

**DEVELOPMENT OF A POINT-OF-USE WATER FILTRATION SYSTEM USING
A CATALYTIC CERAMIC MEMBRANE COATED WITH IRON OXIDE**

BY

VICTORIA NABWIRE

(B.Eng. Mech & Manuf. Eng, KYU)


22/U/GMEM/474/PE

**A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH
AND GRADUATE TRAINING IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER
OF SCIENCE IN ADVANCED MANUFACTURING SYSTEMS
ENGINEERING OF KYAMBOGO UNIVERSITY**

OCTOBER, 2024

DECLARATION

I, Nabwire Victoria, declare that this dissertation is my original work and has never been presented for any award in any tertiary institution.

Sign. 

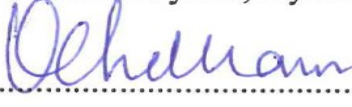
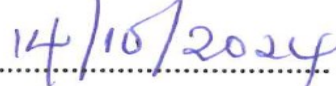
Date. 11/10/2024

APPROVAL

This dissertation entitled “*Development of a Point of Use Water Filtration System Using a Catalytic Ceramic Membrane Coated with Iron Oxide*”, prepared and submitted by Nabwire Victoria in partial fulfillment of the requirements for the Masters of Science in Advanced Manufacturing Systems Engineering of Kyambogo University has been under our supervision.

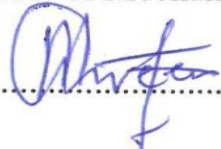
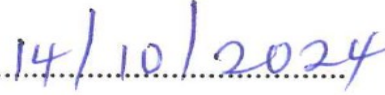
1. Dr. William Ochen

Department of Physics, Kyambogo University

Sign.  Date. 

2. Dr. Maureen Nalubowa Ssempijja

Department of Mechanical and Production Engineering, Kyambogo University

Sign.  Date. 

DEDICATION

I dedicate this dissertation to my family for their constant encouragement and belief in me which has fueled my determination to see this dissertation through.

ACKNOWLEDGEMENTS

First and foremost, my praises and thanks to the Lord Almighty, who has granted me countless blessings, knowledge, and opportunity, so that I accomplish my research study. I would like to express my gratitude to my supervisors Dr. Ochen William and Dr. Maureen Nalubowa for their patient guidance, enthusiastic encouragement, and useful critiques of this research work. My grateful thanks are also extended to my husband, Mr. Okumu Mark Wanyama who has been a source of strength, support, patience, and motivation for me throughout this entire experience.

TABLE OF CONTENTS

DECLARATION	Error! Bookmark not defined.
APPROVAL	ii
DEDICATION	iii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	v
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF ACRONYMS AND ABBREVIATIONS	xiii
LIST OF EQUATIONS	xiv
ABSTRACT	xv
CHAPTER ONE: INTRODUCTION	1
1.1 Background of the Study	1
1.2 Statement of the Problem	3
1.3 Research Objectives	3
1.3.1 General Objective	3
1.3.2 Specific Objectives	4
1.3.3 Research Questions	4
1.4 Significance of the Study	4
1.5 Scope of the Study	5
1.6 Conceptual Framework	5
CHAPTER TWO: LITERATURE REVIEW	7

2.1 Introduction	7
2.2 Characterization of Raw Materials	7
2.2.1 Chemical Composition of Clay.....	7
2.2.2 Chemical Composition of Rice Husks	8
2.2.3 Catalytic Ozonation	9
2.3 Water Filtration	10
2.3.1 Water Filtration Systems	11
2.3.2 Absorption Filtration.....	11
2.3.3 Reverse Osmosis Filtration	12
2.4 Membranes.....	13
2.4.1 Geometrical Configuration of Membranes	13
2.4.2 Types of Membranes	15
2.4.3 Application of Membranes.....	15
2.4.4 Membrane Fouling.....	16
2.5 Ceramic Membranes	17
2.5.1 Catalytic Ceramic Membranes.....	17
2.6 Challenges and Research Gaps	18
CHAPTER THREE: MATERIALS AND METHODS	19
3.1 Introduction.....	19
3.2 Materials Collection and Preparation.....	20
3.2.1 Collection of the Raw Materials	20
3.2.2 Preparation of the Raw materials	20

3.2.3 Preparation of Influent and Effluent Water	22
3.3 Characterization of the Raw Materials.....	22
3.3.1 Characterization of Ball Clay.....	22
3.4 Fabrication of the Ceramic Membrane	23
3.4.1 Mixing of Raw Materials	23
3.4.2 Molding of the Ceramic Disks	24
3.4.3 Firing of the Green Body	24
3.5 Ceramic Membrane Coating Using Iron Oxide	25
3.6 Microstructural Analysis	26
3.7 Fabrication of Point of Use Filtration System	27
3.7.1 Filtration Setup Process	27
3.7.2 Determining Water Turbidity	29
3.7.3 Conductivity and pH Tests	30
3.8 Heavy Metal Removal Tests	30
3.9 Data Analysis	31
CHAPTER FOUR: RESULTS AND DISCUSSION.....	32
4.1 Introduction.....	32
4.2 Characterization of the Samples	32
4.2.1 Chemical Composition of Ball Clay	32
4.2.2 Chemical Composition of Rice Husks Powder.....	33
4.2.3 Elemental Composition of the Developed Membranes	34
4.2.4 Uncoated Ceramic Membranes.....	35

4.2.5 Coated Ceramic Membranes	38
4.3 Microstructural Analysis of the Ceramic Membranes	39
4.3.1 Uncoated Ceramic Membranes	40
4.3.2 Coated Ceramic Membranes	42
4.4 Properties of Influent and Effluent Water	43
4.4.1 Turbidity and Color	44
4.4.2 pH Levels of the Water	47
4.4.3 Conductivity of the Water	48
4.4.4 Reduction of Total Suspended Solids in Water	50
4.4.5 Removal of Heavy Metals	52
CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS	56
5.1 Conclusion	56
5.2 Recommendations	57
REFERENCES	58
APPENDICES	72
Appendix A: Laboratory Data	73
Appendix B: Experiment Process and Setup	75
Appendix D: Introductory Letters	77
Appendix E: Plagiarism Report	82

LIST OF TABLES

Table 3.1: Mixing ratios of clay and rice husks.	23
Table 3. 3: Firing temperatures of the ceramic membranes.	25
Table 4.1: Chemical composition of ball clay.....	33
Table 4. 2: Chemical composition of the rice husks powder	34
Table 4. 3: Chemical composition of ceramic membranes	35
Table 4. 4: Chemical composition of the ceramic membranes	35

LIST OF FIGURES

Figure 1. 1: Conceptual Framework for the study	6
Figure 2.1: Plate ceramic membranes (Amin et al., 2016)	14
Figure 2.2: Tubular/straw membranes	14
Figure 2.3: The membrane separation market based on different materials (Samadi et al., 2022).	16
Figure 2. 4: A representation of a catalytic ceramic membrane Davies et al., (2010).	18
Figure 3.1: Schematic flow processes for the development of the membrane	19
Figure 3. 2: (a) The rice husks used and (b) ball clay sourced from Ntawo deposit.....	20
Figure 3. 3: (a) Preparation of ball clay, (b) sieving of rice husks powder to obtain fine powder, (c) colloidal solution of iron oxide, and (d) prepared fine powders of rice husks and clay.	21
Figure 3.4: (a) Pressing machine used for membrane pressing and (b) the green body of the prepared disks.	24
Figure 3. 5: (a) Uncoated ceramic membrane and (b) membrane coated with iron oxide....	26
Figure 3. 6: (a) Scanning Electron Microscope with samples ready for analysis (SEM) and (b) sample holder.....	27
Figure 3.7: Point of Use system setup.	28
Figure 3.8: Collection of influent water using the PoU filter.	28
Figure 3.9: Determination of water turbidity.	29
Figure 3.10: Conductivity and pH testing of the water samples.....	30

Figure 4.1: EDX spectrum for uncoated ceramic membrane (a) sample CM-1U with 60 wt% clay and 40 wt% rice husks sintered at 900 °C, (b) sample CM-2U with 70 wt% clay and 30 wt% rice husks sintered at 1000 °C, and (c) for sample CM-3U with 80 wt% clay and 20 wt% rice husks sintered at 1100 °C. 37

Figure 4.2: EDX spectrum for coated ceramic membrane (a) sample CM-1C with 60 wt% clay and 40 wt% rice husks sintered at 900 °C, (b) sample CM-2C with 70 wt% clay and 30 wt% rice husks sintered at 1000 °C, and (c) sample CM-3C with 80 wt% clay and 20 wt% rice husks sintered at 1100 °C. 39

Figure 4. 3: SEM analysis of the sintered uncoated membrane (a) CM-1U with 60 wt% clay and 40 wt% rice husks sintered at 900 °C, (b) CM-U2 with 70 wt% clay and 30 wt% rice husks sintered at 1000 °C, and (c) CM-3U with 80 wt% clay and 20 wt% rice husks sintered at 1100 °C.41

Figure 4.4: SEM analysis of the sintered coated membrane (a) CM-1C with 60 wt% clay and 40 wt% rice husks sintered at 900 °C, (b) CM-2C with 70 wt% clay and 30 wt% rice husks sintered at 1000 °C, and (c) CM-3C with 80 wt% clay and 20 wt% rice husks sintered at 1100 °C.43

Figure 4.5: Samples of (a) Influent, (b) Effluent through Uncoated Membranes, and46

Figure 4. 6: Percentage turbidity reduction by the ceramic membranes.....47

Figure 4.7: pH levels of the effluent through ceramic membranes.....48

Figure 4.8: Conductivity levels of the water samples.....49

Figure 4.9: Percentage removal efficiency of TSS from water by the membranes.51

Figure 4.10: Concentration of detected heavy metals in unfiltered water.53

Figure 4.11: Concentration of heavy metals in water samples collected from the uncoated ceramic membranes.	54
Figure 4.12: Concentration of heavy metals in water samples collected from the coated ceramic membranes.	54
Figure 4.13: Percentage removal of heavy metals by the fabricated ceramic membranes. ...	55

LIST OF ACRONYMS AND ABBREVIATIONS

AC – Activated carbon

ATF – Atomic force microscopy

CM – Ceramic membrane

EDX - Energy dispersive X-ray

POU – Point of Use

PVC – Polyvinyl chloride

SEM – Scanning electron microscopy

TSS – Total suspended solids

XRD - X-ray Diffraction

XRF – X-ray fluorescence

LIST OF EQUATIONS

Equation 2. 1.....	8
Equation 2. 2.....	8
Equation 2.3.....	9
Equation 3. 1.....	29
Equation 3. 2	31

ABSTRACT

Access to safe and clean water is a challenge especially in developing countries. Consumption of water contaminated with heavy metals causes health problems such as brain damage, kidney and liver failure. Point of Use (PoU) ceramic water filters are cheap and easy to use method of water treatment. In this study, six PoU ceramic water filters were made by mixing clay powders and rice husk powder in predetermined varying proportions, firing of the ceramic filters was done and then coated with 300g of iron oxide and 100ml of phytic acid. The system was used to remove heavy metals such as; zinc, lead, cadmium, manganese, copper, chromium, iron, nickel from water. The turbidity, total suspended solids, conductivity and pH levels of the influent and effluent water was determined. The results showed that; heavy metal removal was high for the coated ceramic membranes as it produced 98.73% when compared to the uncoated ceramic membranes which produced 74.11%. The study also revealed that uncoated ceramic membrane CM-3U produced the highest turbidity reduction of 81.08% while coated membranes CM-3C produced the lowest reduction of 22.97%. This was attributed to leaching of the iron oxide during the filtration process. The measured pH values ranged from 6.65 to 7.34 for the influent water samples for both the uncoated and coated ceramic membranes. This range is recommended for drinking water by world health organization. Therefore, the coated ceramic membranes exhibited a high-performance level of heavy metal removal when compared to the uncoated ceramic membrane.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Globally, the rate at which natural water resources are contaminated is on the rise. This is partly due to human activities such as industrialization, urbanization, and agricultural practices. Contaminants such as insecticides, plastics, pharmaceuticals, cosmetics products, heavy metals and pathogens have been found in ground water, surface water, and wastewater resources thereby deeming the water unsafe for human consumption (Kumar et al., 2022). This has adversely affected the quality of water in the water distribution systems across the globe. Thus, there is a need to have safe and clean water to mitigate the unhealthy effects caused by dirty contaminated water. The accumulation of the heavy metals in the natural water resources is mainly attributed to various factors; 1) discharge of untreated industrial wastes into water streams, 2) poor disposal of electronic gadgets and batteries, 3) domestic wastes such as agricultural pesticides and fertilizers (Buckner et al., 2016).

Point of use (PoU) system offer a sustainable solution to households by promoting an effective way of producing water free from heavy metals and pathogens (Menya et al., 2023). PoU are easier to install, user friendly and require less maintenance. Therefore, they can be used by the world's poor (Yang. et al., 2020). PoU purification techniques like flocculation, sand filtration, sedimentation, or coagulation have been used to remove pollutants from water for a long period of time (Nisha et al., 2017). However, these traditional techniques cannot effectively remove the emerging chemical contaminants and some heavy metals in waste water due to their comparably hydrophilic properties (Samuel et al., 2022). In recent technological developments, activated carbons (ACs) which are produced from a variety of

high-density predecessors such as coconut shells, animal bones, coal, apricot stone, peanut shell, cane bagasse among other wastes have been used as adsorbent materials in water purification processes to remove heavy metals and emerging contaminants as compared to traditional techniques (Neme et al., 2022). Additionally, uncoated ceramic membranes have also demonstrated high efficiency in removing pathogens from waste water (Menya et al., 2023). The ceramic filters have also reduced diseases such as diarrhoea in communities within Uganda (Williams, 2020). However, they have not been efficient in removing some heavy metals (Buonomenna et al., 2022).

Ceramic membranes have also been employed in water purification for a long period of time. However, the performance of the membranes deteriorates with increased contamination (Kyriakou et al., 2023). Moreover, when they are poorly maintained, their performance gives room for the growth of viruses and bacteria (Fu et al., 2023). Rakcho et al. (2023) created an uncoated ceramic membrane made of clay and tea waste for the treatment of industrial waste water and tested only for pH and turbidity levels. Study results showed that turbidity removal efficiencies of 99.76% and 99.16% for seawater and tannery wastewater were achieved. Psaltou et al. (2021) conducted a study on catalytic membrane ozonation, a technique used in wastewater treatment that combines membrane filtration (ceramic or polymeric in nature) and catalytic ozonation in which the membrane is covered with solid metal oxide. The author reported that different types of metal oxides can be used as a catalytic layer and these include; Al_2O_3 , TiO_2 , ZnO_2 , Mn_2O_3 and Fe_2O_3 . These layers can improve the dissolution of ozone into liquid phase and the oxidation of organic compounds. The study found that the catalytic membrane ozonation technique improves the elimination of bacteria and viruses from

wastewater. However, dearth of information was reported on its performance on heavy metal removal ability. On this note therefore, the goal of this study is to create a point of use water purification system using a ceramic membrane made from clay and low-density bio-waste mass such as rice husks, coated with iron oxide with the aim to remove selected heavy metals from wastewater.

1.2 Statement of the Problem

Water is an important and valuable resource for human life. With increasing population growth across the globe, the need for clean and safe water for consumption purposes is on a rapid rise. However, the quality of water available for use is becoming a severe global challenge. Emerging contaminants including heavy metals are contaminating water resources at a rapid pace and the increasing contamination of these resources with heavy metals possess significant health risks to people such as brain damage, and kidney and liver failure. Although uncoated ceramic water filters have been successful in removing pathogens from contaminated water, their performance in terms of heavy metal removal has been ineffective. Coated ceramic filters are inadequate due to their limited effectiveness for certain contaminants like organic compounds. Therefore, the study aims to develop a PoU ceramic water filter coated with iron oxide to remove selected heavy metals from waste water.

1.3 Research Objectives

1.3.1 General Objective

To develop a point of use water purification system using a catalytic ceramic membrane coated with iron oxide.

1.3.2 Specific Objectives

The specific objectives are to:

- (i) Analyze the properties of the raw materials used in the ceramic membrane development process.
- (ii) Analyze the water parameters such as turbidity, total suspended solids, conductivity, and pH levels of the influent and effluent water.
- (iii) Determine the performance of the developed point-of-use system for removing of heavy metals from wastewater.

1.3.3 Research Questions

The research questions of the study are:

- (i) What are the properties of raw materials used to create the catalytic ceramic membrane?
- (ii) What is the water's physical and chemical properties before and after filtration?
- (iii) How efficient can the catalytic ceramic membrane be?

1.4 Significance of the Study

The quality of water is becoming a severe global challenge which has led to this study to aim at developing a PoU system with a high heavy metal removal rate. The PoU system will help to reduce the potential health concerns that contaminants bring to human life such as high mortality rate, diseases. This will address the United Nations sustainable development goal number six and nine of enhancing water quality, public health, sustainability and innovation. Furthermore, it addresses the goal of the NDP III of increasing average household incomes as the PoU improves health and skills development.

1.5 Scope of the Study

In this research project, the water samples were collected from Namanve industrial park in Mukono district, Central Uganda. It is anticipated that industrial wastes are channeled into the water stream. The clay used was sourced from Ntawo deposits located in Mukono district. Six membranes are designed in circular form with a thickness of 2 mm and a diameter of 20 mm. Water parameters such as turbidity, pH levels, presence of total suspended solids (TSS), apparent color, and conductivity of the influent and effluent water were tested in this study. Some of the discs were coated with iron oxide and the performance evaluation of the filters was based on their ability to remove heavy metals such as lead, manganese, nickel, iron, zinc and cadmium from waste water.

1.6 Conceptual Framework

Figure 1.1 illustrates the conceptual structure of the research investigation. The independent variable influences the dependent variables and the outputs. The processes involved in the development of the membrane constitute the moderating variables.

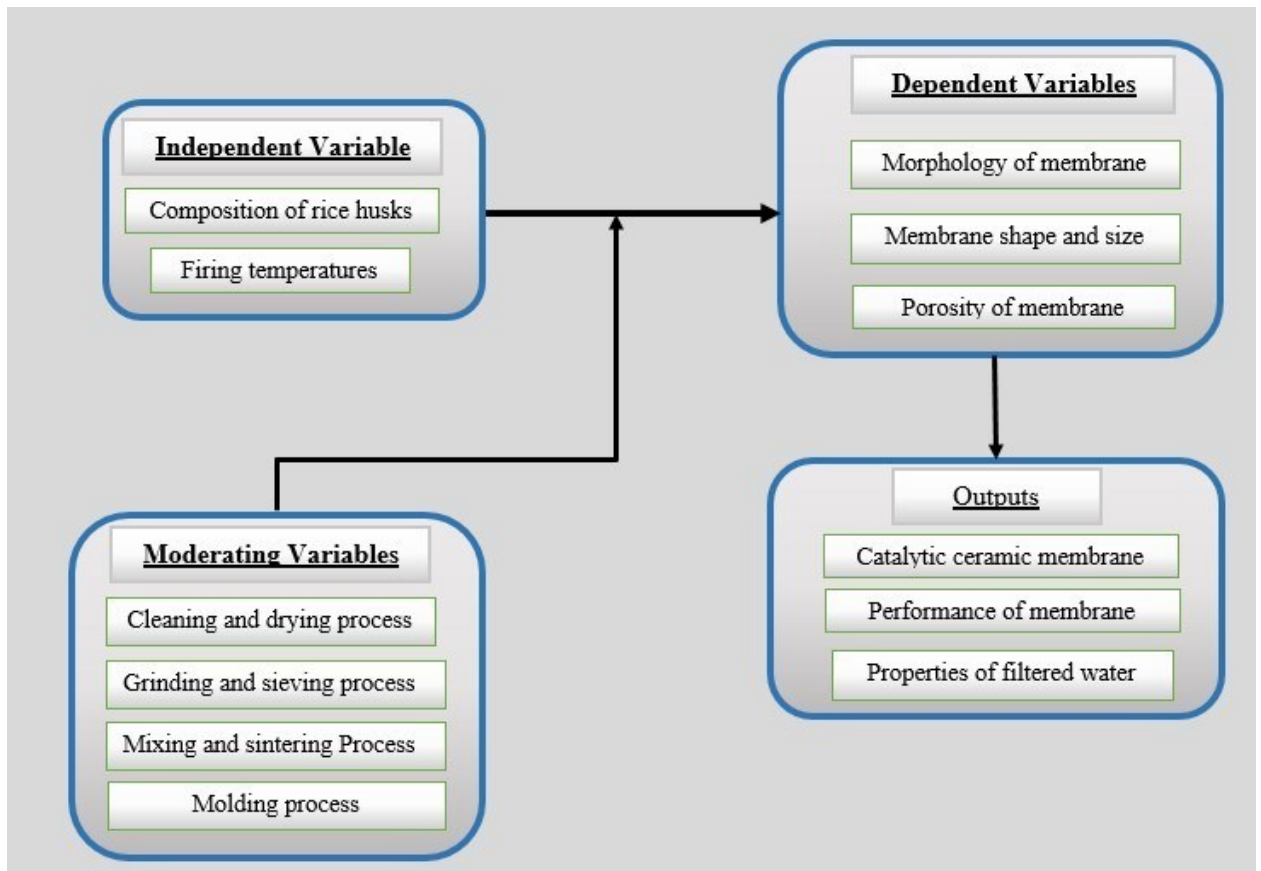


Figure 1.1: Conceptual Framework for the study

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents a description of the ceramic membranes as applied to the development of a point-of-use water filtration system. The characterization of the materials used in the development of ceramic membranes, water filtration systems, and membranes are all presented in this section.

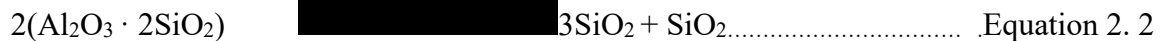
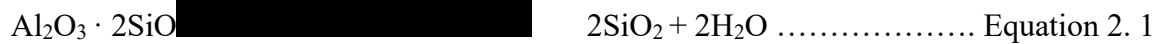
2.2 Characterization of Raw Materials

2.2.1 Chemical Composition of Clay

Clay materials are increasingly being used in ceramic membrane manufacture due to their diverse features and possibilities for natural resource conservation (Mestre et al., 2019). The utilization of natural materials like clay in the development of ceramic membranes is cost-effective, environmentally benign, and has a significant potential for improving the water filtration sector (Rakcho et al., 2023). According to Rakcho et al. (2023) utilization of natural materials like clay in the development of ceramic membranes is cost-effective, environmentally friendly, and has a significant potential for improving the water filtration sector.

