Enhancing Water Quality in Bored Wells Through Zeolite/Bentonite-Based Ceramic Filter Membranes

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Abstract. This study addresses the issue of water contamination in boreholes, which often contain elevated levels of E. coli bacteria and Total Suspended Solids (TSS), posing significant health risks. We propose a novel approach utilizing adsorbents within ceramic membranes to effectively reduce E. coli and TSS levels in borehole water. Zeolite and bentonite, both with a particle size of 20 mesh, are employed as adsorbents. Ceramic membranes are selected for their filtration capabilities, with the research conducted using surface water obtained from a drilled well near the Faculty of Engineering, Universitas Lampung. The ceramic membranes, composed of clay, quartz sand, zeolite, and bentonite, are designed to achieve optimal porosity through firing at temperatures ranging from 800 to 1200°C. The experimental setup involves continuous flow of borehole water through the ceramic membranes, with E. coli and TSS levels monitored at regular intervals. Results demonstrate a significant reduction in both E. coli and TSS levels, with E. coli decreasing by 98% when utilizing ceramic membrane, A and TSS decreasing by 65% with the same membrane. The resulting water meets clean water standards, devoid of E. coli bacteria and TSS. This research highlights the potential of ceramic membranes as effective adsorbents for enhancing the quality of borehole water, ensuring its compliance with clean water standards.

Keywords: Surface water, Boreholes water, Adsorption, Ceramic membrane, Zeolite, Bentonite, E. Coli, TSS

1 Introduction

1.1 Universitas Lampung (UNILA)

Specifically at the Faculty of Engineering, relies on water supplied from multiple drilled wells to meet the water demands, especially during high-activity periods on campus such as laboratory practical, new student enrollments, graduations, and other

A. Zakaria et al. (eds.), *Proceedings of the 1st International Conference on Industry Science Technology and Sustainability (IConISTS 2023)*, Advances in Engineering Research 235,
https://doi.org/10.2991/978-94-6463-475-4_11

academic community engagements. However, the water from these drilled wells at Faculty of Engineering (or FT) UNILA often fails to meet quality requirements, particularly regarding parameters like pH, turbidity, and the presence of E. coli and coliform bacteria, as stipulated in Ministry of Health regulations or Permenkes RI/492/Menkes/Per/IV/2010. The contamination of bacteria such as Escherichia coli (E. coli) is a serious issue in clean water supplies. E. coli serves as a common indicator of fecal contamination in water, which can lead to severe gastrointestinal diseases in humans. To address this problem, the use of membrane technology has become an effective approach in water treatment. Ceramic membranes are one of the types of membranes widely used in water treatment. Ceramic membranes have a strong structure and very small pores, which allow for the retention of small particles such as bacteria, including E. coli. Typically, ceramic membranes are used in microfiltration or ultrafiltration processes, which enable the removal of particles even at the micron or nanometer level. Previous studies have shown the effectiveness of ceramic membranes in removing E. coli from water. Loi-Brügger et al. (2006) conducted research on the use of ceramic membranes for direct river water treatment by applying coagulation and microfiltration processes. The results of their study showed that ceramic membranes effectively removed E. coli and other contaminants from river water. In another study, Ashaghi et al. (2007) presented a brief overview of the use of ceramic ultra- and nanofiltration membranes for oilfield produced water treatment. Although the main focus of their study was on oilfield produced water treatment, their results are also relevant in the context of E. coli removal, as ceramic membrane technology has been proven to effectively reduce bacteria and other contaminants from water. The literature review by Li et al. (2017) also provides useful insights into the application of zeolites in sustainable chemistry, including their use in water treatment to remove contaminants such as E. coli. Although zeolites are not membranes themselves, they can be used as adsorbents to bind and remove bacteria from water. To address this issue, research has been conducted to treat the borehole water and ensure that it meets the standards for clean water. This research involves the use of a combination of adsorbents and ceramic membranes for filtration, with zeolite and bentonite being the two types of adsorbents tested.

1.2 Ceramic Membrane

Various applications of ceramic membranes in water treatment include UF and NF ceramic membranes used for treating water produced during crude oil and natural gas production, which often contain numerous organic and inorganic substances. UF and NF membranes have proven effective in separating oil, emulsion, and sludge. Still, they are susceptible to fouling by wax and asphalt (K. Shams Ashaghi et al., 2007). Ceramic filters, made from a mixture of clay and rice husks fired at 900°C for 8 hours, have been employed for small-scale water treatment at home. These filters are known to remove bacteria with an efficiency ranging from 97.8% to 100% (Vinka A. Oyanedel-Craver et al., 2008). Ceramic membranes used for the direct treatment of river water have demonstrated the ability to treat turbidity levels ranging from 3 to 100 FNU, with a filter flow rate ranging from 80 to 300 L/m^2 h. The recovery rate falls between 95.9% and 98.9% (A. Loi-Brügger et al., 2006). The results of the pervaporation process, including ethanol concentration, flux, and selectivity, are influenced by factors such as the membrane type, temperature, and operating time. The best outcomes in the study were achieved at

60°C using a membrane composed of 90% diatomaceous earth and 10% clay, with an ethanol concentration of 72% (Djana, 2018).

