wood-based polymers, Membrane technology, Life cycle analysis

### INTRODUCTION

All sectors have virtually witnessed growth at different levels due to increased industrialization, agricultural and other human activities (Abu-Bakar et al., 2021; Muhammad, 2019; Mathai et al., 2021). Our daily activities and industrial processes generate a lot of waste with increase in the demand for products by the populace (Sharma et al., 2020). Consequently, there is increase in the challenges associated with resource management and the handling of waste. Improper disposal and management have continuously imposed negative impacts on human health (Rautela et al., 2021; Akan et al., 2021; Alshehrei and Ameen, 2021). This has led to more studies on sustainable use of cleaner resources and technology related to waste management, the circular economy and product life cycle assessment (Zhang et al., 2021; Sharma et al., 2021; Luttenberger, 2020). The circular economy is a resource-efficient model that emphasizes eliminating waste and making the entire economy more sustainable through waste reuse, reduction, and recycling. Circular strategies have been proposed in industrial sectors to realize the recovery of waste products that have potentials to be used as raw materials to find a lasting solution to economic and environmental challenges (Yaw Agyabeng-Mensah et al., 2012). New innovative ways of sourcing for safer raw materials have become the current trend in manufacturing industries. Interestingly, many unwanted wastes have now be converted into useful products thereby reducing the amount of waste getting into the landfills. The European Union's Waste Management Directive advocates the prevention of waste has the highest priority in a waste hierarchy system.

The present study work will address 7 sustainable development goals namely: SDG3 – good health and well-being in reducing harmful releases from chemical and biological processes; SDG6 – clean water and sanitation – in allowing water recycling, effluent treatment and desalination in both urban and rural environments; SDG9 - Industry, Innovation and Infrastructure – enabling cleaner technologies with less emissions, SDG12 – Responsible Consumption & Production – in enabling cleaner manufacturing; SDG13 – Climate Action – for new emission environment by adsorption or conversion from catalytic membranes; SDG14 – Life below Water – by preventing waste effluents and emissions entering water-ways and oceans; SDG15 – Life on Land – particularly through allowing increased land use efficiency within cleaner environments. This research work will involve development of new membranes from renewable materials, including wood-based polymers (bio-based polymers). Fully bio-based fibres for green membrane fabrication (This is a challenging problem because many polymer membranes have been developed to be chemically, thermally and mechanically robust (for process/product durability) and processed using low-cost, large-scale manufacturing solutions). Green-membrane research work will use a variety of approaches to these problems and will operate holistically to share knowledge across interest areas and

applications to allow new synthesis methods, testing/characterization and demonstration of feasibility for future development and exploitation; Re-use and recycling of biopolymers and LCA methodology to realize green membranes synthesis and production completely.

## **2. THEORETICAL ANALYSIS**

### **2.1 Wood-based polymer**

One option for lowering the environmental impact of plastics and timber debris is to use these wastes to make wood-polymer composites (WPC) goods, such as pallets, which are made of wood fiber and polymer. However, to evaluate the sustainability impact of WPC pallets, a comprehensive life cycle analysis must be performed. Aside from that, it is crucial to keep in mind that various commodities have varying lifespans, recycling abilities, and recycling potential. It is defined by the International Organization for Standardization (ISO) as being one of the environmental management techniques that addresses the social and environmental risks, ecological consequences throughout a product's life cycle from raw material obtaining through manufacturing, utilizing edge treatment, recycling, and disposal practices (Faggian et al., 2014; Zakariya, et al., 2022; Regulation (EC) No 1907/2006).

In recent years, WPC has also become interesting for other industries, namely the packaging and automotive sectors (Partanen and Carus, 2016). These are under increasing pressure to minimize the consumption of fossil-plastics. WPC saves petrochemical polymers, and this in the amount of the wood-fibers added. This leads to an almost balanced cradle-to-gate CO<sub>2</sub>-balance. The reason for this is that during their growth, the wood fibers already absorbed exactly the amount of harmful greenhouse gases from the atmosphere, which is later emitted for production in the form of energy and fuel consumption

### **2.2 Raw material for membrane fabrication**

Keratin, cellulose, and plastics can be widely found in domestic/industrial solid wastes and can be potentially used for liquid separation membrane fabrication.