According to Zhou et al. (2010), there are various varieties of clay, each defined by chemical, mechanical, and physical qualities, with kaolinite, illite, and montmorillonite being the most common clay minerals. Abdullayev et al. (2019) stated that kaolin (kaolinite being the predominant mineral form) is better suited for membrane construction due to its mechanical qualities and pore architectures that may be created via thermal procedures. Kaolin has been examined in terms of its components in inorganic membranes, ultrafiltration, microfiltration,

and ultrafiltration layers (Ben Ali et al., 2018). When compared to most typical oxide ceramics, kaolin requires lower thermal processing temperatures. However, Mestre et al. (2019) stated that membranes derived from clay raw materials have some drawbacks, such as limited porosity, significant sintering shrinkage, and small pore diameter due to high densification caused by the presence of impurities in their composition. Abdullayev et al. (2019) stated that particle sizes used in water purification membranes range from 115 μm to 1 μm and sintering temperatures are between 850 $^{\circ}\text{C}$ and 155 $^{\circ}\text{C}$. The author further stated that the heat degradation of kaolin results in the creation of an alumino-silicate, as shown in equations (2.1) and (2.2). However, the production of the silicate at high temperatures results in poor porosity and tiny pore size (Saffaj et al., 2006).



Rakcho et al. (2023) made a ceramic membrane from red clay and tea waste, however, analytical tests revealed that the clay contained 56.203% silica and 15.109% aluminium, respectively.

2.2.2 Chemical Composition of Rice Husks

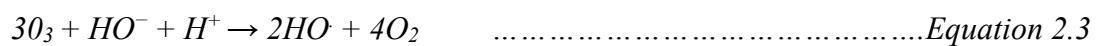
A rice husk is an outermost layer of paddy grain that separates off the grains during milling (Goodman, 2020) (International Rice Research Institute, 2013). Rice husk’s chemical composition changes according to paddy type, crop year, climate, and geographical location (Pode, 2016). Because of its poor nutritious value, it is rarely used as animal food. According to S. Rani et al. (2021), the raw materials utilized in the manufacture of CM’s are determined

by their local availability, and the production of low-cost ceramic membranes is becoming an appealing endeavor in the filtering business.

Biomass wastes like rice husks are readily available and less expensive adsorbents. Rice husk ash, which is formed by burning rice husks at controlled temperatures, includes a significant quantity of silica, carbon, and other minor minerals, this has the ability to remove heavy metals during water purification operations (Hossain. et al., 2018). In fact, the rice husk ash has amorphous silica as its highest composition ranging from 83% – 90% (Pode, 2016). According to Karnib et al. (2014), silicates can react with heavy metal compounds to form insoluble complexes and salts, making it easier to remove them through filtration. Hubadillah et al. (2017) made a hollow fibre membrane from rice husk ash sintered at 1200 °C, and the results showed that the membrane could remove heavy metals.

2.2.3 Catalytic Ozonation

Catalytic membrane ozonation is a hybrid process that combines membrane filtration and catalytic ozonation for which the membrane is deposited with an appropriate solid material that acts as a catalyst (Mansas et al., 2020). The process bases on the production of HO radicals during an oxidation process. Ozone being a highly reactive gas with low solubility levels, ozone is formed through dry air or pure oxygen. When dissolved in water, it undergoes full breakdown, creating hydroxyl radicals as shown in equation (2.3) (Psaltou et al., 2021).



The addition of a suitable metal oxide such as Al₂O₃, TiO₂, Fe₂O₃ among others, on the surface of a virgin ceramic membrane that has no particular catalytic activity, can enhance

the generation of hydroxyl radicals (Psaltou et al., 2021). Metal oxides operate as catalysts for micro-pollutant elimination and help to reduce fouling. Yu et al. (2016) coated a membrane with MnO₂ nano-particles and discovered that the presence of MnO₂ reduced ozonation fouling. Huang et al. (2023) dispersed metal oxides (CO₃O₄, MnO₂, Fe₂O₃, and CuO) on different membrane surface and study results showed that catalytic ceramic membranes have a good prospect in degradation of organic pollutants.

2.3 Water Filtration

Water filtration offers a wide range of benefits, from safeguarding people's health to enhancing the taste and smell of water. Currently, official guidelines limit the maximum quantities of dangerous contaminants that can be allowed in water around the world (Herschy, 2012). Because safe water for home or industrial use cannot be determined solely by its appearance, a variety of procedures; biological, chemical, and physical studies, have extensively been developed to investigate water contamination levels. According to Qasem et al. (2021), chemical process involves determining the chemical parameters such as water hardness, pH, chemical oxygen demand, and total dissolved solids. The biological process is based on receptors of contaminants such as e.coli, bacteria, and viruses that are biologically active substances or organisms to assess the degree of pollution (Szczerbin'ska & Galczyn'ska, 2015). The physical process involves conducting tests to provide indications of water quality such as turbidity, color, temperature, odor, and taste. To assess the contamination levels and the quality of water, different parameters such as, microbial pathogens, dissolved and suspended solids, organic and inorganic chemicals, conductivity, odor, color, and water pH should all be analyzed.

2.3.1 Water Filtration Systems

The implementation of different water treatment systems ensures constant and continuous supply of safe water for utilization, either industrially or domestically (Muncan et al., 2020). Filtration of water helps to remove or reduce the concentration of suspended particles, fungi, bacteria, virus, algae, in addition to the undesirable chemical contaminants. With the current energy challenges around the world, renewable energy-based water filtration systems could offer the best solution (Phuangpornpitak & Katejanekarn, 2016). Ishikawa et al. (2023) claimed that point-of-use water filtration systems are well known for their easy installation while still providing safe water to communities. With regards to the required application and what to remove, different types of water filtration are employed in water purification systems. Mechanical filters are used in water purification systems to remove dirt, silt, and other particles from water through a barrier. Mechanical filters can either be a simple mesh filter that removes big particles or a ceramic filter with minute pores that remove microparticles or organisms. Estim et al. (2019) developed aquaponics subsystems and employed sponge pads as mechanical filters to remove unwanted particles and solid wastes from fish excrement, uneaten feed particles, and sludge. Brochot et al. (2020) investigated the performance of five distinct mechanical filters and test results showed that their particle sizes ranged from 20 nm to 500 nm, and the experimental results were consistent with classical filtering theory for mechanical media.

2.3.2 Absorption Filtration

According to Atabaki (2014), absorption filtration involves the trapping of the contaminants by an absorbent material such as an activated carbon. For the effective capturing of

waterborne contaminants, carbon is used for absorption purposes in water filters. Most domestic filters contain activated carbon because of its potential to reduce the unwanted tastes and odors in water by absorption. Wood, coconut shell, sugarcane bagasse, palm kernel shell are some of the most commonly used raw materials in the development of activated carbons (Oladimeji et al., 2021). Soffian et al. (2022) claimed that absorption has proven to be a more effective method for eliminating a varied range of water pollutants. These are; organic toxics, heavy metals, dyes, pesticides, inorganic toxics and pharmaceutical wastes. Boulanger et al. (2024) used a wasted mushroom substrate activated carbon for dye removal, and the experimental findings showed that 82% of RO-16 dye could be extracted from an aqueous solution at an initial 200 mg/L concentration.

2.3.3 Reverse Osmosis Filtration

One of the most effective ways of purifying water is reverse osmosis filtration which is usually a combination with other filters such as mechanical and absorption filters, thereby, returning water with reduced contaminants. In a study on the assessment of ground water quality and reverse osmosis water treatment plants by Imbulana et al. (2020), results showed that reverse osmosis plants can achieve high major ion removal of more than 90% but with low recoveries of approximately 46%. Reverse osmosis filtering can drastically lower the bacterial growth potential of ground water compared to conventional water treatment approaches (Sousi et al., 2020). Other filtrations methods used in the water purification systems include; sequestration and ion exchange filtration.

2.4 Membranes

According to Amin et al. (2016), a membrane is a selective barrier that enables only certain components of matter to pass through while preventing others. The components can be in liquid, gaseous, or solid state. In membrane separation technology, the influent is referred to as the feed stream, and the liquid allowed to pass through the membrane is referred to as the permeate. Membranes are attractive prospects for separation technology and have a wide range of applications including water treatment, gas purification, production of drinking water, and acid and alkaline media separation (Padaki et al., 2015).

2.4.1 Geometrical Configuration of Membranes

Membranes are generally fabricated into different shapes which include; tubular/straw membranes (Figure 2.2), pillow shaped membranes, hollow fiber membranes, and capillary membranes. Tubular membranes are used in viscous fluids, and the modules do not require any water pretreatment prior to use. Hollow fiber membranes typically have a diameter of less than 0.5 mm and are primarily used to clean water with low suspended particles concentration. On the other hand, capillary membranes usually serve as a selective barrier that can effectively high filtration pressures (Amin et al., 2016). According to Chen et al. (2015), most commercialized membranes are in disc, plate or tubular configurations as shown in Figure 2.1.



Figure 2.1: Plate ceramic membranes (Amin et al., 2016)



Figure 2.2: Tubular/straw membranes

2.4.2 Types of Membranes

In the industry of membrane development, membranes are categorized into two different types; dense and porous membranes. According to Shimizu (1990), porous membranes are typically characterized by thickness, surface porosity, and pore size whilst in dense membranes, the separation and permeation principles are a bit more complex. The membranes' pore size is the most important component in determining their applicability.

2.4.3 Application of Membranes

Porous membranes find their wide applications in solid-liquid and solid-gas separation while dense membranes are typically used in gas separation. Furthermore, in water filtering procedures, membrane technology is widely used, with polymeric membranes commonly used in reverse osmosis desalination units for the elimination of unwanted minerals in water (Alsubei et al., 2024). In contrast, in ultrafiltration and nanofiltration, ceramic membranes are favored because of their features such as superior chemical and thermal stability and less fouling potential (Chihi et al., 2019). Ceramic membranes are developed by fabricating the ceramic substrate and di-coating the inner substrate, with the membrane consisting of three layers with varying porosities and pore diameters (Samadi et al., 2022). The availability of vast volumes of biomass waste such as rice husks, coco nut shell, palm oil fly ash, and sugarcane bagasse give a substantial opportunity for the development of low-cost ceramic membranes (Hossain & Roy, 2020). In comparison with polymeric membranes, ceramic membranes installed in water filtration systems enable sufficient aggressive permeability (Jarvis et al., 2022). However, in the membrane market, ceramic membranes have an estimated market of about 26% as illustrated in Figure 2.3.

In contrast, membranes are used in refineries and metallurgical industries to separate oil from oily waste water prior to treatment. High density ceramic membranes are widely utilized in gas separation. At temperatures higher than 500 °C, Tong et al. (2015) separated carbon dioxide (CO₂) from flue gas using a carbonated ceramic membrane.

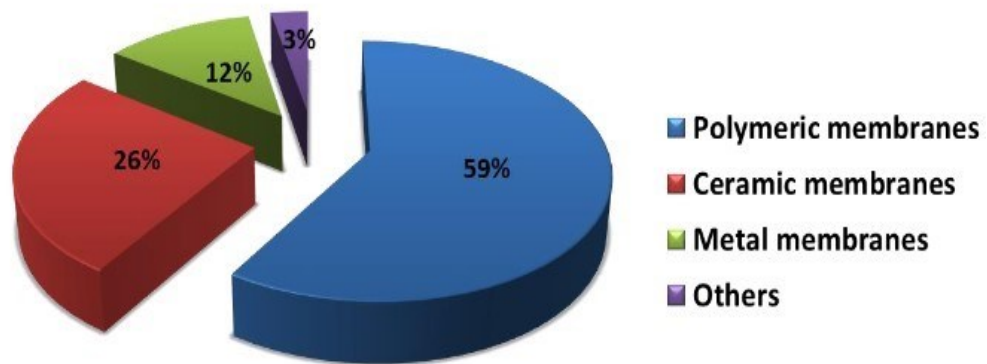


Figure 2.3: The membrane separation market based on different materials (Samadi et al., 2022).

2.4.4 Membrane Fouling

Membrane filtration is an effective technique of eliminating particles and organic chemicals from waste water, however the deposit of organic and inorganic particles on the membrane's surface (referred to as fouling) is unavoidable, which decreases the membrane's filtration performance (Chen et al., 2015). In study conducted by Hong and Elimelech (1997) on fouling of nanofiltration membranes, experimental results showed that fouling on membrane surfaces increased with higher electrolyte concentrations and lower pH. Alresheedi and Basu (2020) stated that water temperature does not only have an effect on its viscosity but also the fouling of organic matter, accounting for about fifty percent of the variation in the membrane's fouling index.

2.5 Ceramic Membranes

Ceramic membranes are typically composite in nature, comprising of many layers of distinct materials. The layers can be; a macro-porous, meso-porous intermediate layers and a microporous support. The bottom layer normally offers mechanical support, while the middle layers bridge the pore-size discrepancies between the top layer and bottom layers (Shimizu, 1990). The true separation process occurs in the uppermost levels.

2.5.1 Catalytic Ceramic Membranes

In filtration operations, catalytic membrane-based oxidation-filtration is a distinct idea that combines physical separation and chemical oxidation. Currently, the development of catalytic membranes is based on covering the ceramic membrane with a nano-catalyst, with or without the usage of energy (e.g., UV radiation, current). The advanced oxidation process (AOP) is a chemical technique that effectively degrades a large variety of developing organic pollutants (Fu et al., 2023) through the interaction of common organic pollutants in water with hydroxyl radicals. Photons can initiate hydroxyl radicals in the presence of oxides mostly composed of titanium, aluminum, silicon, zirconium, and silicon carbide (Samaei et al., 2018); (Deng & Zhao, 2015). Depending on the operational conditions and application needs, different metal oxides have variable performance, chemical, and hydrothermal stability (Hofs et al., 2011). Rosman et al. (2018) revealed that hybridizing AOPs in a single membrane layer can have a considerable effect, particularly in the treatment and removal of pharmaceutical residues from waste water. There are many methods utilized in fabricating ceramic membranes, and ultrafiltration is a membrane-based separation technology that is commonly utilized in industrial waste water treatment operations (Ren et al., 2021). Ceramic

ultrafiltration and nanofiltration membranes are primarily made up of many layers, with the filtration layer supported by a substrate as illustrated in Figure 2.4 (Davies et al., 2010).

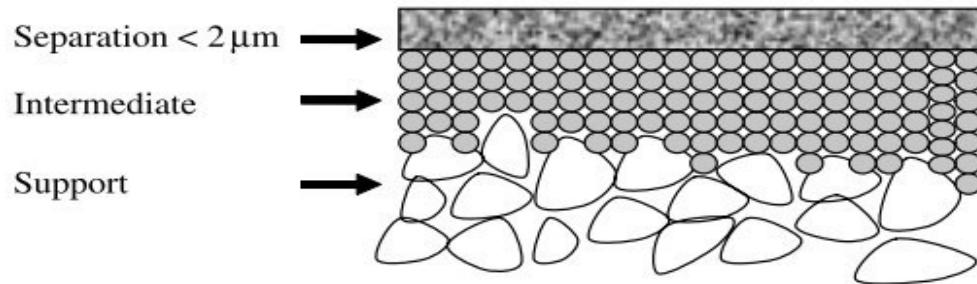


Figure 2. 4: A representation of a catalytic ceramic membrane Davies et al., (2010).

2.6 Challenges and Research Gaps

While significant progress has been made in the development of ceramic filters for water purification, current research primarily focuses on the use of kaolinite and montmorillonite clays (Zhou et al., 2010). However, few studies have explored the integration of biomass waste materials, such as rice husk ash, in the production of these filters (S. L. S. Rani & Kumar, 2021). This presents a significant gap in the research, as the use of alternative, low-cost materials could enhance the affordability and accessibility of filtration systems, particularly in low-income regions. Additionally, challenges such as membrane fouling and limited porosity remain unresolved. Addressing these issues through innovative material combinations and improved filter design could significantly enhance the efficiency and sustainability of ceramic filters in water purification.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

This section details the materials and procedures that were utilized in the development and manufacture of the catalytic ceramic membrane. The synthesis of the catalytic ceramic membranes involved a series of preparation steps such as collection of raw materials, drying of the rice husks and ball clay, sieving of the rice husks and ball clay, mixing rice husks and ball clay, hydraulic pressing of the green body, sintering the ceramic membrane and coating some of the ceramic disks with iron oxide. All the above steps are precisely followed, Figure 3.1 depicts the flow processes followed in the synthesis of the catalytic membrane. The influent and effluent samples were subjected to tests such as heavy metal presence, pH, total suspended solids (TSS), apparent color, turbidity, and conductivity.

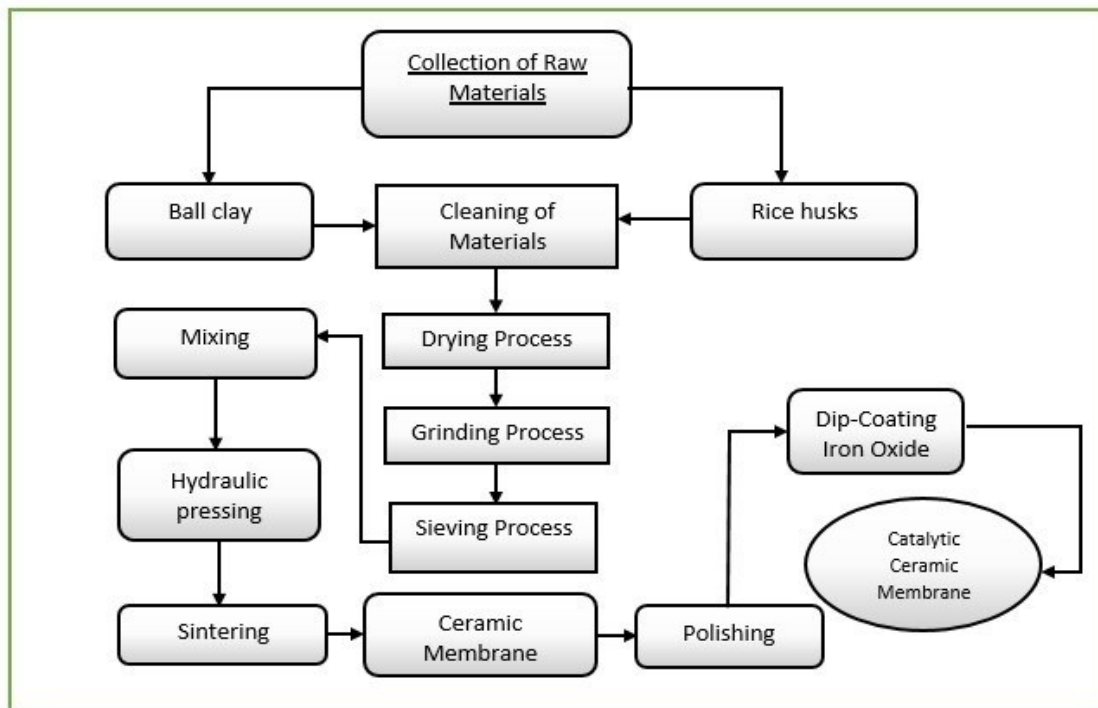


Figure 3.1: Schematic flow processes for the development of the membrane

3.2 Materials Collection and Preparation

3.2.1 Collection of the Raw Materials

The raw materials used to prepare and formulate the catalytic ceramic membrane were ball clay, rice husks, and iron oxide. The rice husks shown in Figure 3.2 (a), a biomass waste, was collected from a rice supplier outlet in Mukono Market. The clay shown in Figure 3.2 (b) was collected from Ntawo deposits found in Mukono district. Iron oxide which acted as catalysts in the ozonation filtration process was bought from Shp Sons Uganda Ltd, dealers in chemicals located in Kampala town. After the collection process, the raw materials were stored in plastic bags to avoid contamination before being used in the catalytic ceramic membrane formulation process.



Figure 3. 2: (a) The rice husks used and (b) ball clay sourced from Ntawo deposit.

3.2.2 Preparation of the Raw materials

Ball clay was processed by removing foreign components such as stones and grass manually using hands, Figure 3.3 (a) shows processed clay. During the processing stage, ball clay was sun-dried for 7 days before crashed using a hammer and sieving to obtain powder samples illustrated in Figure 3.3(d). The rice husks were sorted to remove any unwanted materials such as stone, soil, and paper and then dried for a period of 4 to 5 days under direct sunlight

as seen in Figure B2. The husks were milled with a YACHAN single phase motor type YCL-1000L-2 electric grinder as shown in Figure B4 and then sieved using a standard 0.05 mm opening sieve to form powder as shown in (Figure 3.3 (b)) and Figure B3. Iron oxide powder of, phytic acid and ethanol were purchased as shown in Figure 3.3 (c), a mixture of 300g of iron oxide and 100ml of phytic acid was employed in the coating of the membrane. Phytic acid helps stick the layers of iron oxide on the membrane. The ethanol was used to wash off the unbonded particles of the iron oxide on to the ceramic filters.



Figure 3. 3: (a) Preparation of ball clay, (b) sieving of rice husks powder to obtain fine powder, (c) colloidal solution of iron oxide, and (d) prepared fine powders of rice husks and clay.

3.2.3 Preparation of Influent and Effluent Water

Industrial waste water was collected from Namanve industrial park in a 20 liter jerrycan. On that day, the waste water underwent tests such as turbidity, pH levels, conductivity, total suspended solids and the concentration of specific heavy metals. Six fabricated point of use filtration systems were set up and water was poured into the PVC pipes as illustrated in figure 3.7. The same tests were also done for the collected six samples of effluent water

3.3 Characterization of the Raw Materials

3.3.1 Characterization of Ball Clay

X-ray Fluorescence (XRF) Epsilon 3 series machine was used for chemical analysis of the powdered ball clay samples as seen in Figure B5. The clay sample was pressed into fused circular discs to achieve uniform surface for analysis. A certified reference material of known concentrations of elements present in the clay sample was used to calibrate the XRF instrument. This ensures that the instrument accurately measures the intensities of X-rays emitted by the sample and correlates them with the elemental concentrations. The prepared sample is placed into the XRF instruments sample chamber and the analysis process is initiated whereby the instrument bombards the sample with X-rays, causing the atoms in the sample to emit characteristic fluorescent X-rays. The emitted X-rays are captured using a detector, the energy and intensity of these X-rays are indicative of the elements present in the sample and their concentrations. The spectrum obtained from the XRF instrument was analyzed and compared using the measured elemental concentrations with the calibration curves established during instrument calibration to ensure accuracy. The same procedure was

used for rice husks characterization. The results of the elemental analysis of the clay sample were then compiled and reported in chapter Four.