1.3 Zeolite

Zeolites find widespread applications, particularly in endeavors aimed at enhancing the efficiency and effectiveness of industrial processes. Due to their relatively low cost and high thermal stability, zeolites hold significant potential in separation processes and as catalysts (Loiola et al., 2012). These versatile materials feature a three-dimensional structure composed of TO_4 tetrahedra, where the 'T' atoms can be either Si^{4+} or Al^{3+} situated at the center of the oxygen tetrahedral structure. The ratio of Si^{4+} to Al^{3+} in the zeolite framework is expressed as the mole ratio of silica to alumina, SiO_2/Al_2O_3 or Si/Al. Zeolite, being a microporous crystalline material derived from aluminosilicate compounds, forms a three-dimensional open framework of tetrahedra, creating a network of pores and cavities, which makes it highly valuable as an adsorbent or ion exchanger (Li et al., 2017; Jiang et al., 2020).

1.4 Bentonite (Diatomaceous Earth)

Diatomaceous earth is a natural absorbent material found in nature. It thrives in areas with pyroclastic rock containing a significant amount of SiO_2. Diatomaceous earth, with the chemical formula ($SiO_2 \cdot nH_2O$), is a siliceous sedimentary rock primarily composed of the fossilized skeletal remains of single-celled aquatic plants known as diatoms and algae. The chemical composition of diatoms typically includes 86% silica, 5% sodium, 3% magnesium, and 2% iron (Rahmah et al., 2011). The specific type and quantity of elements, considered impurities, present in diatomaceous earth vary depending on its place of origin.

Properties of diatomaceous earth: 1. Hardness: 1-5 Mohs scale 2. Specific Gravity: 2.1-2.2 (except pure ones around 0.13-0.45) 3. Melting Point: 1.610-1.750 °C 4. Refractive index: 1.44-1.46 5. Color: white, gray, sometimes it can be in other colors such as reddish-orange, yellowish (depending on pollution) 6. Absorbency: high 7. Very porous 8. Easily broken 9. Has the ability to withstand temperature (Samosir, A. 2009).

Diatomaceous earth is widely employed in numerous industries due to its unique properties. Some common applications include:

1. Dry Cleaning: Used as an absorbent material in the dry-cleaning process.
2. Pharmaceutical Industry: Employed for various purposes in pharmaceutical applications.
3. Beverage Industry: Utilized in the production of beverages such as beer, wine, and liquor.
4. Sap Water: Used in sap water processing.
5. Swimming Pools: Employed for water treatment in swimming pools.
6. Paint Industry: Serves as fillers and extenders in paint production.
7. Heat Insulation: Used for heat insulation and prevention of hardening.
8. Catalyst Carriers: Used as carriers for catalysts.
9. Chromatography: Applied as auxiliaries in chromatography processes.

Escherichia coli (E. coli)

Escherichia coli (E. coli) contamination in water treatment is a significant concern due to its potential threat to public health. E. coli is a common indicator of fecal contamination in water sources and can lead to severe gastrointestinal illnesses if ingested by humans. To address this issue, various water treatment technologies are employed, including membrane filtration, chemical disinfection, and ultraviolet (UV) irradiation. Membrane filtration, particularly using ceramic membranes, has emerged as an effective method for removing E. coli from water. Ceramic membranes offer several advantages, including high mechanical strength, chemical resistance, and precise filtration capabilities. Their microporous structure allows for the retention of pathogens such as E. coli, thereby effectively reducing microbial contamination in treated water.

Several studies have demonstrated the efficacy of ceramic membranes in removing E. coli from water sources. For example, Loi-Brügger et al. (2006) investigated the use of ceramic membranes for direct river water treatment through coagulation and microfiltration processes. Their findings showed that ceramic membranes effectively removed E. coli and other contaminants from river water, highlighting the potential of this technology in water treatment. In addition to membrane filtration, chemical disinfection methods such as chlorination and ozonation are commonly used to inactivate E. coli in water. However, these methods may have limitations, including the formation of disinfection by-products and incomplete removal of pathogens. Ultraviolet (UV) irradiation is another effective method for E. coli removal, as it disrupts the DNA of bacteria, rendering them unable to replicate. Overall, the combination of membrane filtration, chemical disinfection, and UV irradiation can provide comprehensive E. coli removal in water treatment processes, ensuring the safety and quality of drinking water for communities.