#### **2.2.1 Keratin**

Keratin is a fibrous, structural protein commonly found in wool, hair, and poultry feather (Donato et al., 2020; Reddy et al., 2021). Wools obtained from textile fabric and hairy parts of animals are especially important keratin extraction sources, as it consists of ~95% raw keratin (Shavandi et al., 2017). Chicken feathers, which consist of ~90% protein keratin, are another major source for extracting keratin (Donner et al., 2019). The living-organism leftovers produced in tanning, slaughterhouse, and poultry industries are treated as waste, and their disposal often leads to vast environmental problems.

#### **2.2.2 Cellulose**

Cellulose is one of the most abundant biopolymers found in nature. Depending on the sources, lignocellulosic biomass typically contains cellulose, 40–60% and hemicellulose, 15–30% and lignin, 10–25%, which weave to each other to establish a strong-stretch network of recalcitrant biomass (Ariffin et al., 2008; Wang et al., 2017). Lignin is the main barrier in the deconstruction of lignocellulosic biomass; hence, lignin extraction during biomass pretreatment using solvent is required to ease the conversion of fibrous cellulosic materials (Tran and Mututuvvari, 2016). Other sources, such as seaweed, are also gaining attention for cellulose extraction. The removal of lignin through harsh chemical treatment necessary for lignocellulosic biomass is not required for this alternative (Esparza et al., 2018).

#### **2.2.3 Plastics and Rubber**

The monomers of commonly used plastics are majorly derived from non-renewable fossil hydrocarbons, so these plastics are highly durable and generally not biodegradable. The share of plastics in municipal solid waste has increased tremendously. Nearly 80% of plastic debris from land-based sources ends up in the ocean as a result of mismanagement of the plastic waste throughout the plastic supply-chain life cycle, starting from production until post-consumer disposal (Li et al., 2016). The non-biodegradable nature of most commercially used plastics leads to their landfill accumulations for many years, hence resulting in direct plastic contamination (Kubowicz and Booth, 2017). On the other hand, the incomplete disintegration of durable plastics result in the formation of microplastic polymer particles of various morphologies that invade the environments and food chains. Therefore, efforts to recycle post-consumer plastics, such as polyethylene terephthalate (PET) bottles, which have been used as single-use packaging for beverages, are necessary to counter white pollution and the subsequent issues resulting from their disposal.

### **2.3 The Bio-based Economy**

The seventh principle of Green Chemistry is “renewable rather than depleting raw materials”. One of the great challenges of the twenty first century is the implementation from an unsustainable economy based on non-renewable fossil resources - oil, coal and natural gas – as raw materials to a bio-based economy with renewable biomass as the feedstock (Sheldon, 2018; Devi et al., 2022). The pressing need for climate change mitigation and the conservation of natural carbon resources is driving the switch to a carbon-neutral manufacture of commodity chemicals, materials and liquid fuels from renewable biomass in integrated biorefineries (Wang et al., 2021). However, the use of common and well-known biomass feedstocks, such as corn and edible oil seeds, won't continue to be a sustainable option in the longer term because of direct or indirect competition with food production.

#### 2.4 Life Cycle Assessment

Full-scale LCAs are useful for comparing products and processes which have already been commercialized. Conducting a full scale LCA in the design or development phase is generally too difficult and time-consuming. In the final analysis, an assessment of the “greenness” of a process or product requires a multivariate approach that includes impacts across all the different metrics. However, the assessment tools for process industries can be simplified by splitting the system boundaries into two domains: the raw materials, production and supply domain and the gate-to-gate manufacturing domain (Sheldon, 2018).

### 3. MATERIALS AND METHODS

#### 3.1 Methodological approach

The methodological approach applied in this work includes a stepwise methodology with three main building elements: identification of raw materials, (eco) toxicological assessment and Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) compliance analysis. The raw materials identified for the membrane production were then evaluated to focus on which chemicals are hazardous and for which endpoint there is a concern. While the production process and the final products were considered to identify to which REACH obligations the membranes manufacturer could be subjected.