3.4 Fabrication of the Ceramic Membrane

In this work, two types of ceramic membranes were developed that is, the ones coated with iron oxide and the uncoated disks. The rational was to determine the effect of iron oxide coating on the removal efficiency of heavy metals in contaminated water.

3.4.1 Mixing of Raw Materials

Powder samples of ball clay and rice husks were mixed in predetermined varying proportions shown in Table 3.1. The idea was to compare and have the best performance of the point of use filtration system at different ratios. The raw materials were thoroughly mixed using an electric mixer, Model 8OLR for about 20 minutes to ensure a homogeneous mixture (Rakcho et al., 2023). Approximately 300 ml of water was added into 500 g mixture to get a uniform dump mixture which was then placed in the casted die and compressed using a Benison Tensile Testing Machine (BTTM). The fabricated ceramic disks were then batched as CM1U, CM-2U, and CM- 3U for the uncoated disks and CM-1C, CM-2C, and CM- 3C for the coated ones.

Table 3.1: Mixing ratios of clay and rice husks.

Membrane Code	Clay (%)	Rice husks (%)
CM-1	60	40
CM-2	70	30
CM-3	80	20

3.4.2 Molding of the Ceramic Disks

After mixing, 500 g of the mixture was measured using a digital beam balance and transferred to a cylindrical mold where a force of 125 kN was applied using a BTTM shown in Figure 3.5 (a). Ceramic disks measuring 2 mm thick and 20 mm in diameter were formulated as shown in Figure 3.5 (b). The thickness and diameter of the disks was measured using a vernier caliper. The disks were left to dry in air for 5 days to avoid cracking due to rapid moisture

escape.



Figure 3.4: (a) Pressing machine used for membrane pressing and (b) the green body of the prepared disks.

3.4.3 Firing of the Green Body

Firing of the green body was done from the ceramics department of Uganda Industrial Research Institute located in Nakawa. Firstly, the green body was dried under sunlight thoroughly before firing to remove any moisture and also prevent defects such as cracking during firing. The green body was placed in the ceramic furnace and fired at a rate of 3 °C/min to peak temperatures shown in Table 3.2. The samples were soaked at peak

temperatures for six hours. The atmosphere inside the furnace was controlled using Nitrogen to prevent oxidation or other chemical reactions that may affect the properties of the ceramic membrane. After sintering, the furnace and the ceramic membrane were allowed to cool gradually to room temperature to minimize thermal stresses and cracking.

Table 3.2: Firing temperatures of the ceramic membranes.

Ceramic Membrane Code	Firing Temperature (°C)
CM-1	900
CM-2	1000
CM-3	1100

3.5 Ceramic Membrane Coating Using Iron Oxide

After the development of the membranes, they were coated with a synthesized colloidal solution which was prepared using well well-defined method for which the reagents included; iron oxide, phytic acid and ethanol. 300g of iron oxide powder was mixed uniformly with 100 ml of phytic acid and the mixture was smeared to three ceramic membranes and left to dry for 24 hours. The coated ceramic membranes were polished with 3 litres of ethanol to remove any unwanted particles there after the polished ceramic membranes were heated to 200 °C to increase on the binding process. The objective of using ethanol was to allow condensation of molecules on the membrane's surface, while the phytic acid acts as a binder for the iron oxide particles. The solution was deposited on to the membrane through smearing and the coating thickness was 0.25 mm. After the coating process, the membranes were then washed with ethanol to detach any unbounded particles, dried under appropriate temperatures for a specified period of 24 hours. The coatings were

assumed to be relatively uniform to ensure optimum performance of the membrane and this will possibly enhance the filtration process.

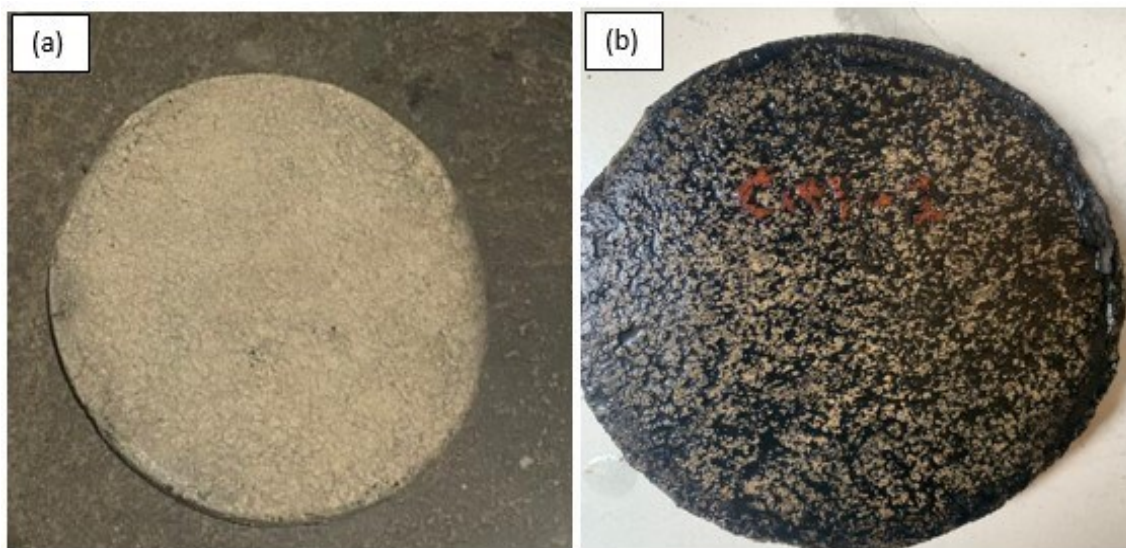


Figure 3. 5: (a) Uncoated ceramic membrane and (b) membrane coated with iron oxide.

3.6 Microstructural Analysis

A scanning electron microscope (SIGMA 300 VP) coupled with the Energy dispersive X-ray spectroscopy (EDX) was used. The sample was first coated with a thin layer of chromium to minimize charging as it is an insulating material. This is done to avoid charging effects during SEM imaging. A SEM was utilized to analyze the microstructure of the catalytic ceramic membranes for both uncoated and coated membranes. The ceramic membrane was ground using a ball mill to achieve an average particle size of less than 0.075 mm. The sample was pressed to obtain a suitable crystalline powder and the sample holder was set at an angle of 40° . The powder samples were firmly mounted on Al-stubs using C-tape as seen in Figure 3.6(a) and (b). The stubs were then fixed onto the ZEISS specimen holder whereby 6 stubs were loaded. The specimen holder was loaded into the SEM as illustrated in Figure

3.6 and the SEM operating conditions were adjusted to suitable conditions such as; voltage (300V-30kV), working distance of (4-30) mm, display of live sample, magnification, aperture alignment. The image was captured using magnifications of 0.1 mm. In this work, SEM was coupled with EDX in order to analyze the elemental composition of the fired ceramic discs.

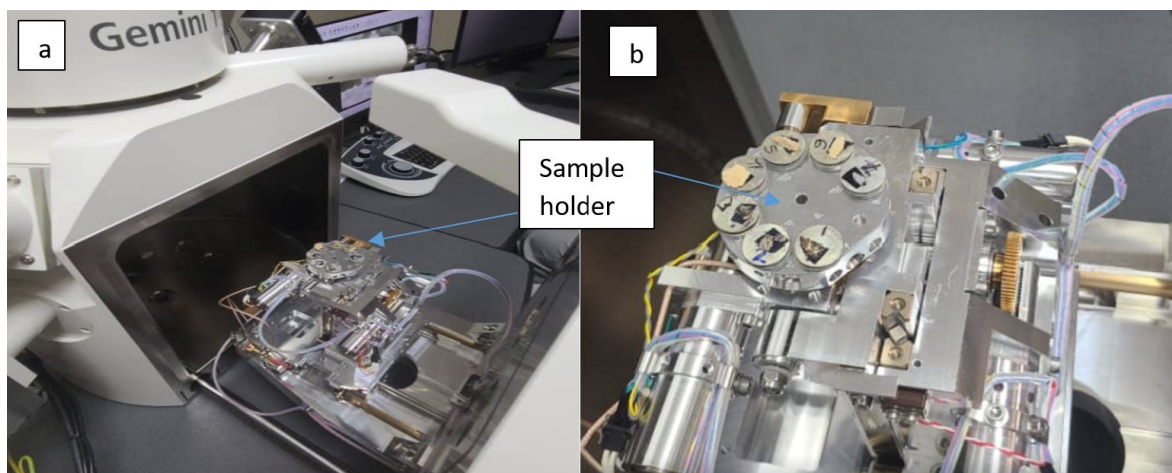


Figure 3. 6: (a) Scanning Electron Microscope with samples ready for analysis (SEM) and (b) sample holder.

3.7 Fabrication of Point of Use Filtration System

3.7.1 Filtration Setup Process

Water was collected from Namanve industrial park in a 20-liter jerrycan. On that day, the waste water underwent tests such as turbidity, pH levels, conductivity, total suspended solids and the concentration of specific heavy metals. A simple design of filtration setup shown in Figure 3.7 was used for the experimentation process. The setup consisted of PVC pipes in cylindrical form which can allow an open flow process (inlet and outlet openings) in which the crafted catalytic ceramic membrane was fitted into. The ceramic membrane was made to sit in between the two vertical pipes of the same diameter. For the membrane to be able to

sit in the pipe, the end of pipe was widened with a 20 mm metallic object. Leakages of waste water between the walls of the pipes and the ceramic membrane's circumference were prevented using PVC cement and silicon sealant to seal off any tiny spaces. Collected samples of contaminated water used was pressurized for it to be able to pass through a ceramic membrane and the influent water was collected as shown in Figure 3.8. Waste water was passed through all the six ceramic membranes and the six collected influent water samples underwent laboratory tests such as; turbidity, pH, conductivity, total suspended solids and the concentration rate of heavy metals.



Figure 3.7: Point of Use system setup.



Figure 3.8: Collection of influent water using the PoU filter.

3.7.2 Determining Water Turbidity

A portable turbidity meter was used to measure the turbidity of influent and effluent water. Two dry, clean beakers were used, one beaker had 20 mls of distilled water, which calibrates the turbidity meter to zero. The other beaker contained the sample which was determined by pouring a volume of 20 ml of the sample water into the beaker. The exterior surface of the beaker was wiped using a clean cloth to remove any dust particles or even finger prints before it is placed in the turbidity meter. Turbidity of the influent and effluent water samples were measured using the turbidity meter method as shown in Figure 3.9. The percentage turbidity reduction of waste water was then determined using equation (3.1) (Bulta et al.,2019).

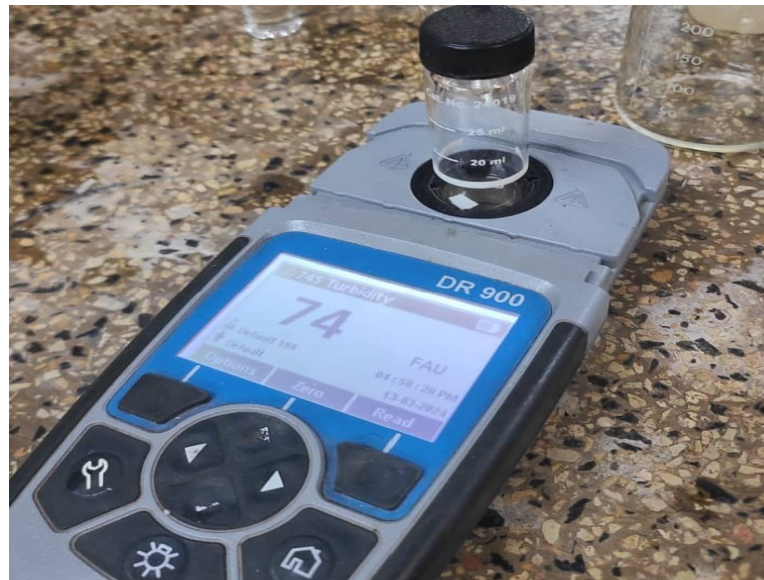


Figure 3.9: Determination of water turbidity.

$$\text{Turbidity reduction (\%)} = \frac{T_u - T_f}{T} \times 100\%, \dots\dots\dots \text{Equation 3. 1}$$

where: T_u is the Initial turbidity (in NTU), T_f is the Final turbidity (in NTU).

3.7.3 Conductivity and pH Tests

The conductivity and pH of the influent and effluent water was measured using a standard pH test meter. The conductivity levels and pH of the water samples were tested using the electrode method as shown in Figure 3.10. However, before the tests were conducted, the performance of the meter was first tested using a working standard whose conductivity values are already known and this is referred to as calibration. Using the electrode method, 200 ml of the sample water was poured into the beaker and an electrode was placed and rotated into the beaker, a reading was taken from the conductivity meter screen. All the samples underwent the same procedures and all results were recorded. pH was also measured using the electrode method and all the procedures were the same as for testing conductivity.



Figure 3.10: Conductivity and pH testing of the water samples.

3.8 Heavy Metal Removal Tests

The heavy metal removal test was conducted to detect the presence of heavy metals using the spectrometry method. Plasma mass spectrometry that is capable of detecting most metals and non-metals present in either waste or treated water at concentrations in milligrams per

litre (mg/L) was used. In this study, heavy metals were determined using an Atomic Absorption Spectrometer (AAS). Before the analysis, the samples were acidified to release the adsorbed metal ions into the water sample. Then, the working standards of 1 ppm, 2 ppm, and 5 ppm were prepared from a stock solution of 1000 ppm. During the analysis, standards were aspirated by the AAS and the absorbance of each of the standards were determined. A calibration curve was generated by plotting the absorbance against concentration. Similarly, the samples were also aspirated and the absorbance of each sample were determined by mapping the absorbance of the sample on the calibration curve of the standards, to establish the concentration of the sample. The percentage removal of the heavy metals was determined from equation (3.2) (Karnib et al., 2014).

$$\text{Percentage removal (\%)} = \frac{C_u - C_f}{C_u} \times 100\% \dots \dots \dots \text{Equation 3. 2}$$

where: C_u is the Initial concentration, and C_f is the Final concentration.

3.9 Data Analysis

The data obtained during the testing of the samples of raw materials was recorded and subjected to analyses. The data sets were then represented using suitable tables and graphs with the help of Origin Pro data analysis tool.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results obtained from the preparation of raw materials, development of ceramic membranes and the performance test of the PoU. The raw materials used in the development of the membranes were subjected to chemical and microstructural characterization. The influent and effluent water was subjected to laboratory tests including; turbidity, total suspended solids presence, pH, conductivity, and heavy metal concentration. The data obtained in form of micrographs and numeral values are all presented in this chapter.

4.2 Characterization of the Samples

4.2.1 Chemical Composition of Ball Clay

To assess and evaluate the suitability of ball clay used in the preparation of ceramic membranes, a chemical analysis of ball clay powder was conducted using an X-ray fluorescence (XRF) technique (Foorginezhad et al., 2022). Table 4.1 provides a breakdown of the chemical composition of the oxides present in their percentage weight. The data shows that the ball clay exhibited high contents of SiO₂ (silica) and Al₂O₃ (alumina) and low composition of the flux oxides (MnO and K₂O, and P₂O₅). However, there was a significant amount of CaO when fired CaO melts at about (1100 c) and the liquid phase formed reduces the size of the voids hence improving strength (Atidi et al., 2024); (Rakcho et al., 2023); (Jaber et al., 2022). Other oxides found present in the ball clay are Cr₂O₃, TiO₂, and Fe₂O₃. There is a significant amount of iron oxide (14.810 wt%) its presence in clay is reported to affect the color and contributes to the darkness of the fired pieces due to oxidation (Khalil et

al., 2024; Chihi et al., 2019). As seen in Table 4.1, SiO₂ is a primary component and its presence allows the gradual and gentle drying thus preventing crack formation during drying process (Messaoudi et al., 2021). Additionally, the presence of the alumina and silica has significant impact on the refractoriness and mechanical strength of the final product, as noted in previous research by (Rakcho et al., 2023; Serra et al., 2016).

Table 4.1: Chemical composition of ball clay

Oxides	Composition (wt%)
SiO ₂	55.888
Al ₂ O ₃	11.973
Cr ₂ O ₃	0.219
Fe ₂ O ₃	14.810
TiO ₂	1.774
CaO	14.643
K ₂ O	0.116
MnO	0.207
P ₂ O ₅	0.211
Total	99.841

4.2.2 Chemical Composition of Rice Husks Powder

The chemical composition of the rice husks powder used in the development of the ceramic membranes was subjected to XRF analysis. The results obtained are presented in Table 4.2, chemical composition tests revealed that the main constituent of the rice husks powder is SiO₂ with a percentage weight of about 92%. The high content of the SiO₂ will have a significant impact on the mechanical strength of the membranes as mentioned earlier (Serra et al., 2016). All flux oxides had low percentage including Fe₂O₃. But the presence of SO₃ could not be detected in the rice husks powder using the XRF analysis.

Table 4. 2: Chemical composition of the rice husks powder

Oxides	Composition (Wt%)
SiO₂	92.94
Fe₂O₃	2.73
CaO	2.15
Al₂O₃	1.42
K₂O	1.23
P₂O₅	0.32
MgO	0.27
Na₂O	0.11
SO₃	0.00
Total	101.17

4.2.3 Elemental Composition of the Developed Membranes

The elemental compositions of the fired membranes were studied using a scanning electron microscope (SEM) coupled with Energy Dispersive X-ray (EDX) analysis, the data can be seen in Table 4.3. This data which shows the percentage weight of each element was used to calculate the chemical composition of the samples and the results are shown in Table 4.4. The EDX analysis was applied to understand and define the chemical composition of the fired membranes, the details are presented in the subsequent paragraphs. Ceramic membrane one (CM-1) was represented with both coated and uncoated. The coated membrane had carbon as its main component followed by oxygen while the uncoated membrane one had oxygen as its main component followed by Iron. All membranes underwent the same process and elemental composition was recorded as seen.

Table 4. 3: Chemical composition of ceramic membranes

Element	CM-1		CM-2		CM-3	
	Coated	Uncoated	Coated	Uncoated	Coated	Uncoated
C	57.22	0.09	3.83	1.03	0.01	0.26
O	35.18	82.33	55.19	40.16	71.66	65.61
Na	0.41	0.53	0.01	4.09	2.54	1.88
Mg	2.12	0.38	0.22	1.68	1.24	1.52
Al	0.73	6.98	3.05	44.42	4.67	18.55
Si	1.60	3.65	4.37	2.75	4.93	6.55
K	0.39	0.00	0.46	1.59	0.49	0.59
Ca	2.01	0.00	14.33	2.98	2.38	0.25
Fe	0.33	6.05	0.00	1.30	5.06	4.79

Table 4. 4: Chemical composition of the ceramic membranes

Element	Uncoated Membranes		Coated Membranes			
	CM-1U	CM-2U	CM-3U	CM-1C	CM-2C	CM-3C
SiO₂	24.94	5.35	22.24	3.13	18.66	29.27
Al₂O₃	42.11	76.42	55.66	1.26	11.50	24.47
Na₂O	2.27	5.02	4.02	0.50	0.02	9.49
MgO	2.01	2.54	4.00	3.22	0.72	5.72
Fe₂O₃	27.62	1.69	10.88	0.43	0.00	20.06
CaO	0.00	3.80	0.56	2.57	40.01	9.24
K₂O	0.00	1.75	1.23	0.43	1.10	1.64
CO₂	1.05	3.43	1.51	88.46	28.00	0.11

4.2.4 Uncoated Ceramic Membranes

From at 1100°C Figure 4.1(a), the EDX spectrum shows that the principle element present in the fired membrane CM-1U is oxygen represented by the highest peak. Other elements included C, Na, Mg, Al, Si, and Fe with K and Ca not being detected. However, the calculated chemical composition for the uncoated membranes as seen in Table 4.4 indicates that Al₂O₃ is the principle oxide followed by SiO₂. Also, Na₂O and MgO exhibited significant values

compared to the rest of the flux oxides. This data is comparable to the chemical composition of the raw materials shown in Tables 4.1 and 4.2. Meaning that firing has no significant effect on the chemical composition of the raw materials used. The presence of the flux oxides favor liquid phase formation during the firing process thus promoting the closure of the open pores and spaces (Atidi et al., 2024). It is known that smaller pores capture contaminants than bigger ones (Cai et al., 2020). This increases performance of the membranes with regards to the removal of heavy metals. The EDX spectrum shown in Figure 4.1(b) shows that aluminum is the principle element present in the fired membrane

CM-2U represented by the highest peak. Other elements present included C, Na, Mg, O, Si, Fe, K, and Ca. Table 4.4 shows that the principle oxide present in the sample CM-2U is also Al_2O_3 followed by SiO_2 and among the flux oxides, Na_2O and CaO exhibited significant values. Figure 4.1(c) illustrates the EDX spectrum for sample CM-3U. The principle element is oxygen, the calculated oxide with the highest percentage by weight is Al_2O_3 and then followed by SiO_2 . Na_2O exhibited the highest percentage by weight among the fluxes. In all the fired membranes, Al_2O_3 and SiO_2 exhibited the highest percentages by weight. These oxides are relevant because of their high adsorption capacity in the removal of heavy metals from waste water and industrial effluents (Rakcho et al., 2023), (Karnib et al., 2014).