1.5 State of Art

Recent research on ceramic membranes and Escherichia coli (E. coli) contamination in water treatment has provided valuable insights into the efficacy and application of this technology. Ceramic membranes, characterized by their strong structure and small pore size, have been extensively studied for their ability to effectively remove E. coli and other contaminants from water sources. One study by Ghaffour et al. (2020) investigated the performance of ceramic membranes in removing E. coli from wastewater effluents. Their findings demonstrated high removal efficiencies, highlighting the potential of ceramic membranes as a reliable barrier against microbial contamination. Similarly, a study by Wang et al. (2019) evaluated the anti-fouling properties of ceramic membranes during the filtration of E. coli-contaminated water. The results showed that ceramic membranes exhibited excellent resistance to fouling, maintaining high filtration rates and microbial removal efficiencies over extended periods. In another study, Zhang et al. (2018) examined the application of ceramic membranes in decentralized water treatment systems for rural communities. They found that ceramic membrane filtration effectively reduced E. coli levels in drinking water, providing safe and reliable water supplies to underserved populations.

Furthermore, research by Li et al. (2017) explored the integration of ceramic membranes with advanced oxidation processes for the removal of E. coli and other pathogens. Their study demonstrated synergistic effects between membrane filtration and oxidation, resulting in enhanced microbial removal rates and water quality improvement. Additionally, studies by Liang et al. (2016) and Chen et al. (2015) focused on the fabrication and optimization of ceramic membranes for E. coli removal. These studies highlighted the importance of membrane material properties and surface modifications in enhancing filtration performance and microbial retention capabilities. Moreover, recent advancements in ceramic membrane technology, as discussed by Su et al. (2021) and Wang et al. (2020), have led to the development of novel membrane materials and manufacturing processes. These advancements have contributed to improved membrane performance, durability, and cost-effectiveness in E. coli removal applications. Overall, the collective findings from these studies underscore the significance of ceramic membranes in mitigating E. coli contamination in water treatment processes. These advancements hold promise for the development of more efficient and sustainable water treatment solutions to safeguard public health and ensure access to clean drinking water for all.

2 Methodology

2.1 Tools and Materials

This research was conducted at the Universitas Lampung Laboratory. The ceramic membrane installation used in this study was prepared using clay, quartz sand, zeolite, and bentonite. The ceramic membrane has dimensions of 12.5 cm in height and 9 cm in diameter. The materials used in this study were zeolite and bentonite, with an average particle size of 20 mesh. The composition of zeolite and bentonite for Membrane A was 25% and 15%, respectively, and for Membrane B, it was 15% and 25%.

Additionally, various other equipment was used, including adsorbent columns, filtrate tanks, feed water tanks, permeate tanks, centrifugal pumps, flow meters, pressure gauges, and other supporting instruments such as pH meters. Water analysis parameters were measured following specific methods: E-coli bacteria using the APHA method, pH following SNI 06-6989.11:2004, turbidity based on SNI 06-6989.25:2005, and temperature per 06-6989.23:2005. The borehole water is collected in a feed water tank and pumped into the adsorbent column at a constant flow rate of 5 L/minute. The filtrate from the column is extracted every 15 minutes for pH, E-Coli content, and TSS analysis.

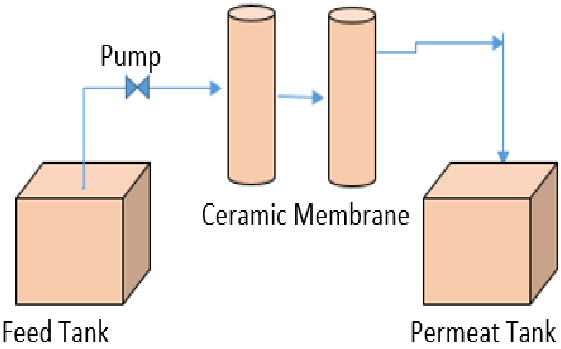

Fig. 1. Research procedure.

The filtrate from the adsorbent column is collected in a 220L tank and then pumped into a ceramic membrane at a constant flow rate of 5 L/minute. Permeate samples of 200 mL each are taken for analysis every 15 minutes. All experiments were conducted at room temperature (28°C-30°C) with varying operating times (15, 30, 45, 60, 75, 90, 120, and 150 minutes) while maintaining a constant feed flow rate. For E. Coli testing, the MPN 333 method, as per Formula Thomas, was employed, and for TSS analysis, the SK SNI M-03-1990F method was used.