##### 3.1.1 Identification of raw materials

Regarding the manufacture of poly(vinylidene fluoride) (PVDF) and PES UF membrane, the dry-wet phase inversion process of GVS company was considered (GVS Group, Italy). In this process, a polymer solution will be prepared by mixing polymer and solvent. The solution is then filtered and cast onto the non-woven support. After a partial evaporation of the solvent, the cast film is immersed in a nonsolvent medium, called coagulation bath. Due to exchange of solvent and nonsolvent between polymer solution and coagulation bath, the composition in the film is changed and phase separation is induced, with the solidification of the polymer film. During the first step of desolvation by solvent evaporation, a thin skin layer of solid polymer is formed instantly at the top of the cast film due to the loss of solvent. In the solvent-nonsolvent exchange process that follows, the nonsolvent diffuses into the polymer solution film through the thin solid layer while the solvent diffuses out. Afterwards the membrane is washed and then lightly dried in an oven.

The raw materials used in phase inversion process will be identified through a visit to membrane manufacturer, by collecting the Material Safety Data Sheets (MSDS) of the chemicals used, as well as information about the uses, functions and amounts. Other suitable data and information were collected from supplier, project partner, and literature.

A special attention will be pose on impurities or residual undesired contaminants (free monomers) in polymers supplied, additives and solvents used and on their presence as residual contaminants in membranes, and on the use of other polymers/copolymers, in addition to those provided by polymers supplier.

##### 3.1.2 (Eco) toxicological assessment of raw materials

A desk-based (eco) toxicological evaluation will be performed to identify the hazard profile of polymers, copolymers, polymeric additives and solvents used for the development of UF membrane. The evaluation was based on literature review and expert judgment.

#### 3.2 Development and Performances of Waste-derived Polymeric

The bio-based polymers, which can be derived from natural sources such as cellulose and chitin or produced through biosynthesis, tend to have high hydrophilicity, biocompatibility, and biodegradability, as well as a low toxicity, carbon footprint, and environmental impact. The majority of bio-sourced polymers used for membrane fabrication are carbohydrates/polysaccharides and their derivatives. The origin of bio sourced materials possesses

a high degree of biodegradability that makes them attractive as green materials to be used for reducing pollution of the environment with plastic wastes. Cellulose is a linear polysaccharide primarily derived from many sources and has ordinary properties which are hydrophilicity and biocompatibility, exhibits excellent mechanical strength and perform chemical modifications with many functional groups. However, cellulose's high crystallinity and strong intermolecular hydrogen bonds make it difficult to dissolve in common solvents, which can hinder the production of cellulose-based membranes (Ariffin et al., 2008; Tran and Mututuvvari, 2016; Wang et al., 2017; Esparza et al., 2018).

#### 4. RESULTS AND DISCUSSION

The possibility of developing both design and functionality of the use of bio-sourced polymeric materials, nanofiber, recyclable polymers fully re-use and nanoparticles with well-defined mechanical stability, ensuring bio-compatibility and high flux rates. Stimulating new ideas in the field of innovative green membrane applications for different sectors through networking activities; contributing on the new innovative green methods for membrane manufacturing as re-use, renewable, recycling, and end-of-life management. Application of the “LCA methodology” to realize green synthesis completely for membrane fabrications will be adopted.

However, there are still some challenges and limitations associated with green or biodegradable membranes, including their degradation rate and composition with non-biodegradable materials, which can lead to waste disposal and secondary pollution. Further research is needed to understand the degradation mechanisms and behaviour of microorganisms and enzymes under different environmental conditions. Additionally, as green membranes are typically produced on pilot scales, more efficient scale-up models are needed to expand the production process.

#### 5. CONCLUSION

Pertinence and innovative aspects of the research programme is that Green-Mem address completely the priorities for a European Union into first European Green Deal strategy, 2030 Climate action plan target directing towards finding an alternative green membrane system from bio-based materials which are sustainable, biodegradable, no toxicity and more eco-friendly. Moreover, membranes play a critical role in maintaining healthy air, land and aquatic environments. They are critical for capture of emissions, filtration of harmful substances and cleaning water sources and emissions.

#### ACKNOWLEDGEMENT

My appreciation goes to my mentor and collaborator Prof. ERSÖZ who has been a wonderful person to me. I also came to know about the conference through my friend Dr. J. A. Adeniran. The kind gesture is well appreciated.