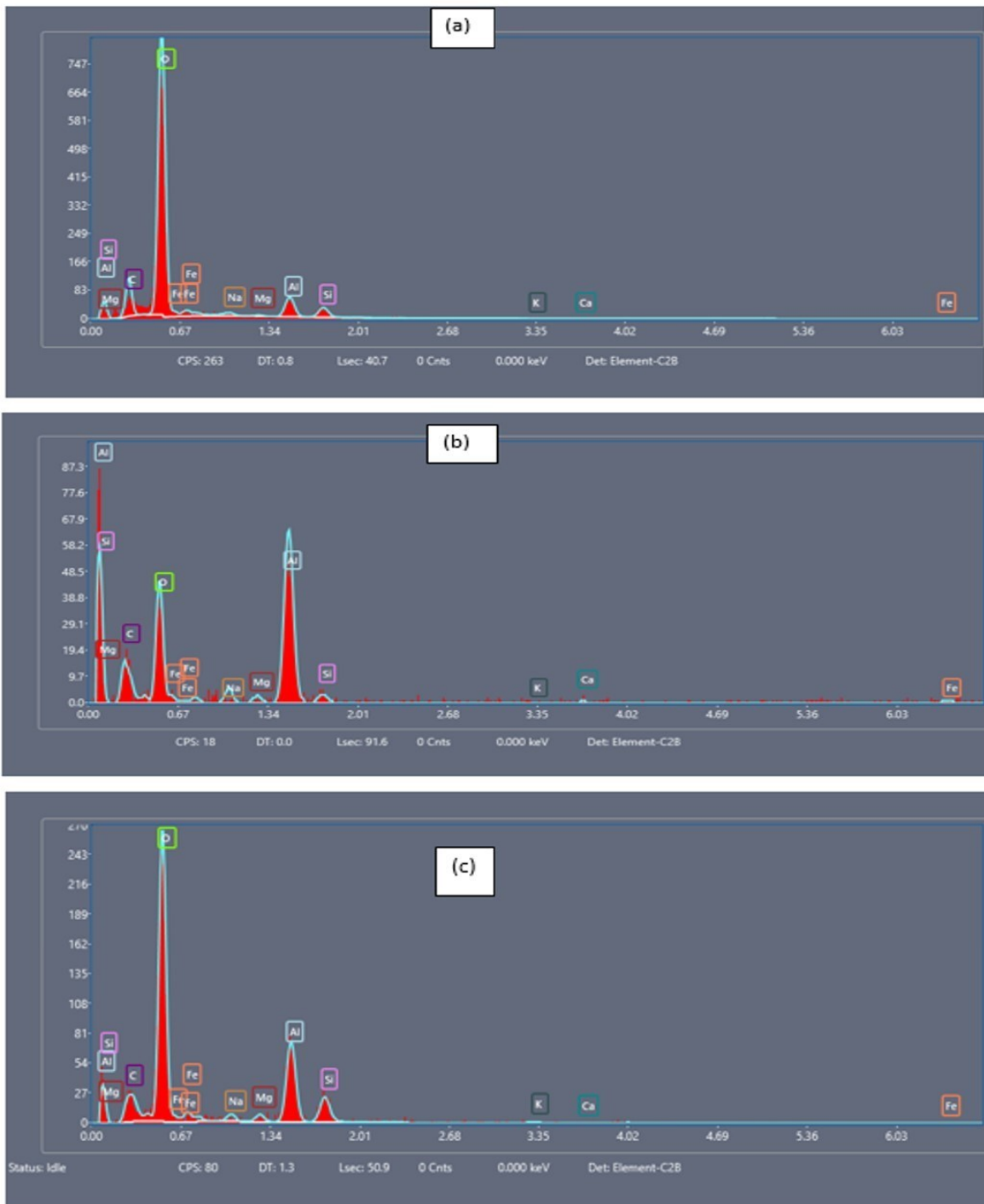


Figure 4.1: EDX spectrum for uncoated ceramic membrane (a) sample CM-1U with 60 wt% clay and 40 wt% rice husks sintered at 900 °C, (b) sample CM-2U with 70 wt% clay and 30 wt% rice husks sintered at 1000 °C, and (c) for sample CM-3U with 80 wt% clay and 20 wt% rice husks sintered at 1100 °C.

4.2.5 Coated Ceramic Membranes

Figure 4.2, shows the EDX spectrum for the fired coated ceramic membranes. Figure 4.2(a) shows that the principle element present in the fired membrane CM-1C is carbon represented by the highest peak. Other elements included O, Na, Mg, Al, Si, Fe, K, and Ca. However, the calculated chemical composition for the coated membranes as seen in Table 4.4 indicates that CO_2 is the principle oxide followed by MgO and SiO_2 . CaO also exhibited a significant value compared to the rest flux oxides. The presence of the flux oxides favor liquid phase formation during the firing process thus promoting the closure of the open pores and spaces (Atidi et al., 2024) ;(Ochen et al., 2021). This increases performance of the membranes with regards to the removal of heavy metals. The EDX spectrum shown in Figure 4.2(b) shows that oxygen is the principle element present in the fired coated membrane CM-2C represented by the highest peak. Other elements present included C, Na, Mg, Al, Si, Fe, K, and Ca. Table 4.4 shows that the principle oxide present in the sample CM-2C is also CO_2 followed by CaO and SiO_2 and among the flux oxides, CaO exhibited a significant value. A similar observation was reported by (Elgamouz et al., 2019). Figure 4.2(c) illustrates the EDX spectrum for sample CM-3C. However, the percentage weight of Fe_2O_3 was low in the coated ceramic membranes except for CM3-C which had a high percentage weight. The lesser the rice husks, the more the voids thus larger pores.

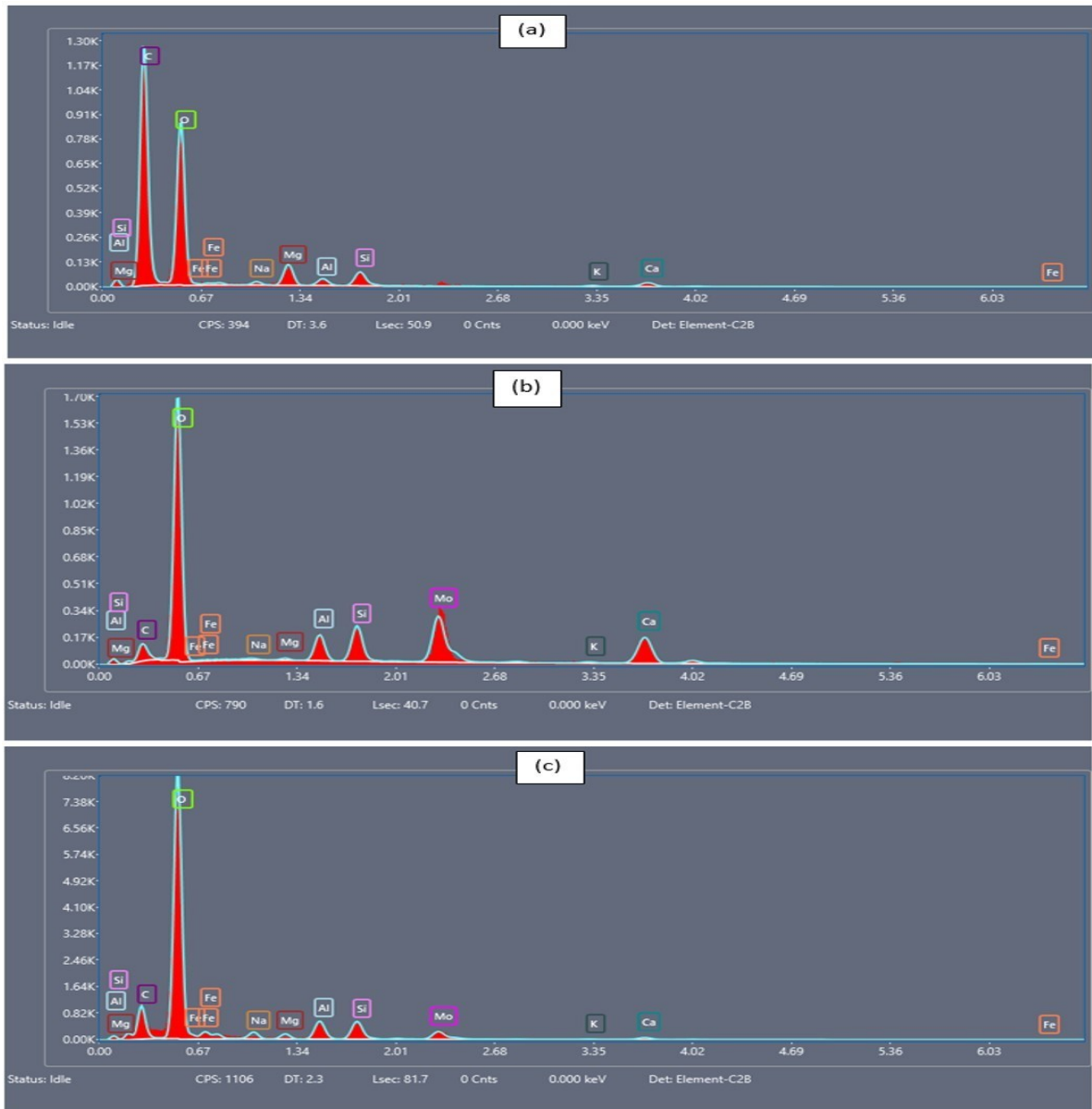


Figure 4.2: EDX spectrum for coated ceramic membrane (a) sample CM-1C with 60 wt% clay and 40 wt% rice husks sintered at 900 °C, (b) sample CM-2C with 70 wt% clay and 30 wt% rice husks sintered at 1000 °C, and (c) sample CM-3C with 80 wt% clay and 20 wt% rice husks sintered at 1100 °C.

4.3 Microstructural Analysis of the Ceramic Membranes

The surfaces of the sintered ceramic membranes developed in this study were studied using a scanning electron microscopy. The aim was to understand the particle distribution and pore structure of the fired membranes.

4.3.1 Uncoated Ceramic Membranes

The morphology of the uncoated ceramic membranes labelled as CM-1U, CM-2U, and CM3U containing different proportions of clay and rice husks powder was characterized using scanning electron microscopy. In Figure 4.3, the membrane surface consists of mullite and pores, the open pores can be seen as dark spots, and mullite crystals are seen as white patches as reported by (Atidi et al., 2024). According to Serra et al. (2016) mullite is a white ware consisting of aluminum silicate formed upon firing of aluminosilicate raw materials such as clay. Their presence is known to improve the mechanical strength according to the mullite hypothesis which states that the strength of ceramic membranes increases with an increase of the mullite population (Aydin et al., 2020).

Figures 4.3 (a) and (c) show higher distribution and dense regions of the mullite on the surface. Mullite is a stable crystalline phase in $\text{Al}_2\text{O}_3\text{-2SiO}_2$ resulting from the thermal treatment of clay minerals at temperatures exceeding $900\text{ }^\circ\text{C}$ as reported by (Rakcho et al., 2023) ;(Serra et al., 2016). Their presence helps to increase in the adsorption of heavy metals due to presence of silica content in the mullite (Karnib et al., 2014). Figure 4.3(a) shows that the membrane sample is non homogenous with noticeable disparities in the pore morphology. Large and interconnected pores are visible as this is attributed to a high amount of rice husks. Figures 4.3(b) shows the microstructure morphology of the sample membranes CM-2U and CM-3U respectively, which contain lower wt% of the rice husks powder. Furthermore, a decreased content of the rice husks powder results to a decrease in the number of open pores formed during sintering of the membranes. This is because the combustion of the rice husks powder leads to the release of carbon dioxide (CO_2) gas, which escapes

(Rakcho et al., 2023). In the process of escaping, the gas promotes the development of a more extensive and intricate porous network of micro pores. The size of the pores present in the ceramic membranes is expected to decrease with a decreased content of the rice husks powder in the membranes. This can be observed in Figure 4.3 (b) and (c). Additionally, the removal of the suspended solids and heavy metals from the water depends on the openness of the micro pores.

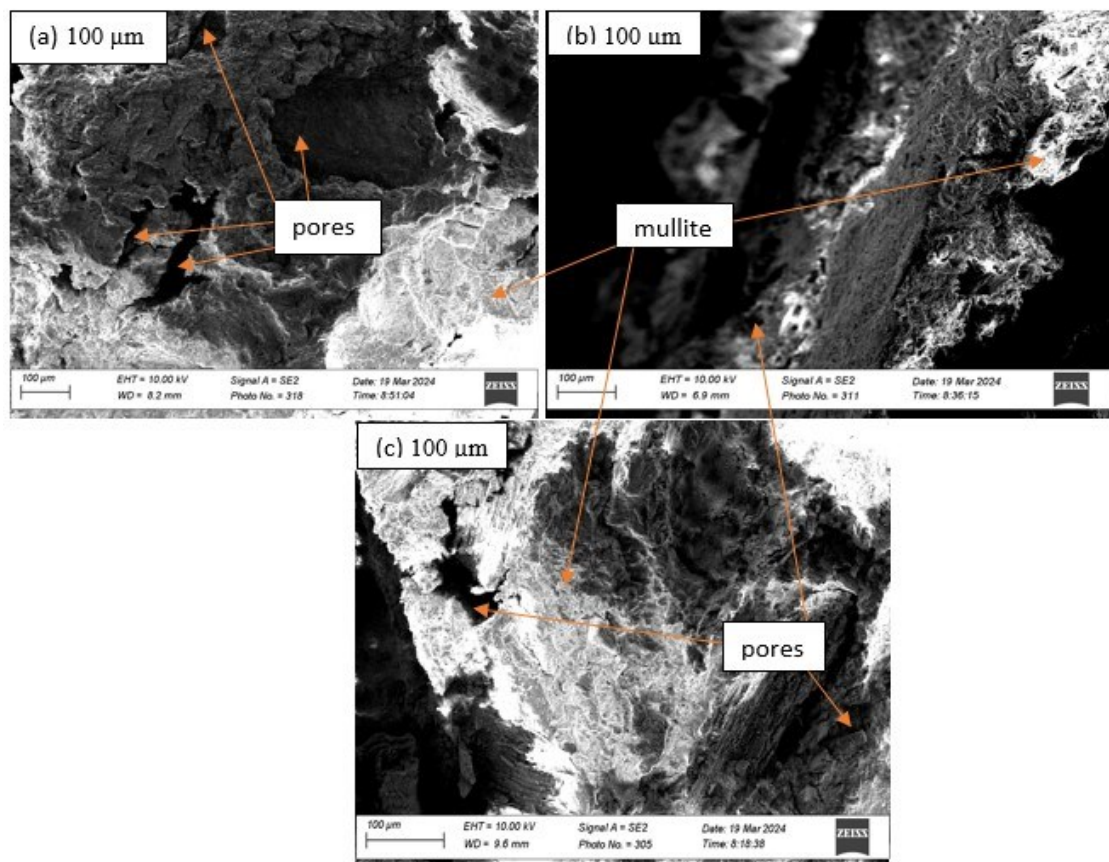


Figure 4. 3: SEM analysis of the sintered uncoated membrane (a) CM-1U with 60 wt% clay and 40 wt% rice husks sintered at 900 °C, (b) CM-U2 with 70 wt% clay and 30 wt% rice husks sintered at 1000 °C, and (c) CM-3U with 80 wt% clay and 20 wt% rice husks sintered at 1100 °C.

4.3.2 Coated Ceramic Membranes

Figure 4.4 shows the SEM analysis of the sintered-coated membrane. The microstructure of the coated ceramic membrane sample CM-1C is shown in Figure 4.4(a). It is observed that the membrane structure is characterized by irregularly distributed pores with a relatively complex shape. It also shows a rough texture probably due to coating of the membrane using iron oxide. For the coated membrane CM-2C, a relatively smooth texture with small pores can be observed from the membrane surface (Figure 4.4(b)). This represents fusion of the raw materials. This phenomenon happens when clay ceramics are treated under high temperature, which contributes to the fusion of the clay particles to produce a membrane with low porosity as reported by (Elgamouz et al., 2019). The decrease in the porosity of the membrane facilitates the effective removal heavy metals from waste water. In addition, the Figure shows the homogeneity in the membrane surface and the appearance of the distribution of pores observed as dark spots. Figure 4.4(c) shows the microstructure of the coated membrane sample CM-3C which has the least percentage of rice husks powder. Karnik et al. (2009) reported that the coating of layer yields smaller pores, which facilitates catalytic performance, thereby, enhancing the removal of heavy metals from the waste water. There exists a significant distinction between the morphology of the uncoated membranes and the coated membranes. More open pores can be observed in the microstructure of the uncoated ceramic membranes (Figure 4.3) compared to those observed in Figure 4.4 for the coated membranes. The decreased openness can be attributed to the colloidal solution of the iron oxide, which enhances the removal of heavy metals from waste water.

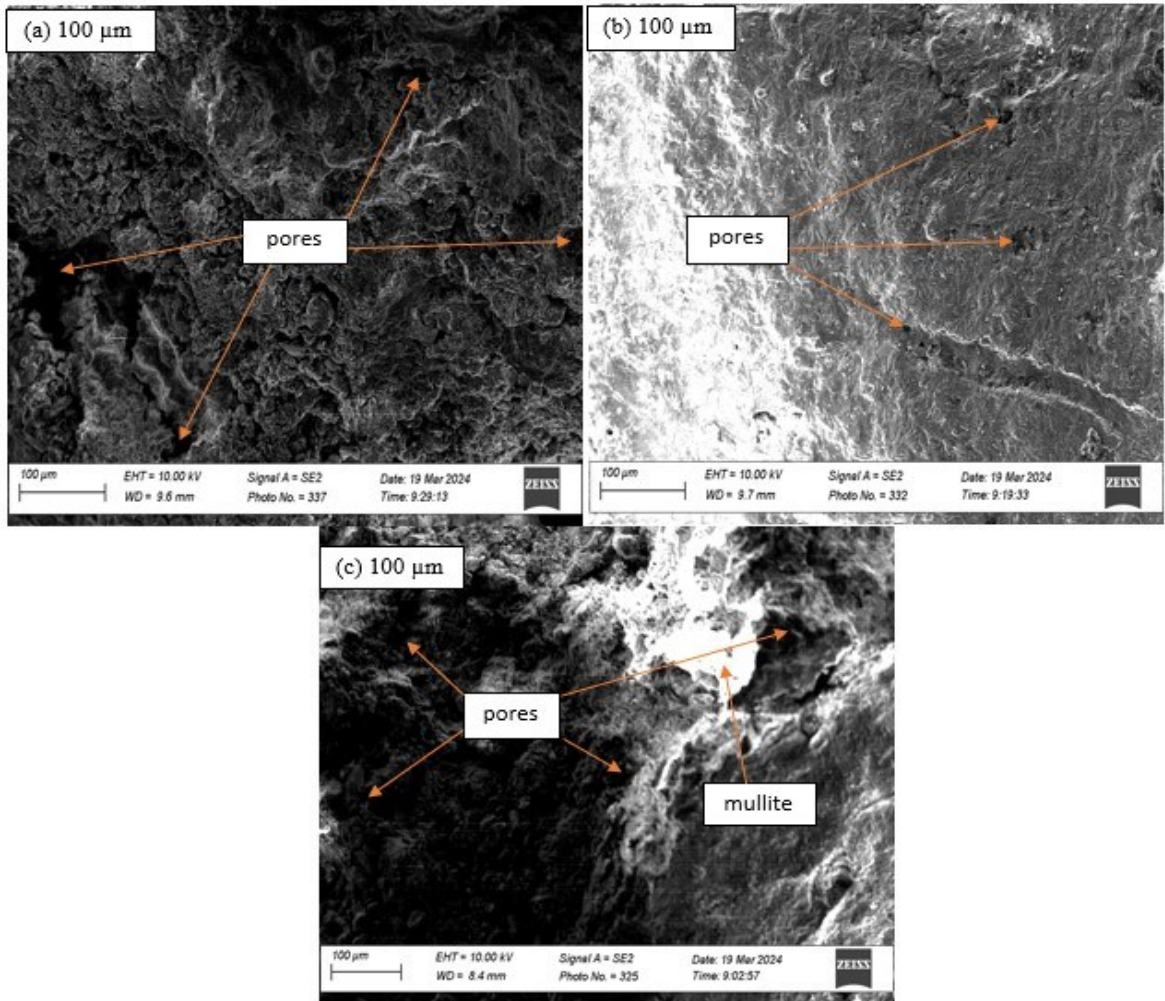


Figure 4.4: SEM analysis of the sintered coated membrane (a) CM-1C with 60 wt% clay and 40 wt% rice husks sintered at 900 °C, (b) CM-2C with 70 wt% clay and 30 wt% rice husks sintered at 1000 °C, and (c) CM-3C with 80 wt% clay and 20 wt% rice husks sintered at 1100 °C.

4.4 Properties of Influent and Effluent Water

Waste water was collected from Namanve Industrial Park as seen in Figure B1. To test the performance of the developed ceramic membranes, the effluent (unfiltered waste water) was subjected to laboratory tests before it was passed through the developed ceramic membranes. After the filtration process, the influent (filtered water) obtained was also subjected to

laboratory tests. Test conducted include; turbidity, pH, conductivity, alkalinity, total suspended solids (TSS) presence, and apparent color. The Figures do show that the turbidity of the water sample collected after filtration processes increased with a reduction in the rice husks powder content in the ceramic membranes. In agreement with the measured turbidity values, the Figures do show that the filtered water samples obtained from the uncoated water membranes were clearer than those collected from the coated membranes. The reason is given in the next subsection. Table 1 of Appendix A presents the results obtained after laboratory tests of the water samples.

4.4.1 Turbidity and Color

The turbidity and color of both the influent and effluent was analyzed, the turbidity was measured using a turbidity meter. The color of the effluent water was light brown as observed in Figure 4.5(a) and that of the influent water for the coated and uncoated membranes appeared clearer as seen in Figure 4.5(b) and (c). The results in Table 1 of Appendix A show that the measured apparent color of the waste water was 572 ptco. A significant decrease in the measured apparent color of the effluents through both the coated and uncoated membranes was observed. The lowest apparent color of 158 ptco was recorded for influent through the uncoated membrane CM-3U containing 20wt% of rice husks powder. Influent through membrane CM-2U containing 30wt% rice husks powder produced the highest apparent color of 380 ptco among the uncoated membranes. According to OMS (2024) the acceptance of apparent color is below 15 true color units of safe water.

The measured turbidity of the waste water was 74 NTUs (Table 1 of Appendix A) which reduced when the water was passed through the uncoated and the uncoated membranes. The

turbidity tests revealed that water filtered with uncoated ceramic membranes that is CM-1U, CM-2U, and CM-3U had turbidities of 20, 39, and 14 NTU respectively. The corresponding percentage reductions of turbidity of the membranes was 72.97%, 47.30%, and 81.08% respectively, the data can be seen in Table 4 of Appendix A. Membrane CM-3U with 20 wt% rice husk content exhibited the highest turbidity reduction, followed by membrane CM-1U with 40 wt%, and lastly membrane CM-2U with 30 wt% rice husk. However, membrane CM-2U unexpectedly produced a lower turbidity reduction than ceramic membrane CM-1U. These results confirm that an increase in the percentage composition of the rice husks powder reduces the turbidity reduction efficiency of the ceramic membranes (Bulta & Micheal, 2019). The turbidity tests further revealed that water filtered with coated ceramic membranes that is CM-1C, CM-2C, and CM-3C had turbidities of 54, 50, and 57 NTUs respectively. The corresponding percentage reductions of turbidity of the membranes was 27.03%, 32.43%, and 22.97% respectively, the data can be seen in Table 4 of Appendix A. Membrane CM-2C with 30 wt% rice husk content exhibited the highest turbidity reduction, followed by membrane CM-1C with 40 wt%, and lastly membrane CM-3U with 20 wt% rice husk. Figure 4.6 shows that the uncoated ceramic membrane CM-3U with 80 wt% clay and 20 wt% rice husks powder produced the highest turbidity reduction of 81.08%. Contrary, its counterpart CM-3C which was coated with a solution of iron oxide produced the lowest turbidity reduction rate computed to be 22.97%. This is attributed to the fact that the coated membranes were coated with a solution of the iron oxide. The iron content in the coating leached into the water during the filtration process. This was evidenced when the effluent

through the coated membranes was found to contain concentrations of 0.088, 0.033, and 0.103 mg/L of iron in the membranes CM-1C, CM-2C, and CM-3C respectively.

For the coated membranes, Figure 4.6 shows that CM-2C produced the highest turbidity reduction efficiency measured at 32.43% followed by membranes CM-1C at a reduction efficiency of 27.03%. Coated membrane CM-3C produced the lowest turbidity reduction efficiency of 22.97%. This is because of all the coated membranes, the effluent through CM-3C had the highest measured apparent color of 385 ptco implying a higher turbidity of the effluent and hence low turbidity reduction efficiency of the membrane. We can see that the turbidity removal efficiency of the uncoated ceramic membranes is high compared to the coated membranes.

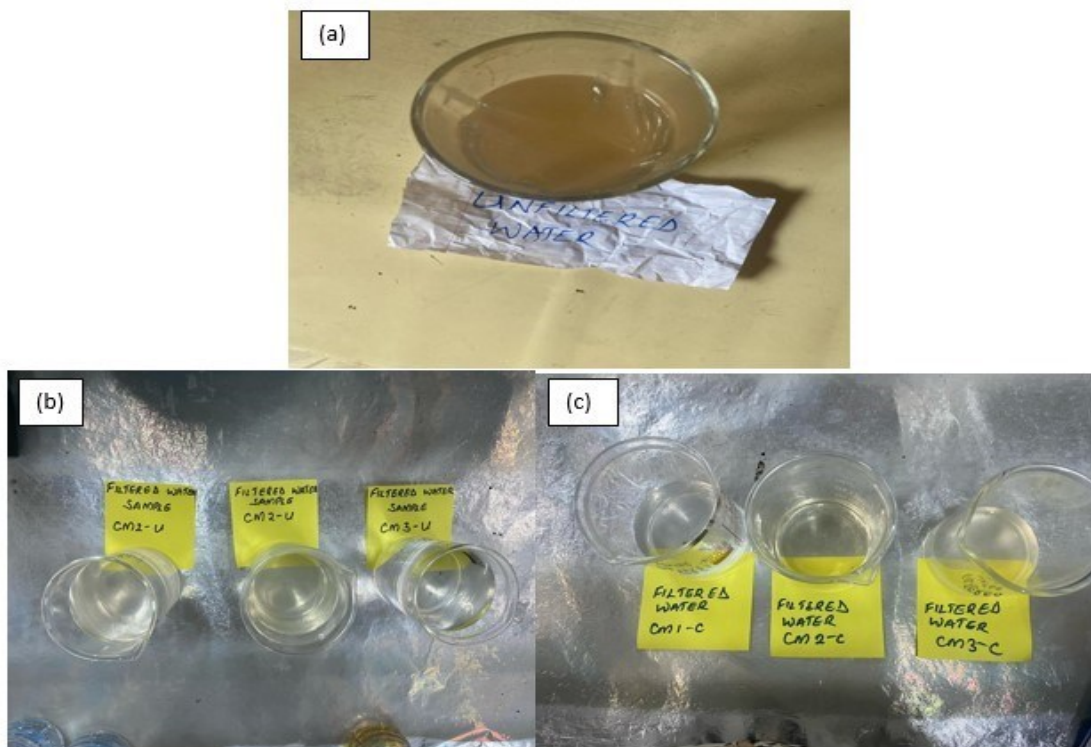


Figure 4.5: Samples of (a) Influent, (b) Effluent through Uncoated Membranes, and (c) Effluent through Coated Membranes.

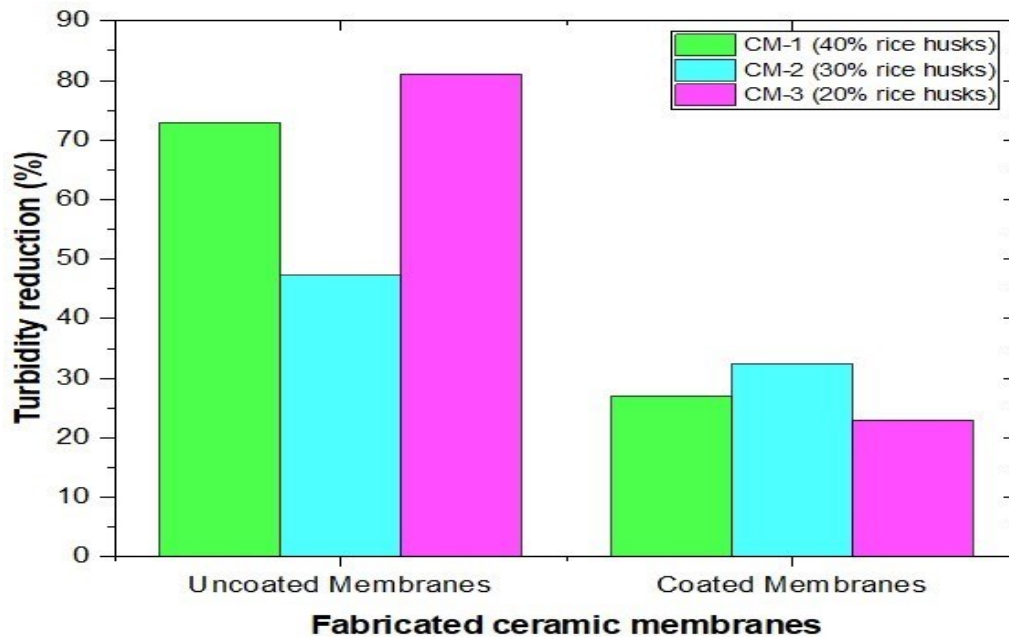


Figure 4. 6: Percentage turbidity reduction by the ceramic membranes

4.4.2 pH Levels of the Water

The pH of the effluent waste water was measured using a pH meter and its value was 6.86. After filtration, the pH of the water was within the acceptable range for safe drinking water according to World Health Organization (WHO). WHO recommends a pH value of 6.5-8.5 for safe drinking water (OMS, 2024). According to Dewangan et al. (2023) the pH range of filtered water between 6.65-7.34 signifies lower levels of contaminants. Figure 4.7 shows the pH levels for the coated and uncoated ceramic membranes, as it can be seen, there was a slight variation in the pH of the filtered water for the coated and uncoated membranes. The measured pH values ranged between 6.65 and 7.3, as illustrated in Table 1 of Appendix A. This range lies within the acceptable standards according to World Health Organization (WHO). Pure water has a pH of 7 and the World Health Organization (WHO) recommends pH levels for drinking water to fall between 6.5 and 8.5 (OMS, 2024). This is because drinking water with a pH value below 6.5 may have a bitter or metallic taste and a pH above

8.5 may have a soda taste and a slippery feel (OMS, 2024). This therefore implies that the filtered water in this study exhibited the pH range acceptance by WHO, and also has no diverse corrosive effects.

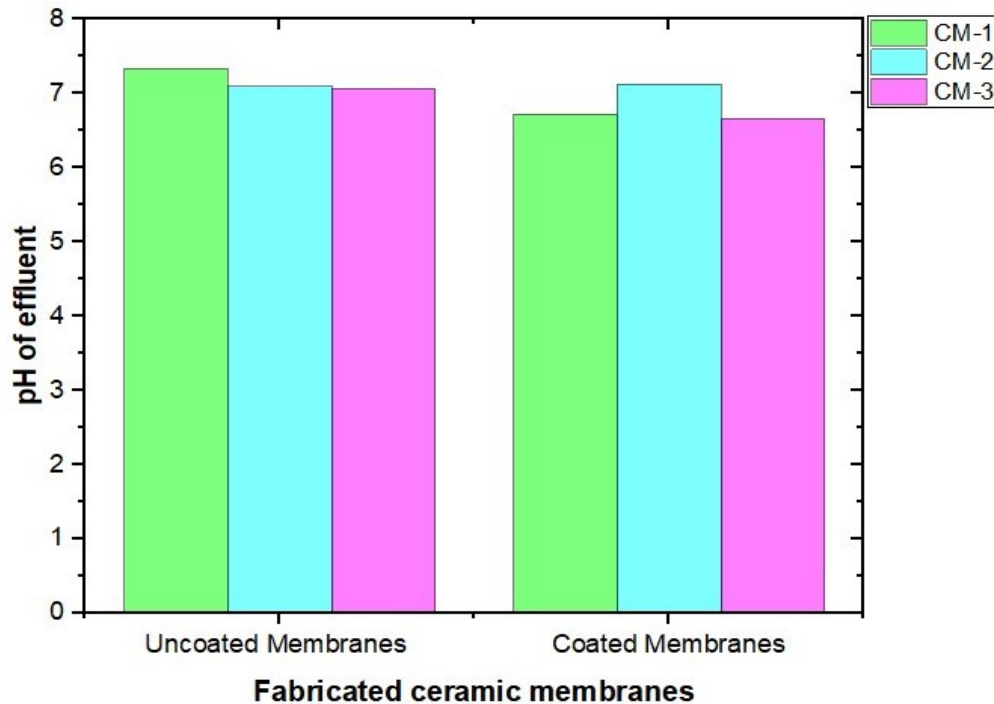


Figure 4.7: pH levels of the effluent through ceramic membranes.

4.4.3 Conductivity of the Water

To assess the water's ability to conduct electricity, a conductivity test of the water samples was carried out using a conductivity meter. To maintain the quality of safe drinking water, conductivity measurements are always done and these typically act as a measure for the total dissolved solids in water (Rusydi, 2018). Conductivity measurements showed that the conductivity of the unfiltered water sample was 204.5 $\mu\text{s}/\text{cm}$. Drinking water with conductivity levels less or equal to 800 $\mu\text{s}/\text{cm}$ is categorized in class A and thus considered to be very good and safe for drinking (Eric et al., 2017). Figure 4.8 shows the conductivity levels of the filtered water samples. As seen, there is a decrease in the conductivities of the

influent samples through from CM-1 to CM-3 for both uncoated and coated membranes. The highest conductivities recorded were for influents through membrane CM-1U and CM-1C with corresponding conductivities of 448 $\mu\text{s}/\text{cm}$ and 714 $\mu\text{s}/\text{cm}$. Likewise, membranes CM-3U and CM-3C had their influents with the lowest conductivities. All the conductivity values obtained for the tested water samples fall within the acceptable of range less than 800 $\mu\text{s}/\text{cm}$ for drinking water. According to Yang et al. (2021) higher conductivity values indicate high concentrations of impurities such as dissolved ionic solids like calcium and magnesium in water that carry electrical charges. High conductivity does not have a direct health impact, however, dissolved ionizable solids may cause frustrating water hardness or alkalinity and corrosion in plumbing system (Rusydi, 2018).

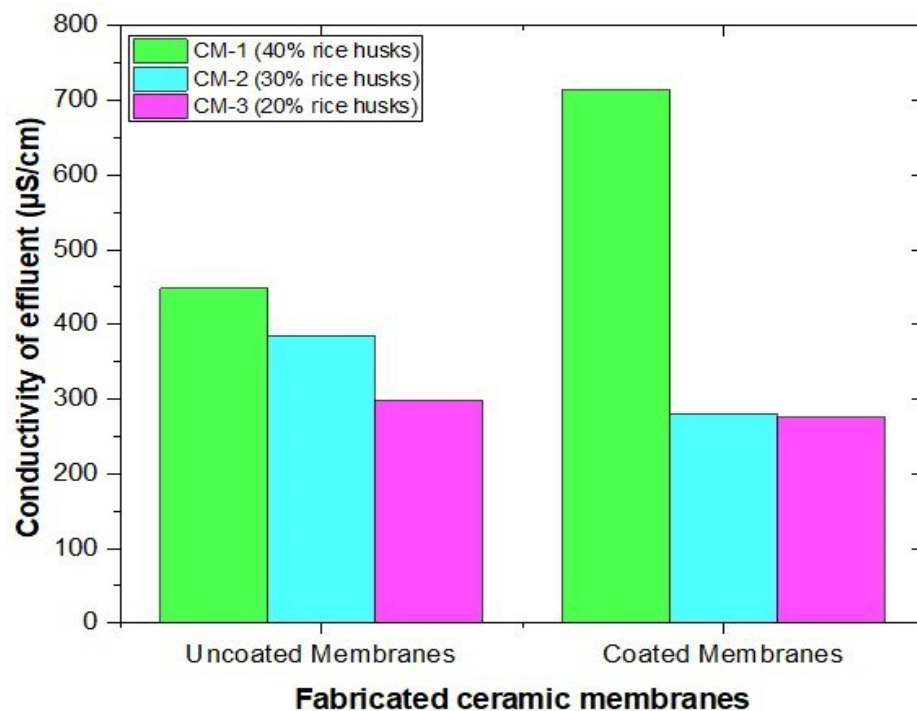


Figure 4.8: Conductivity levels of the water samples.

4.4.4 Reduction of Total Suspended Solids in Water

The performance of the developed ceramic membranes was further evaluated by conducting tests on the presence of the total suspended solids in the water samples using the photometric technique. According to Branigan (2013), total suspended solids (TSS) are solid particles in water that can be trapped by filters. As a water quality parameter, the TSS test was carried out to assess the quality of water, since a higher concentration of TSS decreases the water clarity (Branigan, 2013). The presence of the TSS in water was measured relative to TSS of the filtered water. The concentrations of the TSS in the unfiltered and filtered water samples were presented in Table 1 of Appendix A. Figure 4.9 shows the percentage removal efficiency of the membranes for the total suspended solids from waste water.

The measured TSS of the waste water was 71 mg/L which reduced when the water was passed through the uncoated and the coated membranes. The TSS tests revealed that water filtered with uncoated ceramic membranes that is CM-1U, CM-2U, and CM-3U had TSS concentrations of 23, 29, and 14 mg/L respectively. The corresponding percentage removal of TSS by the membranes were 67.61%, 59.15%, and 80.28% respectively, the data can be seen in Table 4 of Appendix A. Membrane CM-3U with 20 wt% rice husk content exhibited the highest removal efficiency, followed by membrane CM-1U with 40 wt%, and lastly membrane CM-2U with 30 wt% rice husk. However, membrane CM-2U unexpectedly produced a lower TSS removal efficiency than ceramic membrane CM-1U. TSS tests further revealed that water filtered with coated ceramic membranes that is CM-1C, CM-2C, and CM-3C had TSS concentrations of 39, 33, and 41 mg/L respectively. The corresponding percentage removal of TSS by the membranes were 45.07%, 53.52%, and 42.25%

respectively, the data can be seen in Table 4 of Appendix A. Membrane CM-2C with 30 wt% rice husk content exhibited the highest TSS removal efficiency, followed by membrane CM-1C with 40 wt%, and lastly membrane CM-3U with 20 wt% rice husk. This indicates that there is no linear correlation between the amount of rice husks and the TSS removal efficiency. Figure 4.9 shows that the uncoated ceramic membrane CM-3U with 80 wt% clay and 20 wt% rice husks powder produced the highest TSS percentage removal of 80.28%. Its counterpart CM-3C which was coated with a solution of iron oxide produced the lowest percentage removal of TSS, computed to be 42.25%. For the coated membranes, Figure 4.9 shows that all the discs had low values of TSS removal efficiency compared to the uncoated ones. The low value could probably be attributed to leaching of the iron oxide during filtration process. In conclusion, on comparing the membranes, the uncoated ceramic membranes produced the highest TSS removal efficiencies as seen in Figure 4.9.

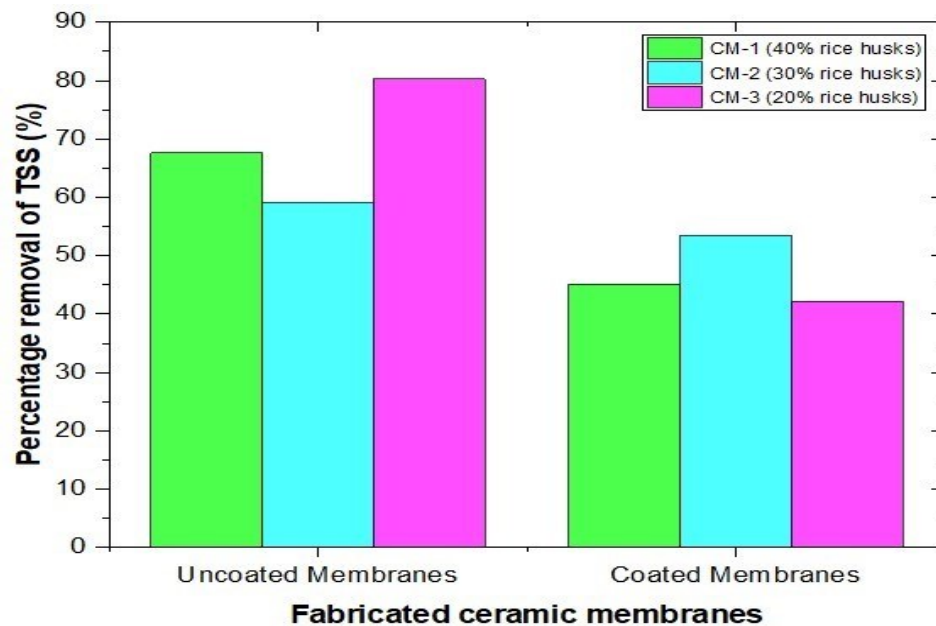


Figure 4.9: Percentage removal efficiency of TSS from water by the membranes.

4.4.5 Removal of Heavy Metals

The performance of the ceramic membranes developed in this study was further evaluated by measuring the concentration levels of the heavy metals present in both the influent and effluent water samples. Using the spectrometry approach, the concentration of the heavy metals in the water samples were determined using an Atomic Absorption Spectrometer (ASS) with model Agilent 240FS. The results obtained from the laboratory test are presented in Table 4 of Appendix A. At limits of detection (LOD) of 0.01 mg/L, heavy metal tests were carried out on collected samples of the waste water. Results showed that iron (Fe) and manganese (Mn) were the most dominant heavy metals present in the influent water with concentrations of 0.9780 mg/L and 0.7140 mg/L respectively. Other heavy metals detected included cadmium (Cd), zinc (Zn), lead (Pb), nickel (Ni) which had moderate concentrations (see Figure 4.10). However, the tests further revealed that copper (Cu) and chromium (Cr) were found below the limits of detection (LOD) for the instrument used. As mentioned earlier, the detection limit for all the test samples was at 0.01 mg/L.

The influent water obtained using uncoated membranes exhibited heavy metals such as Cd, Zn, Pb, and Mn. As can be seen in Figure 4.11, the concentration of Mn is high in the influent water obtained using uncoated membranes. CM2-U exhibited the highest amount of Mn and CM1-U had the least indicating that the percentage composition of rice husks had no effect on the removal efficacy of Mn. Also, the concentration of lead (Pb) in the influent water was significant. Amounts of Zn was present especially in CM1-U and CM2-U. However, in CM3-U filter its value was negligible. For coated membranes, with the exception of Fe, all other heavy metals were completely removed from effluent water as illustrated in Figure 4.12.

However, uncoated filters successfully removed Zn, Cd, Fe and Ni in the effluent water. Coating of the membrane changes the average pore size from micropores to nanopores within the surface layer of the material thus improving the removal ability of heavy metals by the membranes (Karnik et al., 2005). However, iron was present in the effluent water which was a surprise. The presence of iron was probably due to leaching of the membranes during the filtration process. It should be noted that the membranes were coated with iron oxide. Only small amounts of the iron were found present in the effluent as shown in Figure 4.12.

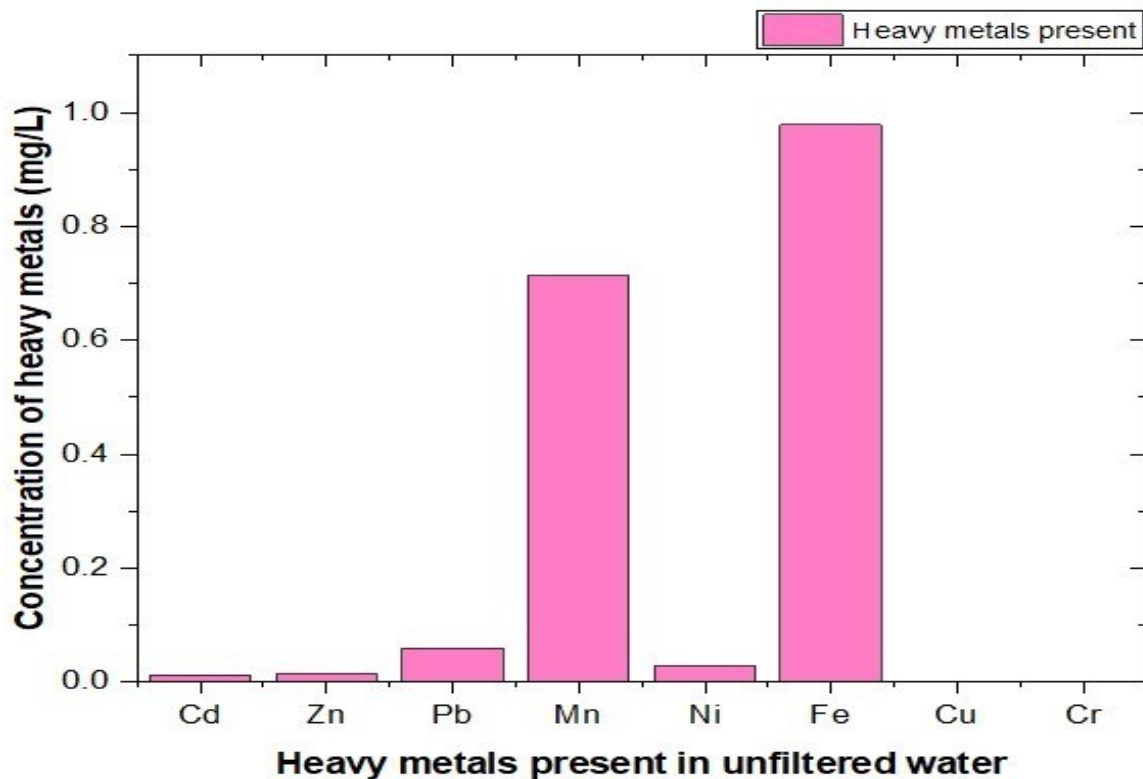


Figure 4.10: Concentration of detected heavy metals in unfiltered water.