#### REFERENCES

- Abu-Bakar, H., Williams, L., & Hallett, S.H. (2021). A review of household water demand management and consumption measurement. *Journal of Cleaner Production*, 292, 125872. <https://www.semanticscholar.org/paper/A-review-of-household-water-demand-management-and-Abu-Bakar-Williams/93c625376fb21ac82f762b92d0a6c7d461dd7869>
- Akan, O. D., Udofia, G. E., Okeke, E. S., Mgbekhidinma, C. L., Okoye, C. O., Zoclanclounon, Y. A. B., Atakpa, E. O., & Adebajo, O. O. (2021). Plastic waste: Status, degradation and microbial management options for Africa. *Journal of environmental management*, 292, 112758. <https://doi.org/10.1016/j.jenvman.2021.112758>
- Alshehrei, F., & Ameen, F. (2021). Vermicomposting: A management tool to mitigate solid waste. *Saudi journal of biological sciences*, 28(6), 3284–3293. <https://doi.org/10.1016/j.sjbs.2021.02.072>
- Ariffin, H., Hassan, M. A., Shah, U. K., Abdullah, N., Ghazali, F. M., & Shirai, Y. (2008). Production of bacterial endoglucanase from pretreated oil palm empty fruit bunch by bacillus pumilus EB3. *Journal of bioscience and bioengineering*, 106(3), 231–236. <https://doi.org/10.1263/jbb.106.231>
- Devi, A., Bajar, S., Kour, H., Kothari, R., Pant, D., & Singh, A. (2022). Lignocellulosic Biomass Valorization for Bioethanol Production: a Circular Bioeconomy Approach. *Bioenergy research*, 15(4), 1820–1841. <https://doi.org/10.1007/s12155-022-10401-9>
- Donato, R.K.; Mija, A. Donato, R.K.; Mija, A. (2020). Keratin Associations with Synthetic, Biosynthetic and Natural Polymers: An Extensive Review. *Polymers*, 12, 32. <https://doi.org/10.3390/polym12010032>.

- Donner, M. W., Arshad, M., Ullah, A., & Siddique, T. (2019). Unravelling keratin-derived biopolymers as novel biosorbents for the simultaneous removal of multiple trace metals from industrial wastewater. *The Science of the total environment*, 647, 1539–1546. <https://doi.org/10.1016/j.scitotenv.2018.08.085>
- Esparza, Y., Bandara, N., Ullah, A., & Wu, J. (2018). Hydrogels from feather keratin show higher viscoelastic properties and cell proliferation than those from hair and wool keratins. *Materials science & engineering. C, Materials for biological applications*, 90, 446–453. <https://doi.org/10.1016/j.msec.2018.04.067>
- Faggian A., Scanferla P., Paulussen S., Zuin S. (2014). Combining the European chemicals regulation and an (eco) toxicological screening for a safer membrane development. *Journal of Cleaner Production*, 83, 404-412, ISSN 0959-6526, <https://doi.org/10.1016/j.jclepro.2014.07.017>.
- Kubowicz, S., & Booth, A. M. (2017). Biodegradability of Plastics: Challenges and Misconceptions. *Environmental science & technology*, 51(21), 12058–12060. <https://doi.org/10.1021/acs.est.7b04051>.
- Li, W. C., Tse, H. F., & Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence and effects. *The Science of the total environment*, 566-567, 333–349. <https://doi.org/10.1016/j.scitotenv.2016.05.084>.
- Luttenberger, L. R. (2020). Waste management challenges in transition to circular economy—case of Croatia. *Journal of Cleaner production*, 256, 120495. <https://www.sciencedirect.com/science/article/pii/S0959652620305424>
- Mathai, M.V.; Isenhour, C.; Stevis, D.; Vergragt, P.; Bengtsson, M.; Lorek, S.; Mortensen, L.F.; Coscieme, L.; Scott, D.; Waheed, A.; Alfredsson E. (2021). The Political Economy of (Un)Sustainable Production and Consumption: A Multidisciplinary Synthesis for Research and Action. *Resources, Conservation and Recycling*, 167, 105265. <https://www.sciencedirect.com/science/article/abs/pii/S0921344920305802>
- Muhammad, B. (2019). Energy consumption, CO2 emissions and economic growth in developed, emerging and Middle East and North Africa countries. *Energy*, 179, 232–245. <https://www.sciencedirect.com/science/article/abs/pii/S0360544219305420>
- Partanen, A. and Carus, M. (2016). Wood and natural fiber composites current trend in consumer goods and automotive parts. *Reinforced Plastic*, 60, 170–173. <https://www.sciencedirect.com/science/article/abs/pii/S0034361716000205>
- Rautela, R., Arya, S., Vishwakarma, S., Lee, J., Kim, K. H., & Kumar, S. (2021). E-waste management and its effects on the environment and human health. *The Science of the total environment*, 773, 145623. <https://doi.org/10.1016/j.scitotenv.2021.145623>
- Sharma, H. B., Vanapalli, K. R., Samal, B., Cheela, V. R. S., Dubey, B. K., & Bhattacharya, J. (2021). Circular economy approach in solid waste management system to achieve UN-SDGs: Solutions for post-COVID recovery. *The Science of the total environment*, 800, 149605. <https://doi.org/10.1016/j.scitotenv.2021.149605>
- Sharma, S., Basu, S., Shetti, N. P., Kamali, M., Walvekar, P., & Aminabhavi, T. M. (2020). Waste-to-energy nexus: A sustainable development. *Environmental pollution (Barking, Essex: 1987)*, 267, 115501. <https://doi.org/10.1016/j.envpol.2020.115501>
- Shavandi, A., Silva, T. H., Bekhit, A. A., & Bekhit, A. E. A. (2017). Keratin: dissolution, extraction and biomedical application. *Biomaterials science*, 5(9), 1699–1735. <https://doi.org/10.1039/c7bm00411g>.
- Sheldon R. A. (2018). Metrics of Green Chemistry and Sustainability: Past, Present, and Future. *ACS Sustainable Chemistry & Engineering*, 6 (1), 32-48. DOI: 10.1021/acssuschemeng.7b03505..... <https://pubs.acs.org/doi/10.1021/acssuschemeng.7b03505>
- Tran, C. D., & Mututuvvari, T. M. (2016). Cellulose, Chitosan and Keratin Composite Materials: Facile and Recyclable Synthesis, Conformation and Properties. *ACS sustainable chemistry & engineering*, 4(3), 1850–1861. <https://doi.org/10.1021/acssuschemeng.6b00084>