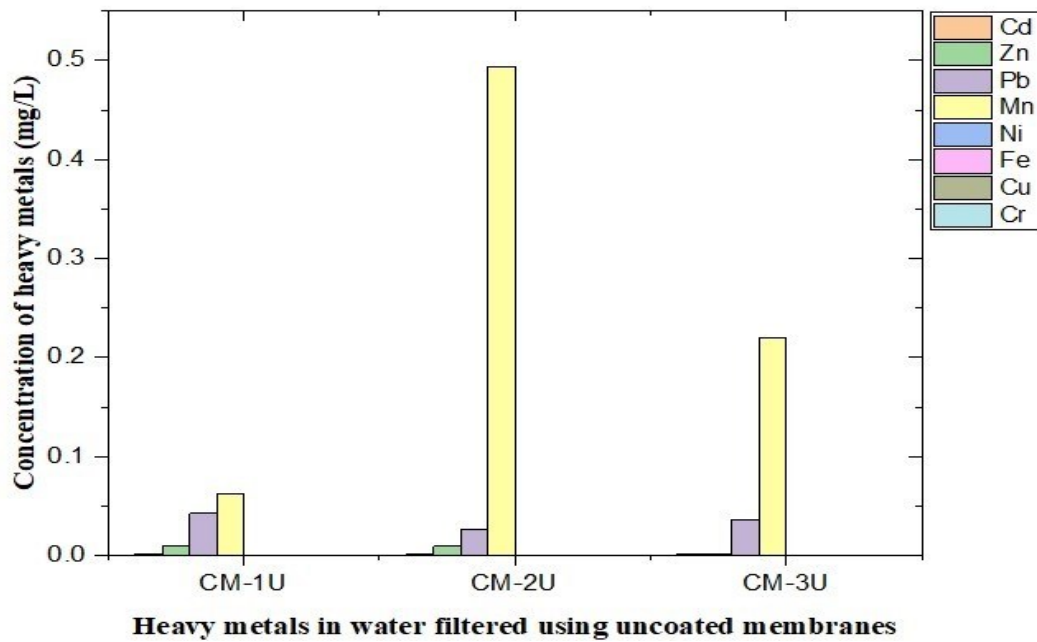


Figure 4.11: Concentration of heavy metals in water samples collected from the uncoated ceramic membranes.

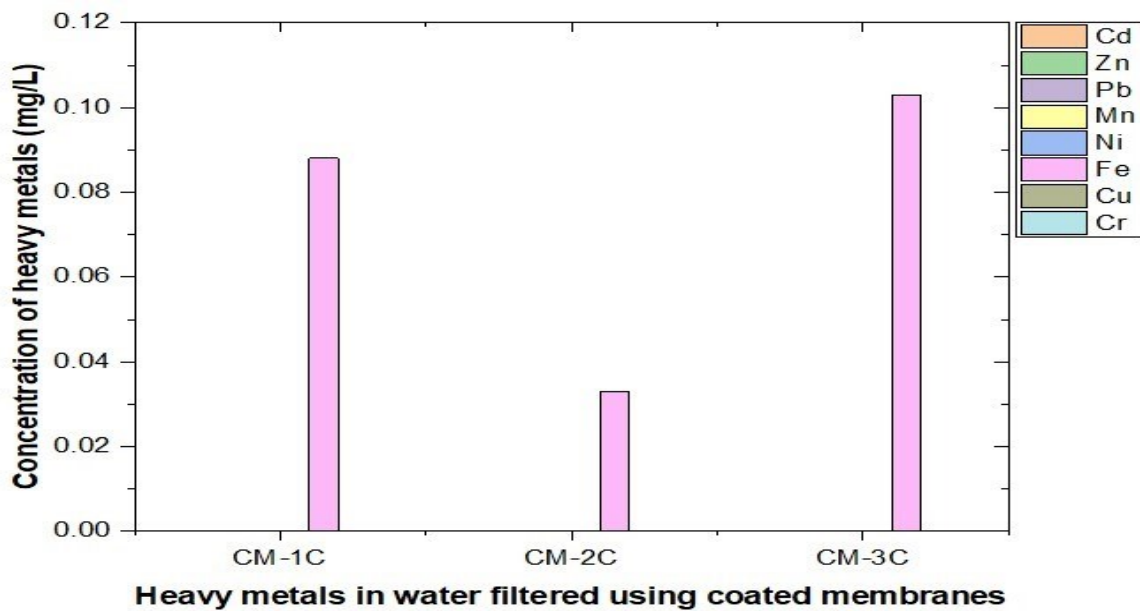


Figure 4.12: Concentration of heavy metals in water samples collected from the coated ceramic membranes.

To ascertain the performance of the developed ceramic membranes with regards to the removal of heavy metals, the percentage removal of the metals was computed relative to the concentration of the heavy metals presented in the effluent water samples. The performance of the membranes measured at percentage (%) levels for the efficient removal of the heavy metals is presented in Table 3 of Appendix A. The results show that amongst all the detected heavy metals, iron (Fe) was the least effectively removed heavy metal when compared to other metals and the reason is given earlier. Figure 4.13 shows that at an average removal efficiency of 98.73%, the coated ceramic membranes were far better than the uncoated membranes when it came to the removal of the heavy metals from the waste water. This is attributed to the reduction of pore size as a result of coating.

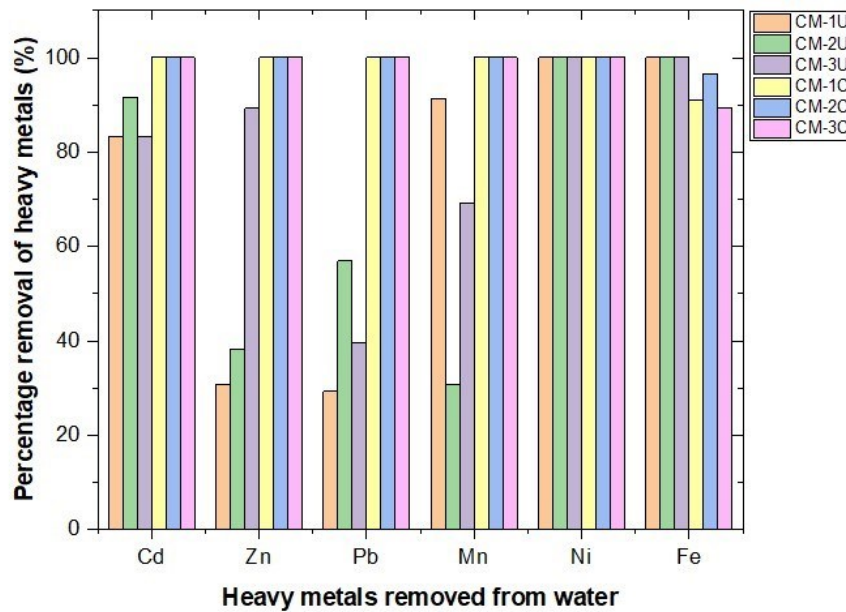


Figure 4.13: Percentage removal of heavy metals by the fabricated ceramic membranes.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In this study, ceramic membranes were developed from ball clay and rice husk powder, both powders underwent XRF process to determine the chemical composition. Six membranes were developed for which three were uncoated and the other three were coated with a solution of iron oxide. SEM analysis was done on the six membranes to determine the microstructure and elemental composition for each membrane. The chemical composition of the membranes was within the same range as the chemical compositions of the raw materials used. The SEM micrographs revealed that the membrane surface of the uncoated and coated fabricated ceramic membranes consisted of mullite and pores. The morphology of the pores was affected by coating using iron oxide as corroborated by SEM micrographs. The pore sizes reduced as a result of coating which resulted in an increase in the removal efficiency of heavy metals. Industrial wastewater was subjected to laboratory test to understand its parameters before the water was filtrated using the developed six ceramic membranes. The results obtained from the evaluation of the performance of the membranes based on parameters of the filtrated water relative to the unfiltered samples are summarized in conclusions stated below. For the water parameters, uncoated ceramic membranes produced the highest turbidity reduction when compared to the coated membranes. This was attributed to the leaching of iron oxide during filtration occurred on the coated ceramic membranes. Additionally, the membranes showed a positive reduction in the concentrations of the total suspended solids (TSS) in the effluent tested water samples. The uncoated ceramic membranes produced the highest removal efficiency when compared to the uncoated membranes. However, the test results revealed that when it came to the removal of heavy

metals from the water, the coated ceramic membranes were far better when compared to the uncoated ones. An overall evaluation on the heavy metal removal efficiency shows that the coated ceramic membranes produced 98.73% compared to the 74.11% of the uncoated ones. However, amongst all the heavy metals, iron was the least effectively removed metal from the tested effluent water samples especially from the coated ceramic membranes due to leaching of iron into the filtered water as it was from the coated ceramic membrane.

5.2 Recommendations

Basing on the above stated conclusions on the performance of the developed ceramic membranes, it is recommended that the developed ceramic membranes can be used for the treatment of industrial waste water though better performances would be obtained if the following recommendations are undertaken;

- (i) Optimizing the coating thickness and composition to enhance filtration performance without compromising membrane durability.
- (ii) Evaluate the cost implications and scalability of production for commercial use in wastewater treatment plants.
- (iii) More detailed structural analysis could provide deeper insights into the mechanisms behind the enhanced filtration.
- (iv) Since the coated membranes showed lower turbidity reduction due to leaching, a model to predict leaching behavior should be conducted to evaluate the durability of the coatings under various filtration conditions and this would help in understanding the lifespan and maintenance requirements of coated membranes.

REFERENCES

- Abdullayev, A., Bekheet, M. F., Hanaor, D. A. H., & Gurlo, A. (2019). Materials and applications for low-cost ceramic membranes. *Membranes*, 9(9), 105. doi: 10.3390/membranes9090105
- Alresheedi, M. T., & Basu, O. D. (2020). Interplay of water temperature and fouling during ceramic ultrafiltration for drinking water production. *Journal of Environmental Chemical Engineering*, 8(5), 104354. doi: 10.1016/j.jece.2020.104354
- Alsubei, D. M., Reid, B., Aljlil, S. A., Coppens, M.-O., & Campos, L. C. (2024, November). Fabrication and characterization of coated ceramic membranes from natural sources for water treatment applications. *Journal of Membrane Science*, 690, 122226. doi: 10.1016/j.memsci.2023.122226
- Amin, S. K., Abdallah, H. A. M., Roushdy, M. H., & El-Sherbiny, S. A. (2016). An overview of production and development of ceramic membranes. *International Journal of Applied Engineering Research*, 11(12), 7708–7721.
- Atabaki, M. (2014). Performance of activated carbon in water filters. January 2013.
- Atidi, J., Kasedde, H., Menya, E., & Olupot, P. W. (2024, November). Optimization of physical and mechanical properties of porcelain tiles from coffee parchment husk ash. *Journal of Engineering Research (Kuwait)*. doi: 10.1016/j.jer.2023.11.013
- Aydin, T., Bican, O., & Gu'mru'k, R. (2020). Investigation of wear resistance of the porcelain tile bodies by solid particle impingement using alumina particles.

Journal of the Australian Ceramic Society, 56(2), 525–531. Retrieved from <https://doi.org/10.1007/s41779-019-00362-2> doi: 10.1007/s41779-019-00362-2

Ben Ali, M., Hamdi, N., Rodriguez, M. A., Mahmoudi, K., & Srasra, E. (2018). Preparation and characterization of new ceramic membranes for ultrafiltration. *Ceramics International*, 44(2), 2328–2335. doi: 10.1016/j.ceramint.2017.10.199

Boulangier, N., Talyzin, A. V., Xiong, S., Hultberg, M., & Grimm, A. (2024, August). High surface area activated carbon prepared from wood-based spent mushroom substrate for supercapacitors and water treatment. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 680, 132684.

Branigan, J. (2013). Development of a field test for total suspended solids analysis. *Digital Commons @ University of Nebraska - Lincoln*, 1–2.

Brochot, C., Abdolghader, P., Haghigat, F., & Bahloul, A. (2020). Performance of mechanical filters used in general ventilation against nanoparticles. *Science and Technology for the Built Environment*, 4731, 1387–1396. doi: 10.1080/23744731.2020.1787085

Buckner, C. A., Lafrenie, R. M., D'enomm'ee, J. A., Caswell, J. M., Want, D. A., Gan, G. G., ... others (2016). We are intechopen , the world ' s leading publisher of open access books built by scientists , for scientists top 1 %. *Intech*, 11(tourism), 13. Retrieved from <https://www.intechopen.com/books/advanced-biometric-technologies/liveness-detection->

- Bulta, A. L., & Micheal, G. A. W. (2019). Evaluation of the efficiency of ceramic filters for water treatment in kambata tabaro zone, southern ethiopia. *Environmental Systems Research*, 8(1), 1–15. doi: 10.1186/s40068-018-0129-6
- Buonomenna, M. G., Mousavi, S. M., Hashemi, S. A., & Lai, C. W. (2022). Water cleaning adsorptive membranes for efficient removal of heavy metals and metalloids. *Water (Switzerland)*, 14(17). Retrieved from <https://doi.org/10.3390/w14172718>
doi: 10.3390/w14172718
- Cai, H., Chen, M., Chen, Q., Du, F., Liu, J., & Shi, H.(2020). Microplastic quantification affected by structure and pore size of filters., 257, 127198. Retrieved from <https://doi.org/10.1016/j.chemosphere.2020.127198>
- Chen, S., Yu, J., Wang, H., Yu, H., & Quan, X. (2015). A pilot-scale coupling catalytic ozonation-membrane filtration system for recirculating aquaculture wastewater treatment. *Desalination*, 363, 37–43. doi: 10.1016/j.desal.2014.09.006
- Chihi, Rim, Blidi, Ibtissem, Trabelsi-Ayadi, M., & Ayari, F. (2019). Elaboration and characterization of a low-cost porous ceramic support from natural tunisian bentonite clay. *Comptes Rendus Chimie*, 22(2–3), 188–197. doi: 10.1016/j.crci.2018.12.002
- Davies, S. H., Baumann, M. J., Byun, S., Corneal, L. M., Tarabara, V. V., & Masten, S. J. (2010). Fabrication of catalytic ceramic membranes for water filtration. *Water Science and Technology: Water Supply*, 10(1), 81–86. doi: 10.2166/ws.2010.789

- Deng, Y., & Zhao, R. (2015). Advanced oxidation processes (aops) in wastewater treatment. *Current Pollution Reports*, 1(3), 167–176. doi: 10.1007/s40726-015-0015-z
- Dewangan, S. K., Shrivastava, S. K., Tigga, V., & Lakra, M. (2023). Review paper on the role of ph in water quality implications for aquatic life, human health, and environmental sustainability. *International Advanced Research Journal in Science, Engineering and Technology (IARJSET)*, 10(6), 215–218. doi: 10.17148/IARJSET.2023.10633
- Elgamouz, A., Tijani, N., Shehadi, I., Hasan, K., & Al-Farooq Kawam, M. (2019). Characterization of the firing behaviour of an illite-kaolinite clay mineral and its potential use as membrane support. *Heliyon*, 5(8), e02281. doi: 10.1016/j.heliyon.2019.e02281
- Eric, W., Wa, E., Eric, U., Pb, N., & Eric, G. (2017). Water quality & standards water quality & standards. *Water*, 76–86.
- Estim, A., Saufie, S., & Mustafa, S. (2019). Water quality remediation using aquaponics subsystems as biological and mechanical filters in aquaculture. *Journal of Water Process Engineering*, 30, February. doi: 10.1016/j.jwpe.2018.02.001
- Foorginezhad, S., Zerafat, M. M., Mohammadi, Y., & Asadnia, M. (2022). Fabrication of tubular ceramic membranes as low-cost adsorbent using natural clay for heavy metals removal. *Cleaner Engineering and Technology*, 10, 100550.

- Fu, W., Tang, T., Chen, X., Yang, Y., Mi, B., Yang, K., ... Zhang, X. (2023). Nanoceramic membranes combined with ozonation for water treatment: Fundamentals and engineering applications. *Journal of Hazardous Materials Advances*, 10, March. doi: 10.1016/j.hazadv.2023.100279
- Goodman, B. A. (2020). Utilization of waste straw and husks from rice production: A review. *Journal of Bioresources and Bioproducts*, 5(3), 143–162. Retrieved from <https://doi.org/10.1016/j.jobab.2020.07.001>
- Herschy, R. W. (2012). Water quality for drinking: WHO guidelines. In *Encyclopedia of earth sciences series* (pp. 876–883). Retrieved from <https://doi.org/10.1007/978-1-4020-4410-6184>
- Hofs, B., Ogier, J., Vries, D., Beerendonk, E. F., & Cornelissen, E. R. (2011). Comparison of ceramic and polymeric membrane permeability and fouling using surface water. *Separation and Purification Technology*, 79(3), 365–374. doi: 10.1016/j.seppur.2011.03.025
- Hong, S., & Elimelech, M. (1997). Chemical and physical aspects of natural organic matter (nom) fouling of nanofiltration membranes. *Journal of Membrane Science*, 132(2), 159–181. doi: 10.1016/S0376-7388(97)00060-4
- Hossain., Mathur, L., & Roy, P. K. (2018). Rice husk/rice husk ash as an alternative source of silica in ceramics: A review. *Journal of Asian Ceramic Societies*, 6(4), 299–313. Retrieved from <https://doi.org/10.1080/21870764.2018.1539210>

- Hossain, S. S., & Roy, P. K. (2020). Sustainable ceramics derived from solid wastes: a review. *Journal of Asian Ceramic Societies*, 8(4), 984–1009. doi: 10.1080/21870764.2020.1815348
- Huang, Y., Guan, Z., Li, Q., Li, Q., & Xia, D. (2023). Preparation, performance and mechanism of metal oxide modified catalytic ceramic membranes for wastewater treatment. *RSC Advances*, 13(25), 17436–17448. doi: 10.1039/d3ra01291c
- Hubadillah, S. K., Othman, M. H. D., Harun, Z., Ismail, A. F., Rahman, M. A., & Jaafar, J. (2017). A novel green ceramic hollow fiber membrane (chfm) derived from rice husk ash as combined adsorbent-separator for efficient heavy metals removal. *Ceramics International*, 43(5), 4716–4720. doi: 10.1016/j.ceramint.2016.12.122
- Imbulana, S., Oguma, K., & Takizawa, S. (2020). Evaluation of groundwater quality and reverse osmosis water treatment plants in the endemic areas of chronic kidney disease of unknown etiology (ckdu) in sri lanka. *Science of the Total Environment*, 745, 140716. doi: 10.1016/j.scitotenv.2020.140716
- International Rice Research Institute. (2013, April-June). A second life for rice husk. *Rice Today*. Retrieved from <http://irri.org/rice-today/a-second-life-for-rice-husk>
- Ishikawa, C., Watari, T., Kawakami, S., Hatamoto, M., Murakami, Y., & Yamaguchi, T. (2023). Development of down-flow hanging sponge – slow sand filter system as

water purification system: Infection risk reduction in an east africa rural area. *Scientific African*, 19, e01500. doi: 10.1016/j.sciaf.2022.e01500

Jaber, L., Elgamouz, A., & Kawde, A. N. (2022). An insight to the filtration mechanism of pb(ii) at the surface of a clay ceramic membrane through its preconcentration at the surface of a graphite/clay composite working electrode. *Arabian Journal of Chemistry*, 15(12), 104303. doi: 10.1016/j.arabjc.2022.104303

Jarvis, Carra, Jafari, & and, J. (2022). Ceramic vs polymeric membrane implementation for potable water treatment. *Water Research*, 215, 118269. doi:10.1016/j.watres.2022.118269

Karnib, M., Kabbani, A., Holail, H., & Olama, Z. (2014). Heavy metals removal using activated carbon, silica and silica activated carbon composite. *Energy Procedia*, 50, 113–120. doi: 10.1016/j.egypro.2014.06.014

Karnik, B. S., Baumann, M. J., Corneal, L. M., Masten, S. J., & Davies, S. H. (2009).

Tem characterization of iron-oxide-coated ceramic membranes. *Journal of Materials Science*, 44(15), 4148–4154. doi: 10.1007/s10853-009-3608-3

Karnik, B. S., Davies, S. H., Baumann, M. J., & Masten, S. J. (2005). Fabrication of catalytic membranes for the treatment of drinking water using combined ozonation and ultrafiltration. *Environmental Science and Technology*, 39(19), 7656–7661. doi: 10.1021/es0503938

- Khalil, A. K. A., Elgamouz, A., Nazir, S., Atieh, M. A., Alawadhi, H., & Laoui, T. (2024). Preparation and characterization of clay based ceramic porous membranes and their use for the removal of lead ions from synthetic wastewater with an insight into the removal mechanism. *Heliyon*, 10(3), e24939.
- Kumar, R., Qureshi, M., Vishwakarma, D. K., Al-Ansari, N., Kuriqi, A., Elbeltagi, A., & Saraswat, A. (2022). A review on emerging water contaminants and the application of sustainable removal technologies. *Case Studies in Chemical and Environmental Engineering*, 6(May), 100219. doi: 10.1016/j.cscee.2022.100219
- Kyriakou, N., Boorsma, E., Aardema, G. J., Ritsema van Eck, G., Drobek, M., de Beer, S., ... Pizzoccaro-Zilamy, M. A. (2023). Hybrid ceramic nanofiltration membranes prepared by impregnation and solid-state grafting of organo-phosphonic acids. *Journal of Membrane Science*, 687(August), 122041. doi: 10.1016/j.memsci.2023.122041
- Mansas, C., Mendret, J., Brosillon, S., & Ayral, A. (2020). Coupling catalytic ozonation and membrane separation: A review. *Separation and Purification Technology*, 236, 116221. Retrieved from <https://doi.org/10.1016/j.seppur.2019.116221> doi: 10.1016/j.seppur.2019.116221
- Menya, E., Jjagwe, J., & Herbert Mpagi Kalibbala, P. W. O., Henning Storz. (2023). Progress in deployment of biomass-based activated carbon in point-of-use filters for removal of emerging contaminants from water: A review. *science Direct*, 192, 412–440. Retrieved from <https://doi.org/10.1016/j.scwa.2023.100000>

- Messaoudi, M., Tijani, N., Baya, S., Lahnafı, A., Ouallal, H., Moussout, H., & Messaoudi, L. (2021). Characterization of ceramic pieces shaped from clay intended for the development of filtration membranes. *South African Journal of Chemical Engineering*, 37(March), 1–11. doi: 10.1016/j.sajce.2021.03.004
- Mestre, S., Gozalbo, A., Lorente-Ayza, M. M., & Sa'nchez, E. (2019). Low-cost ceramic membranes: A research opportunity for industrial application. *Journal of the European Ceramic Society*, 39(12), 3392–3407. doi: 10.1016/j.jeurceramsoc.2019.03.054
- Muncan, J., Matovic, V., Nikolic, S., Askovic, J., & Tsenkova, R. (2020). Aquaphotomics approach for monitoring different steps of purification process in water treatment systems. *Talanta*, 206(August 2019), 120253. doi: 10.1016/j.talanta.2019.120253
- Neme, I., Gonfa, G., & Masi, C. (2022). Activated carbon from biomass precursors using phosphoric acid: A review. *Heliyon*, 8(12), e11940. doi:10.1016/j.heliyon.2022.e11940
- Nisha, R. R., Jegathambal, P., Parameswari, K., & Kirupa, K. (2017). Biocompatible water softening system using cationic protein from moringa oleifera extract. *Applied Water Science*, 7(6), 2933–2941. doi: 10.1007/s13201-017-0591-8
- Ochen, W., D'ujanga, F. M., & Oruru, B. (2021). Influence of residual stress on the mechanical behavior of ceramics with various quartz sizes. *Scientific African*, 11, e00648. doi: 10.1016/j.sciaf.2020.e00648

- Oladimeji, T. E., Odunoye, B. O., Elehinafe, F. B., Obanla, O. R., & Odunlami, O. A. (2021). Production of activated carbon from sawdust and its efficiency in the treatment of sewage water. *Heliyon*, 7(1), e05960. doi: 10.1016/j.heliyon.2021.e05960
- OMS. (2024). Guidelines for drinking-water quality.
- Padaki, M., Surya Murali, R., Abdullah, M. S., Misdan, N., Moslehyani, A., Kassim, M. A.,... Ismail, A. F. (2015). Membrane technology enhancement in oil-water separation a review. *Desalination*, 357, 197–207. doi: 10.1016/j.desal.2014.11.023
- Phuangpornpitak, N., & Katejanekarn, T. (2016). Suitability analysis for implementing a renewable energy powered water purification system. *Energy Procedia*, 89, 55–68. doi: 10.1016/j.egypro.2016.05.008
- Pode, R. (2016). Potential applications of rice husk ash waste from rice husk biomass power plant. *Renewable and Sustainable Energy Reviews*, 53, 1468–1485. doi: 10.1016/j.rser.2015.09.051
- Psaltou, S., Mitrakas, M., & Zouboulis, A. (2021). Catalytic membrane ozonation. *Encyclopedia*, 1(1), 131–143. doi: 10.3390/encyclopedia1010014
- Qasem, N. A. A., Mohammed, R. H., & Lawal, D. U. (2021). Removal of heavy metal ions from wastewater: A comprehensive and critical review. *Npj Clean Water*, 4(1), 1–15. Retrieved from <https://doi.org/10.1038/s41545-021-00127-0> doi: 10.1038/s41545-021-00127-0

- Rakcho, Y., Mouiya, M., Bouazizi, A., Abouliatim, Y., Sehaqui, H., Mansouri, S., ...
Abourriche, A. (2023). Treatment of seawater and wastewater using a novel low-cost ceramic membrane fabricated with red clay and tea waste. *Arabian Journal of Chemistry*, 16(11), 105277. doi: 10.1016/j.arabjc.2023.105277
- Rani, S., L. S., & Kumar, R. V. (2021). Insights on applications of low-cost ceramic membranes in wastewater treatment: A mini-review. *Case Studies in Chemical and Environmental Engineering*, 4, 100149. Retrieved from <https://doi.org/10.1016/j.cscee.2021.100149> doi:10.1016/j.cscee.2021.100149
- Rani, S. L. S., & Kumar, R. V. (2021). Insights on applications of low-cost ceramic membranes in wastewater treatment: A mini-review. *Case Studies in Chemical and Environmental Engineering*, 4, 100149. doi: 10.1016/j.cscee.2021.100149
- Ren, Y., Ma, Y., Min, G., Zhang, W., Lv, L., & Zhang, W. (2021). A mini review of multifunctional ultrafiltration membranes for wastewater decontamination: Additional functions of adsorption and catalytic oxidation. *Science of the Total Environment*, 762. doi: 10.1016/j.scitotenv.2020.143083
- Rosman, N., Salleh, W. N. W., Mohamed, M. A., Jaafar, J., Ismail, A. F., & Harun, Z. (2018). Hybrid membrane filtration-advanced oxidation processes for removal of pharmaceutical residue. *Journal of Colloid and Interface Science*, 532, 236–260. doi:10.1016/j.jcis.2018.07.118

- Rusydi, A. F. (2018). Correlation between conductivity and total dissolved solid in various type of water: A review. *IOP Conference Series: Earth and Environmental Science*, 118(1). doi: 10.1088/1755-1315/118/1/012019
- Saffaj, N., Persin, M., Younsi, S. A., Albizane, A., Cretin, M., & Larbot, A. (2006). Elaboration and characterization of microfiltration and ultrafiltration membranes deposited on raw support prepared from natural moroccan clay: Application to filtration of solution containing dyes and salts. *Applied Clay Science*, 31(1–2), 110–119. doi: 10.1016/j.clay.2005.07.002
- Samadi, A, Gao, Kong, Orooji, Y., & Zhao, S. (2022). Waste-derived low-cost ceramic membranes for water treatment: Opportunities, challenges and future directions. *Resources, Conservation and Recycling*, 185, 1–52. doi: 10.1016/j.resconrec.2022.106497
- Samaei, S. M., Gato-Trinidad, S., & Altaee, A. (2018). The application of pressure-driven ceramic membrane technology for the treatment of industrial wastewaters – a review. *Separation and Purification Technology*, 200, 198–220. doi: 10.1016/j.seppur.2018.02.041
- Samuel, Venkatesan, Chandrasekar, Balaji, R., & Selvarajan, E. (2022). Removal of environmental contaminants of emerging concern using metal–organic framework composite. *Environmental Technology and Innovation*, 25, 102216. doi: 10.1016/j.eti.2021.102216

- Serra, M. F., Conconi, M. S., Gauna, M. R., Sua´rez, G., Aglietti, E. F., & Rendtorff, N. M. (2016). Mullite (3Al₂O₃•2SiO₂) ceramics obtained by reaction sintering of rice husk ash and alumina, phase evolution, sintering and microstructure. *Journal of Asian. Ceramic Societies*, 4(1), 61–67. doi: 10.1016/j.jascer.2015.11.003
- Shimizu, Y. (1990). Ceramic membranes for bioprocesses. *Membrane*, 15(4). doi:10.5360/membrane.15.179
- Soffian, M. S., Abdul Halim, F. Z., Aziz, F., ARahman, M., Mohamed Amin, M. A., & Awang Chee, D. N. (2022). Carbon-based material derived from biomass waste for wastewater treatment. *Environmental Advances*, 9, 100259. doi:10.1016/j.envadv.2022.100259
- Sousi, M., Liu, G., Salinas-Rodriguez, S. G., Chen, L., Dusseldorp, J., Wessels, P., ... van der Meer, W. (2020). Multi-parametric assessment of biological stability of drinking water produced from groundwater: Reverse osmosis vs. reverse osmosis.
- Szczerbin´ska, N., & Ga lczyn´ska, M. (2015). Biological methods used to assess surface water quality. *Archives of Polish Fisheries*, 23(4), 185–196. Retrieved from <https://doi.org/10.1515/aopf-2015-0021> doi: 10.1515/aopf-2015-0021
- Tong, J., Zhang, L., Han, M., & Huang, K. (2015). Electrochemical separation of CO₂ from a simulated flue gas with high-temperature ceramic-carbonate membrane: New observations. *Journal of Membrane Science*, 477, 1–6. doi: 10.1016/j.memsci.2014.12.017

- Williams, F. N. (2020). *Fantasia practicum*. University of Michigan, Deep Blue Repository.
(<https://deepblue.lib.umich.edu/handle/...>)
- Yang., Xu, S., Chitwood, D. E., & Wang, Y. (2020). Ceramic water filter for point-of-use water treatment in developing countries: Principles, challenges and opportunities. *Frontiers of Environmental Science and Engineering*, 14(5), 1–10. doi: 10.1007/s11783020-1254-9
- Yang, X., Liang, S., Hu, J., & Xia, J. (2021). Application analysis of conductivity in drinking water quality analysis. *IOP Conference Series: Earth and Environmental Science*, 784(1). doi: 10.1088/1755-1315/784/1/012028
- Yu, W., Brown, M., & Graham, N. J. D. (2016). Prevention of pvdf ultrafiltration membrane fouling by coating mno₂ nanoparticles with ozonation. *Scientific Reports*, 6(June), 1–12. doi: 10.1038/srep30144
- Zhou, J., Zhang, X., Wang, Y., Larbot, A., & Hu, X. (2010). Elaboration and characterization of tubular macroporous ceramic support for membranes from kaolin and dolomite. *Journal of Porous Materials*, 17(1), 1–9. doi: 10.1007/s10934-008-9258-z

APPENDICES

Appendix A: Laboratory Data

Tables Showing the test results obtained for the chemical composition of the fabricated ceramic membranes, and the laboratory test properties of the influent and effluent water samples.

Table 1: Properties of the tested samples of water

Parameter	Unit	Before Filtration	After Filtration					
			CM1U	CM2U	CM3U	CM1C	CM2C	CM3C
Turbidity	-	74	20	39	14	54	50	57
pH	-	6.86	7.34	7.10	7.07	6.72	7.13	6.66
Conductivity	µs/cm	204.5	448	385	298	714	281	276
Apparent color	ptco	572	216	380	158	328	374	385
Total suspended solids	mg/L	71	23	29	14	39	33	41
Total alkalinity	mg/L	100	145	135	105	210	190	216

Table 2: Concentrations of heavy metals at the detection limit 0.01 mg/L

Element	Before Filtration (mg/L)	After Filtration (mg/L)					
		CM1U	CM2U	CM3U	CM1C	CM2C	CM3C
Cd	0.0120	0.0020	0.0010	0.0020	nd	nd	nd
Zn	0.0149	0.0103	0.0092	0.0016	nd	nd	nd
Pb	0.0600	0.0424	0.0258	0.0362	nd	nd	nd
Mn	0.7140	0.0620	0.4940	0.2200	nd	nd	nd
Ni	0.0290	nd	nd	nd	nd	nd	nd
Fe	0.9780	nd	nd	nd	0.088	0.033	0.103
Cu	nd	nd	nd	nd	nd	nd	nd
Cr	nd	nd	nd	nd	nd	nd	nd

Table 3: Percentage removal of heavy metals from water by ceramic membranes

Element	CM-1U	CM-2U	CM-3U	CM-1C	CM-2C	CM-3C
Cd	83.33	91.67	83.33	100.00	100.00	100.00
Zn	30.87	38.26	89.26	100.00	100.00	100.00
Pb	29.33	57.00	39.67	100.00	100.00	100.00
Mn	91.32	30.81	69.19	100.00	100.00	100.00
Ni	100.00	100.00	100.00	100.00	100.00	100.00
Fe	100.00	100.00	100.00	91.00	96.63	89.47
Average	72.48%	69.62%	80.24%	98.50%	99.44%	98.24%
Overall Average	74.11%		98.73%			

Table 4: Percentage change in parameters after filtration

Parameter	Percentage Change (%)					
	CM1U	CM2U	CM3U	CM1C	CM2C	CM3C
Turbidity	72.97	47.30	81.08	27.03	32.43	22.97
Apparent color	62.24	33.57	72.38	42.66	34.62	32.69
Total suspended solids	67.61	59.15	80.28	45.07	53.52	42.25

Appendix B: Experiment Process and Setup



Figure 1: B1



Figure 2: B2



Figure 3: B3



Figure 4: B4



Figure 5: B5

Appendix D: Introductory Letters



P. O. BOX 1, KYAMBOGO – KAMPALA, UGANDA
TEL: 041-287341, FAX: 041-220464
www.Kyambogo.ac.ug

Department of Mechanical and Production Engineering

12th February 2024

The In-charge,
Geology Department,
Makerere University.

RE: INTRODUCTION OF MISS VICTORIA NABWIRE

Dear Sir/Madam,

This is to introduce to you the above named student with Registration number **22/U/GMEM/474/PE** pursuing a Master of Science Degree in Advanced Manufacturing Systems Engineering, Department of Mechanical and Production Engineering, Kyambogo University.

She is carrying out research on "**Development of a Point of Use Water Filtration System Using a Catalytic Ceramic Membrane Coated with Iron Oxide**", in partial fulfillment of the requirements for the award of a Master of Science Degree in Advanced Manufacturing Systems Engineering.

The purpose of this letter therefore is to request you to help her carry out laboratory tests concerning the research samples in your institution and get the findings related to the research area.

Any assistance rendered to her will be highly appreciated. Thank you

Yours sincerely,

Maureen Nalubowa Ssempijja (PhD)

Head of Department Mechanical and Production Engineering

Email: maurenssempijja@kyu.ac.ug Tel: 0752810261





KYAMBOGO UNIVERSITY

P. O. BOX 1, KYAMBOGO – KAMPALA, UGANDA
TEL: 041-287341, FAX: 041-220464
www.Kyambogo.ac.ug

Department of Mechanical and Production Engineering

12th February 2024

The In-charge,
Chemistry Laboratory,
Hima Cement, Kampala Uganda

RE: INTRODUCTION OF MISS VICTORIA NABWIRE

Dear Sir/Madam,

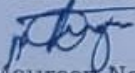
This is to introduce to you the above named student with Registration number **22/U/GMEM/474/PE** pursuing a Master of Science Degree in Advanced Manufacturing Systems Engineering, Department of Mechanical and Production Engineering, Kyambogo University.

She is carrying out research on "**Development of a Point of Use Water Filtration System Using a Catalytic Ceramic Membrane Coated with Iron Oxide**", in partial fulfillment of the requirements for the award of a Master of Science Degree in Advanced Manufacturing Systems Engineering.

The purpose of this letter therefore is to request you to help her carry out laboratory tests concerning the research samples in your institution and get the findings related to the research area.

Any assistance rendered to her will be highly appreciated. Thank you

Yours sincerely,



Maureen Nalubowa Ssempijja (PhD)

Head of Department Mechanical and Production Engineering

Email: maurenssempijja@kyu.ac.ug Tel: 0752810261





KYAMBOGO UNIVERSITY

P. O. BOX 1, KYAMBOGO – KAMPALA, UGANDA
TEL: 041-287341, FAX: 041-220464
www.Kyambogo.ac.ug

Department of Mechanical and Production Engineering

12th February 2024

The In-charge,
Ceramics Department,
Uganda Industrial Research Institute (UIRI).

RE: INTRODUCTION OF MISS VICTORIA NABWIRE

Dear Sir/Madam,

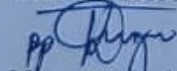
This is to introduce to you the above named student with Registration number **22/U/GMEM/474/PE** pursuing a Master of Science Degree in Advanced Manufacturing Systems Engineering, Department of Mechanical and Production Engineering, Kyambogo University.

She is carrying out research on "**Development of a Point of Use Water Filtration System Using a Catalytic Ceramic Membrane Coated with Iron Oxide**", in partial fulfillment of the requirements for the award of a Master of Science Degree in Advanced Manufacturing Systems Engineering.

The purpose of this letter therefore is to request you to help her carry out laboratory tests concerning the research samples in your institution and get the findings related to the research area.

Any assistance rendered to her will be highly appreciated. Thank you

Yours sincerely,



Maureen Walubowa Ssempijja (PhD)

Head of Department Mechanical and Production Engineering

Email: maurenssempijja@kyu.ac.ug Tel: 0752810261





RICE HUSKS SAMPLE TEST REPORT

Address: Plot 6, Block 95, Bunyangabu, Kasagama Road (Kasese-FortPortal Road)

Lab Name: Hima Cement Laboratory

Field No: Feb 2024

Sample description: Rice husks Samples

Weight of samples:

Issue date: 6th March 2024

Sample receipt date: 21st Feb 2024

Date of testing: 27th Feb 2024

Report ID:

Test methods: US EAS 148-2:2017

Customer Name: NABWIRE VICTORIA

Test Results

Customer Address:

Date	Sample ID	Sample Name	LOI ₂	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	Na ₂ O	P ₂ O ₅	GHV	MOIS	ASH
			%	%	%	%	%	%	%	%	%	%	Mj/Kg	%	%
27.02.2024	HIM24006711	RICE HUSKS	0.06	92.94	1.42	2.73	2.15	0.27	0.00	1.23	0.11	0.32	15.36	8.2	28.68

Remarks

The testing was carried out as per the request and from Hima Cement Laboratory at the address above using the test method indicated above and the results are only valid for these particular sample as received. (HIM24004683)

Analysed by:

Reviewed

Authorized by:

PAMPAS OBWANGOLE

Pampas Obwangole

Mariko Beegira

Emmanuel Lutebuuka

Lab Technician

Quality Control Engineer

Quality Control & Assurance Manager

This test report is only valid if it bears an authorized signature and has been issued without any alterations and therefore may not be reproduced other than with written approval from the Quality Control and Assurance Manager, Hima Cement Limited Kasese.

Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

In any Correspondence on
this subject please
quote No.....

GE 219/2024

09th May 2024

Ms. VICTORIA NABWIRE
KYAMBOGO UNIVERSITY
P.O BOX 1, KYAMBOGO
KAMAPALA-UGANDA
Tel: 256-778-198383



MINISTRY OF INTERNAL AFFAIRS
DIRECTORATE OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 Lourdel Road
Wandegeya,
P.O. BOX 105639
Kampala - Uganda

REPORT OF ANALYSIS

Description of the Samples

One sample of a transparent polythene bag was submitted by Ms. Nabwire Victoria, on 06th May 2024, and analysed on 07th May 2024. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Grey powdered substances packed in a transparent polythene bag.	01	Sample "A" GE 219/2024

Analysis Requested

Elemental analysis

Method of Analysis

Elemental analysis was done using the XRF Method.

Results of Analysis

The above sample has been analyzed with the following results as below.

Parameter	Units	Results
		Clay Sample GE 219/2024
Silicon dioxide	% m/m	55.888
Iron (III) Oxide	% m/m	14.810
Calcium Oxide	% m/m	14.643
Aluminum Oxide	% m/m	11.973
Titanium di oxide	% m/m	1.774
Manganese (II) Oxide	% m/m	0.207
Phosphorous pentoxide	% m/m	0.211
Chromium (III) Oxide	% m/m	0.219
Potassium Oxide	% m/m	0.116

Remarks

1. Results relate to sample analyzed and are reported as on received basis.

Semalago Fredrick 09/05/2024

Semalago Fredrick
Government Analyst

Appendix E: Plagiarism Report

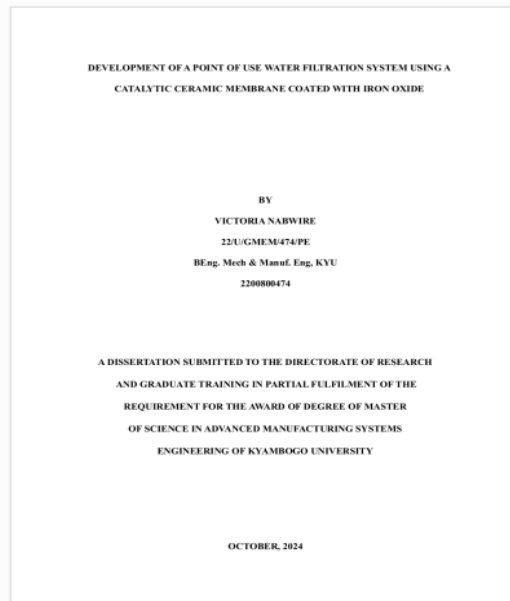


Digital Receipt

This receipt acknowledges that Turnitin received your paper. Below you will find the receipt information regarding your submission.

The first page of your submissions is displayed below.