Reddy, C.C.; Khilji, I.A.; Gupta, A.; Bhuyar, P.; Mahmood, S.; AL-Japairai, K.A.S.; Chua, G.K (2021). Valorization of keratin waste biomass and its potential applications. *Journal of Water Process Engineering*, 40, 101707. <https://www.sciencedirect.com/science/article/abs/pii/S2214714420305857>

Regulation (EC) No 1907/2006 - Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). <https://osha.europa.eu/en/legislation/directives/regulation-ec-no-1907-2006-of-the-european-parliament-and-of-the-council>.

Wang, S., Dai, G., Yang, H., & Luo, Z. (2017). Lignocellulosic biomass pyrolysis mechanism: A state-of-the-art review. *Progress in Energy and Combustion Science*, 62, 33-86.

Wang, F., Harindintwali, J. D., Yuan, Z., Wang, M., Wang, F., Li, S., Yin, Z., Huang, L., Fu, Y., Li, L., Chang, S. X., Zhang, L., Rinklebe, J., Yuan, Z., Zhu, Q., Xiang, L., Tsang, D. C. W., Xu, L., Jiang, X., Liu, J., ... Chen, J. M. (2021). Technologies and perspectives for achieving carbon neutrality. *Innovation (Cambridge (Mass.))*, 2(4), 100180. <https://doi.org/10.1016/j.xinn.2021.100180>

Yaw Agyabeng-Mensah, Y. Agyabeng-Mensah, Liang Tang, L. Tang, Ebenezer Afum, E. Afum, Charles Baah, C. Baah, & Essel Dacosta, E. Dacosta. (2012). Organisational identity and circular economy: Are inter and intra organisational learning, lean management and zero waste practices worth pursuing?. *Sustainable Production and Consumption*, 28, 648-662. doi: [10.1016/j.spc.2021.06.018](https://doi.org/10.1016/j.spc.2021.06.018). <https://pubag.nal.usda.gov/catalog/7440356>

Zakariya, S.; Yeong, Y.F.; Jusoh, N.; Tan, L.S. (2022). Performance of Multilayer Composite Hollow Membrane in Separation of CO<sub>2</sub> from CH<sub>4</sub> in Mixed Gas Conditions. *Polymers*, 14, 1480. <https://doi.org/10.3390/polym14071480>

Zhang, J., Qin, Q., Li, G., & Tseng, C. H. (2021). Sustainable municipal waste management strategies through life cycle assessment method: A review. *Journal of environmental management*, 287,112238. <https://doi.org/10.1016/j.jenvman.2021.112238>