Submission author: Victoria Nabwire
Assignment title: Thesis/Dissertation: revised 3
Submission title: Vicky Nabwire dissertation.docx
File name: Vicky_Nabwire_dissertation.docx
File size: 10.05M
Page count: 122
Word count: 16,208
Character count: 89,245
Submission date: 08-Oct-2024 12:25PM (UTC+0100)
Submission ID: 2478976374



victoria Nabwire Report.pdf

ORIGINALITY REPORT

17%

SIMILARITY INDEX

11%

INTERNET SOURCES

12%

PUBLICATIONS

3%

STUDENT PAPERS

PRIMARY SOURCES

1

link.springer.com

Internet Source

<1%

2

Juhana Jaafar, Asad A. Zaidi, Muhammad Nihal Naseer. "Membrane Technologies for Heavy Metal Removal from Water", CRC Press, 2024

Publication

<1%

3

William Ochen, Florence Mutonyi D'ujanga, Bosco Oruru. "Influence of residual stress on the mechanical behavior of ceramics with various quartz sizes", Scientific African, 2021

Publication

<1%

4

www.mdpi.com

Internet Source

<1%

5

Abdelrahman K.A. Khalil, Abdelaziz Elgamouz, Saad Nazir, Muataz Ali Atieh, Hussain Alawadhi, Tahar Laoui. "Preparation and characterization of clay based ceramic porous membranes and their use for the removal of lead ions from synthetic wastewater with an insight into the removal mechanism", Heliyon, 2024

<1%

Publication

6	www.ijsred.com Internet Source	<1 %
7	Submitted to Mbarara University of Science and Technology Student Paper	<1 %
8	alphamayengoh.blogspot.com Internet Source	<1 %
9	Yassine Rakcho, Mossaab Mouiya, Abdelmjid Bouazizi, Younes Abouliatim et al. "Treatment of Seawater and Wastewater using a Novel Low-Cost Ceramic Membrane Fabricated with Red Clay and Tea Waste", Arabian Journal of Chemistry, 2023 Publication	<1 %
10	etd.aau.edu.et Internet Source	<1 %
11	Submitted to The University of Manchester Student Paper	<1 %
12	Submitted to University of Lincoln Student Paper	<1 %
13	gyan.iitg.ac.in Internet Source	<1 %
14	www.scielo.br Internet Source	<1 %

15	"Ceramic Membranes: New Opportunities and Practical Applications", Wiley, 2016 Publication	<1 %
16	gyan.iitg.ernet.in Internet Source	<1 %
17	encyclopedia.pub Internet Source	<1 %
18	www.scirp.org Internet Source	<1 %
19	theses.fr Internet Source	<1 %
20	repository.aust.edu.ng Internet Source	<1 %
21	Harman, B.I.. "The use of iron oxide-coated ceramic membranes in removing natural organic matter and phenol from waters", Desalination, 20101015 Publication	<1 %
22	psasir.upm.edu.my Internet Source	<1 %
23	www.researchgate.net Internet Source	<1 %
24	Submitted to International Health Sciences University Student Paper	<1 %

- | | | |
|---------------|--|------|
| 25 | Shuiping Cheng, Wolfgang Grosse, Friedhelm Karrenbrock, Manfred Thoennesen. "Efficiency of constructed wetlands in decontamination of water polluted by heavy metals", Ecological Engineering, 2002 | <1 % |
| Publication | | |
| 26 | Yingchao Dong, Hui Wu, Fenglin Yang, Stephen Gray. "Cost and Efficiency Perspectives of Ceramic Membranes for Water Treatment", Water Research, 2022 | <1 % |
| Publication | | |
| 27 | Lubna Jaber, Ayman A. AbdelHamid, Abdelaziz Elgamouz, Abdel-Nasser Kawde. "Prediction of a natural clay membrane selectivity towards heavy metal cations removal from wastewater: An electrochemical study", Journal of Solid State Electrochemistry, 2023 | <1 % |
| Publication | | |
| 28 | Submitted to Addis Ababa University | <1 % |
| Student Paper | | |
| 29 | Mansour, S.A.. "Ecotoxicological Studies. 3. Heavy metals contaminating water and fish from Fayoum Governorate, Egypt", Food Chemistry, 200207 | <1 % |
| Publication | | |
| 30 | Panida Wimuktiwan. "INFLUENCE OF THE ADDITION OF PORE FOAMING AGENT ON | <1 % |

MECHANICAL AND THERMAL PROPERTIES OF PORCELAIN TILES", Ceramics - Silikat, 2020

Publication

31	Stephen Gray, Toshinori Tsuru, Yoram Cohen, Woei-Jye Lau. "Advanced Materials for Membrane Fabrication and Modification", Routledge, 2018 Publication	<1 %
32	Sundergopal Sridhar. "Membrane Technology - Sustainable Solutions in Water, Health, Energy and Environmental Sectors", Routledge, 2018 Publication	<1 %
33	coek.info Internet Source	<1 %
34	dokumen.pub Internet Source	<1 %
35	etd.repository.ugm.ac.id Internet Source	<1 %
36	www.grin.com Internet Source	<1 %
37	Kang Li. "Ceramic Membranes for Separation and Reaction", Wiley, 2007 Publication	<1 %
38	Submitted to Kyungpook National University Student Paper	<1 %

39	<p>Mohammed Messaoudi, Najib Tijani, Sara Baya, Adnane Lahnafi, Hassan Ouallal, Hamou Moussout, Lahcen Messaoudi. "Characterization of ceramic pieces shaped from clay intended for the development of filtration membranes", South African Journal of Chemical Engineering, 2021</p> <p>Publication</p>	<1 %
40	<p>acikbilim.yok.gov.tr</p> <p>Internet Source</p>	<1 %
41	<p>hdl.handle.net</p> <p>Internet Source</p>	<1 %
42	<p>ris.utwente.nl</p> <p>Internet Source</p>	<1 %
43	<p>m.hausarbeiten.de</p> <p>Internet Source</p>	<1 %
44	<p>www.ukessays.com</p> <p>Internet Source</p>	<1 %
45	<p>B.B.Y. Lau, E.T. Luis, M.M. Hossain, W.E.S. Hart, B. Cencia-Lay, J.J. Black, T.Q. To, L. Aldous. "Facile, room-temperature pre-treatment of rice husks with tetrabutylphosphonium hydroxide: Enhanced enzymatic and acid hydrolysis yields", Bioresource Technology, 2015</p> <p>Publication</p>	<1 %

46	<p>Mohd Haiqal Abd Aziz, Mohd Hafiz Dzarfan Othman, Nur Awanis Hashim, Mohd Ridhwan Adam, Azeman Mustafa. "Fabrication and characterization of mullite ceramic hollow fiber membrane from natural occurring ball clay", Applied Clay Science, 2019</p>	<1 %
Publication		
47	<p>Submitted to universititeknologimara</p>	<1 %
Student Paper		
48	<p>"Combined Application of Physico-Chemical & Microbiological Processes for Industrial Effluent Treatment Plant", Springer Science and Business Media LLC, 2020</p>	<1 %
Publication		
49	<p>Abdelnasser Abidli, Yifeng Huang, Zeineb Ben Rejeb, Aniss Zaoui, Chul B. Park. "Sustainable and efficient technologies for removal and recovery of toxic and valuable metals from wastewater: Recent progress, challenges, and future perspectives", Chemosphere, 2021</p>	<1 %
Publication		
50	<p>Ali Fadili, Ali Murtaza, Pacelli Zitha. "Injectivity decline by nanoparticles transport in high permeable rock", Journal of Petroleum Science and Engineering, 2022</p>	<1 %
Publication		
51	<p>Submitted to Federal University of Technology</p>	
Student Paper		

<1 %

52

Nurafiqah Rosman, W.N.W. Salleh, Mohamad Azuwa Mohamed, J. Jaafar, A.F. Ismail, Z. Harun. "Hybrid membrane filtration-advanced oxidation processes for removal of pharmaceutical residue", Journal of Colloid and Interface Science, 2018

Publication

<1 %

53

Vasile I. Parvulescu, Florence Epron, Hermenegildo Garcia, Pascal Granger. "Recent Progress and Prospects in Catalytic Water Treatment", Chemical Reviews, 2021

Publication

<1 %

54

Leticya Lais Coelho, Gidiane Scaratti, Adriano Martins Hissanaga, Bruno Francisco Oechsler et al. "Modeling and fouling control in a hybrid membrane process using CuO-catalytic membrane coupled to ozone", Journal of Environmental Chemical Engineering, 2021

Publication

<1 %

55

Meraj Ahmad, Chandra Prakash, Arti Sharma, Ambesh Dixit, Meenu Chhabra, Anand K. Plappally. "Development and Performance Evaluation of a Portable Ceramic Water Filter with Exfoliated Graphite and Sawdust as an Additive", Water Conservation Science and Engineering, 2024

<1 %

-
- 56** Mohamed Farag Twibi, Saber Abdulhamid Alftessi, Mohd Hafiz Dzarfan Othman, Mohd Ridhwan Bin Adam et al. "Chapter 3 Hydrophobic Ceramic Hollow Fiber Membrane: Fabrication and Potential Use in Membrane Distillation for Desalination", Springer Science and Business Media LLC, 2024
Publication <1 %
-
- 57** Submitted to National University of Singapore <1 %
Student Paper
-
- 58** dspace.nm-aist.ac.tz <1 %
Internet Source
-
- 59** ir.mu.ac.ke:8080 <1 %
Internet Source
-
- 60** journals.openedition.org <1 %
Internet Source
-
- 61** psaspb.upm.edu.my <1 %
Internet Source
-
- 62** worldwidescience.org <1 %
Internet Source
-
- 63** Abentin Estim, Syafiqah Saufie, Saleem Mustafa. "Water quality remediation using aquaponics sub-systems as biological and <1 %

mechanical filters in aquaculture", Journal of Water Process Engineering, 2018

Publication

64	Anjali Bishnoi, Pratik Patel, Nikita Ambegaonkar. "SYNTHESIS AND APPLICATIONS OF NANOMATERIALS IN VARIOUS INDUSTRIES", Journal of Emerging Technologies and Innovative Research, 2019	<1 %
Publication		
65	Submitted to Higher Education Commission Pakistan	<1 %
Student Paper		
66	essayoutlinesforcollege526.blogspot.com	<1 %
Internet Source		
67	www.peakscientific.com	<1 %
Internet Source		
68	api-depositonce.tu-berlin.de	<1 %
Internet Source		
69	comptes-rendus.academie-sciences.fr	<1 %
Internet Source		
70	doaj.org	<1 %
Internet Source		
71	erepository.uonbi.ac.ke	<1 %
Internet Source		
72	m.moam.info	<1 %
Internet Source		

73	pt.scribd.com Internet Source	<1 %
74	pure.tudelft.nl Internet Source	<1 %
75	tel.archives-ouvertes.fr Internet Source	<1 %
76	www.masdar.ac.ae Internet Source	<1 %
77	www.scientific.net Internet Source	<1 %
78	"Advances in Chemical, Bio and Environmental Engineering", Springer Science and Business Media LLC, 2022 Publication	<1 %
79	Domenic Grasso. "Hazardous Waste Site Remediation - Source Control", CRC Press, 2017 Publication	<1 %
80	E. K. Arthur, E. Gikunoo. "Property analysis of thermal insulating materials made from Ghanaian anthill clay deposits", Cogent Engineering, 2020 Publication	<1 %
81	Isah Mohammed, Mohamed Mahmoud, Dhafer Al Shehri, Abdulwahab Bello. "A Complementary Eco-Friendly Approach to	<1 %

Heavy Metal Removal from
Wastewater/Produced Water Streams
Through Mineralization", Journal of
Environmental Chemical Engineering, 2024

Publication

82	Submitted to University of Johannesburg Student Paper	<1 %
83	Yang Yu, Hui Jia, Fei Gao, Haifeng Zhu, Lei Zhang, Jie Wang. "Spectral Fusion-based Machine Learning Classifiers for Discriminating Membrane Breakage in Multiple Scenarios", Water Research, 2024 Publication	<1 %
84	digitalcommons.unl.edu Internet Source	<1 %
85	eprints.usm.my Internet Source	<1 %
86	jebas.org Internet Source	<1 %
87	rosdok.uni-rostock.de Internet Source	<1 %
88	smartech.gatech.edu Internet Source	<1 %
89	wpt.kpi.ua Internet Source	<1 %

www.ijert.org

90	Internet Source	<1 %
91	www.researchsquare.com Internet Source	<1 %
92	A. Ramesh, D. J. Lee, M. L. Wang, J. P. Hsu, R. S. Juang, K. J. Hwang, J. C. Liu, S. J. Tseng. "Biofouling in Membrane Bioreactor", Separation Science and Technology, 2006 Publication	<1 %
93	Anil Kumar Pabby, Syed S.H. Rizvi, Ana Maria Sastre Requena. "Handbook of Membrane Separations - Chemical, Pharmaceutical, Food, and Biotechnological Applications, Second Edition", CRC Press, 2019 Publication	<1 %
94	Arne Herman. "Orchestra Management - Models and Repertoires for the Symphony Orchestra", Routledge, 2022 Publication	<1 %
95	Bolun Zhang, Yiping Jin, Jiacheng Lin, Ziyu Guo, Guang Chen, Yingjie Su, Xiaoxiao Yu, Shanshan Tang, Siji Chen, Jian Li. "Biochar with enhanced performance prepared based on "graphite-structure regulation" conjecture designed to effectively control water pollution", Science of The Total Environment, 2024 Publication	<1 %

96	Chandra Bhan, Jiwan Singh, Yogesh Chandra Sharma, Janardhan Reddy Koduru. "Synthesis of lanthanum-modified clay soil-based adsorbent for the fluoride removal from an aqueous solution and groundwater through batch and column process: mechanism and kinetics", Environmental Earth Sciences, 2022 Publication	<1%
97	Elham Asrari. "Heavy Metal Contamination of Water and Soil - Analysis, Assessment, and Remediation Strategies", Apple Academic Press, 2019 Publication	<1%
98	J. Ketharani, M.A.C.K. Hansima, Suresh Indika, D.R. Samarajeewa et al. "A comparative study of community reverse osmosis and nanofiltration systems for total hardness removal in groundwater", Groundwater for Sustainable Development, 2022 Publication	<1%
99	Karnik, B.S.. "The effects of combined ozonation and filtration on disinfection by-product formation", Water Research, 200508 Publication	<1%
100	Kecheng Wen, Yanting Zhang, Jinhui Xu, Xinyu Wang, Tinghui Zheng, Zhiwei Yang, Guozhong Zheng, Yuan Huang, Jing Zhang. "New insights into magnetic fields selective	<1%

enhancement of ferrate(VI) combined with hydrogen peroxide for removal of organic pollutants", Separation and Purification Technology, 2024

Publication

101 Liza Melia Terry, Melvin Xin Jie Wee, Claudia Li, Guoqiang Song et al. "Advancements in dual-phase carbonate membranes for carbon capture and syngas production", Carbon Capture Science & Technology, 2024 <1 %

Publication

102 Mike Agbesi Acheampong. "Sustainable gold mining wastewater treatment by sorption using low-cost materials", CRC Press, 2020 <1 %

Publication

103 Mohamed Zoubeik, Mohamed Ismail, Amgad Salama, Amr Henni. "New Developments in Membrane Technologies Used in the Treatment of Produced Water: A Review", Arabian Journal for Science and Engineering, 2017 <1 %

Publication

104 Mun, K.J.. "Development and tests of lightweight aggregate using sewage sludge for nonstructural concrete", Construction and Building Materials, 200707 <1 %

Publication

105	<p>Saffaj, N.. "Elaboration and characterization of microfiltration and ultrafiltration membranes deposited on raw support prepared from natural Moroccan clay: Application to filtration of solution containing dyes and salts", Applied Clay Science, 200601</p> <p>Publication</p>	<1 %
106	<p>Vladimir Litvinenko. "Innovation-Based Development of the Mineral Resources Sector: Challenges and Prospects - Proceedings of the XI Russian-German Raw Materials Conference, November 7-8, 2018, Potsdam, Germany", CRC Press, 2018</p> <p>Publication</p>	<1 %
107	<p>Yibin Wei, Zixuan Xie, Hong Qi. "Superhydrophobic-superoleophilic SiC membranes with micro-nano hierarchical structures for high-efficient water-in-oil emulsion separation", Journal of Membrane Science, 2020</p> <p>Publication</p>	<1 %
108	<p>dspace.mak.ac.ug</p> <p>Internet Source</p>	<1 %
109	<p>epubs.surrey.ac.uk</p> <p>Internet Source</p>	<1 %
110	<p>file.scirp.org</p> <p>Internet Source</p>	<1 %

111	ikee.lib.auth.gr Internet Source	<1 %
112	ir.busitema.ac.ug Internet Source	<1 %
113	ir.gu.ac.ug Internet Source	<1 %
114	jurnal.upnyk.ac.id Internet Source	<1 %
115	repository.kaust.edu.sa Internet Source	<1 %
116	repository.tudelft.nl Internet Source	<1 %
117	scholar.sun.ac.za Internet Source	<1 %
118	slideplayer.com Internet Source	<1 %
119	uwspace.uwaterloo.ca Internet Source	<1 %
120	v-des-dev-lnx1.nwu.ac.za Internet Source	<1 %
121	www.nature.com Internet Source	<1 %
122	7universum.com Internet Source	<1 %

123 Anjana K Vala, Dushyant R Dudhagara, Bharti P Dave. "Marine Microbial Bioremediation", CRC Press, 2021

Publication

<1 %

124 D.A. Alonso-De la Garza, A.M. Guzmán, C. Gómez-Rodríguez, D.I. Martínez, N. Elizondo. "Influence of Al₂O₃ and SiO₂ nanoparticles addition on the microstructure and mechano-physical properties of ceramic tiles", Ceramics International, 2022

Publication

<1 %

125 Eliche-Quesada, D., M.A. Felipe-Sesé, J.A. López-Pérez, and A. Infantes-Molina. "Characterization and evaluation of rice husk ash and wood ash in sustainable clay matrix bricks", Ceramics International, 2016.

Publication

<1 %

126 Fernando J. Beltrán, Francisco J. Rivas, Ramón Montero-de-Espinosa. "Ozone-Enhanced Oxidation of Oxalic Acid in Water with Cobalt Catalysts. 2. Heterogeneous Catalytic Ozonation", Industrial & Engineering Chemistry Research, 2003

Publication

<1 %

127 Junjian Zheng, Jinxing Ma, Zhiwei Wang, Shaoping Xu, T. David Waite, Zhichao Wu. "Contaminant Removal from Source Waters Using Cathodic Electrochemical Membrane

<1 %

Filtration: Mechanisms and Implications",
Environmental Science & Technology, 2017

Publication

128 K. Swarnalatha, S. Ayoob. "Adsorption studies on coir pith for heavy metal removal", International Journal of Sustainable Engineering, 2016

Publication

129 M.F. Serra, M.S. Conconi, M.R. Gauna, G. Suárez, E.F. Aglietti, N.M. Rendtorff. " Mullite (3Al O ·2SiO) ceramics obtained by reaction sintering of rice husk ash and alumina, phase evolution, sintering and microstructure ", Journal of Asian Ceramic Societies, 2018

Publication

130 Maria Giovanna Buonomenna, Seyyed Mojtaba Mousavi, Seyyed Alireza Hashemi, Chin Wei Lai. "Water Cleaning Adsorptive Membranes for Efficient Removal of Heavy Metals and Metalloids", Water, 2022

Publication

131 Noel Jacob Kaleekkal, Prasanna Kumar S. Mural, Saravanamuthu Vigneswaran, Upal Ghosh. "Sustainable Technologies for Water and Wastewater Treatment", CRC Press, 2021

Publication

132 Razegheh Akhbarizadeh, Sina Dobaradaran, Iraj Nabipour, Saeed Tajbakhsh, Amir Hossein

Darabi, Jörg Spitz. "Abundance, composition, and potential intake of microplastics in canned fish", Marine Pollution Bulletin, 2020

Publication

133 Richa Soni, Shefali Bhardwaj, Dericks Praise Shukla. "Various water-treatment technologies for inorganic contaminants: current status and future aspects", Elsevier BV, 2020

Publication

134 S. B. Pillai, C. Walder, P. Gupta, Y. P. Koganti, J. Lahnsteiner. "Groundwater treatment by ceramic membranes: pilot tests at the Commonwealth Games Village in Delhi, India", H2Open Journal, 2019

Publication

135 S. Lakshmi Sandhya Rani, R. Vinoth Kumar. "Insights on applications of low-cost ceramic membranes in wastewater treatment: A mini-review", Case Studies in Chemical and Environmental Engineering, 2021

Publication

136 Submitted to University of Witwatersrand

Student Paper

137 Wirginia Tomczak, Marek Gryta, Ireneusz Grubecki, Justyna Miłek. "Biogas Production in AnMBRs via Treatment of Municipal and Domestic Wastewater: Opportunities and

Fouling Mitigation Strategies", Applied Sciences, 2023

Publication

138	Zilong Song, Yanning Li, Zhenbei Wang, Jingyi Sun et al. "Interfacial reactions of catalytic ozone membranes resulting in the release and degradation of irreversible foulants", Water Research, 2022 Publication	<1 %
139	acikerisim.cumhuriyet.edu.tr Internet Source	<1 %
140	digitalcommons.njit.edu Internet Source	<1 %
141	dspace.library.uu.nl Internet Source	<1 %
142	epdf.pub Internet Source	<1 %
143	erepository.uonbi.ac.ke:8080 Internet Source	<1 %
144	iiste.org Internet Source	<1 %
145	ir.uitm.edu.my Internet Source	<1 %
146	journals.orclever.com Internet Source	<1 %

147	mospace.umssystem.edu Internet Source	<1 %
148	oulurepo oulu.fi Internet Source	<1 %
149	pdffox.com Internet Source	<1 %
150	riunet.upv.es Internet Source	<1 %
151	rsdjournal.org Internet Source	<1 %
152	vital.seals.ac.za Internet Source	<1 %
153	www.deswater.com Internet Source	<1 %
154	www.frontiersin.org Internet Source	<1 %
155	www.globalscientificjournal.com Internet Source	<1 %
156	www.growingscience.com Internet Source	<1 %
157	www.horticulture.com.au Internet Source	<1 %
158	www.intechopen.com Internet Source	<1 %

159	www.science.gov Internet Source	<1 %
160	www.suaire.sua.ac.tz Internet Source	<1 %
161	www2.mdpi.com Internet Source	<1 %
162	"A New Generation Material Graphene: Applications in Water Technology", Springer Science and Business Media LLC, 2019 Publication	<1 %
163	Bukke Vani, Moola Shivakumar, Swayampakula Kalyani, Sundergopal Sridhar. "TiO ₂ nanoparticles incorporated high-performance polyphenyl sulfone mixed matrix membranes for ultrafiltration of domestic greywater", Iranian Polymer Journal, 2021 Publication	<1 %
164	Harshita Jain, Renu Dhupper, Anamika Shrivastava, Maya Kumari. "Enhancing groundwater remediation efficiency through advanced membrane and nano-enabled processes: A comparative study", Groundwater for Sustainable Development, 2023 Publication	<1 %

165	Meltem Ağtaş, Mehmet Dilaver, İsmail Koyuncu. "Ceramic membrane overview and applications in textile industry: a review", Water Science and Technology, 2021 Publication	<1 %
166	Zhong Sheng Tai, Mohd Haiqal Abd Aziz, Mohd Hafiz Dzarfan Othman, Mohd Irfan Hatim Mohamed Dzahir et al. "Ceramic Membrane Distillation for Desalination", Separation & Purification Reviews, 2019 Publication	<1 %
167	"Persistent Pollutants in Water and Advanced Treatment Technology", Springer Science and Business Media LLC, 2023 Publication	<1 %
168	"The use of rice husk ash in concrete", Waste Materials Used in Concrete Manufacturing, 1996 Publication	<1 %
169	C Brochot, A Bahloul, P Abdolghader, F Haghghat. "Performance of mechanical filters used in general ventilation against nanoparticles", IOP Conference Series: Materials Science and Engineering, 2019 Publication	<1 %
170	K. P. Jibin, Nandakumar Kalarikkal, Sabu Thomas, Ange Nzihou. "Re-Use and Recycling	<1 %

of Materials - Solid Waste Management and Water Treatment", Routledge, 2022

Publication

171 M. Chino, T.B. Goh, P.H. Hsu, D.W. Oscarson, L.M. Shuman. "Soils and Groundwater Pollution and Remediation - Asia, Africa, and Oceania", CRC Press, 2020 <1 %

Publication

172 Mohd Riduan Jamalludin, Zawati Harun, Mohd Hafiz Dzarfan Othman, Siti Khadijah Hubadillah et al. "Morphology and property study of green ceramic hollow fiber membrane derived from waste sugarcane bagasse ash (WSBA)", Ceramics International, 2018 <1 %

Publication

173 R Reshmy, Eapen Philip, Aravind Madhavan, Arivalagan Pugazhendhi et al. "Nanocellulose as green material for remediation of hazardous heavy metal contaminants", Journal of Hazardous Materials, 2021 <1 %

Publication

Exclude quotes Off

Exclude matches Off

Exclude bibliography On