3 Result and Discussion

The sample used was water from a drilled well located at the Faculty of Engineering, University of Lampung. The analysis of the sample revealed values exceeding the standards for several parameters, including turbidity, acidity (pH), and the presence of e-coli and coliform bacteria. This research aims to investigate the composition of the adsorbent to enhance the quality of borehole water, making it free from e-coli and TSS.

The effect of time on the pH of borehole water, pumped into a ceramic membrane as an adsorbent with a bentonite-zeolite composition of 25%:15%, reveals an initial increase in pH within the first 15 minutes of operation. This increase stabilizes in the subsequent 30 minutes. A similar trend is observed with the bentonite-zeolite composition of 15%:25%, which raises the pH of the filtrate to approximately 7.6. Notably, the operating time shows no significant effect on the resulting pH. The pH increase in various bentonite-zeolite compositions within ceramic membranes, compared to the initial sample pH values, demonstrates that both zeolite and bentonite can rapidly elevate the pH of borehole water. The use of zeolite as an adsorbent can elevate the pH from 5.21 to a range between 7.1 and 7.6. These results suggest that zeolite, with its hollow structure and high cation exchange capacity, can adsorb and exchange cations dissolved in the feed water. Additionally, water molecules can be removed from the zeolite structure, creating void spaces that can accommodate other species of suitable size, shape, and polarity. Thus, zeolite can also act as a molecular sieve (Li et al., 2017; Jiang et al., 2020).

E-coli and Coliform bacteria are parameters regulated by Permenkes/No.492/Menkes/Per/IV/2010, which mandates a maximum concentration of 0 per 100 ml sample. The initial sample had an E. coli bacteria content of 3 per 100 ml sample. Based on the measurements of ceramic membrane porosity, it was determined that membrane A has a pore size of 32.10478 x 10-4 mm, while membrane B has a pore size of 31.72169 x 10-4 mm. The inlet water test results indicated an E. Coli content of 1752 MPN/100 mL for both membrane A and membrane B, with TSS levels of 143 mg/L for membrane 1 and 139 mg/L for membrane 2.

Table 1. Percentage of Decreased E-Coli Levels using two types of membranes.

Sample minute	Inlet (MPN/100ml)	Membrane A		Membrane B	
		Outlet (MPN/100ml)	Efficiency (%)	Outlet (MPN/100ml)	Efficiency (%)
15	1752	890	49	1028	41
30	1752	689	61	741	58
45	1752	540	69	652	63
60	1752	425	76	521	70
75	1752	268	85	428	76
90	1752	112	94	246	86
120	1752	96	95	128	93
150	1752	41	98	97	94

The reduction in the concentration of E. Coli on the ceramic membrane is a result of the filtration and adsorption processes. Organic contaminants in the borehole water are unable to pass through the membrane. Instead, they are filtered and absorbed by the ceramic membrane, which exerts strong pressure, causing these impurities to adhere to the membrane walls. As a result, the water produced is clean and free from pollutant particles. This phenomenon is closely related to the pore size of the membrane, which is smaller than the size of E. Coli (0.5-1 micron).

The various time intervals during the experiment play a significant role in determining the saturation time of the drilled well water sample. The ceramic membrane's filtration process is designed to capture solid materials, dissolved substances, and suspended particles present in raw water or wastewater. Additionally, the ceramic membrane undergoes an adsorption process, involving collisions between suspended particles and the composition of zeolite and bentonite, which are mixed during the manufacture of ceramic membranes. These zeolite and bentonite components carry a negative electric charge, enabling them to adsorb positively charged particles.

Table 2. Efficiency of Reducing TSS Concentration using two type of membranes.

Sample minute		Membrane A			Membrane B	
	Inlet (mg/L)	Outlet (mg/L)	Efficiency (%)	Inlet (mg/L)	Outlet (mg/L)	Efficiency (%)
15	143	91	36	139	97	30
30	136	82	40	126	89	29
45	122	73	40	119	80	33
60	111	68	39	108	71	34
75	108	60	44	99	64	35
90	101	45	55	94	52	45
120	96	38	60	91	41	55
150	91	32	65	86	36	58

Table 2 illustrates that both ceramic membrane compositions A and B exhibit a decrease in TSS concentration at the inlet. This decline can be attributed to the settling process of particles present in the borehole water. In these conditions, the borehole water contains larger and heavier particles that readily settle. The reduction in TSS concentration at the outlet is primarily due to the ceramic membrane's capacity to filter and adsorb suspended solids (TSS) found in the borehole water. The ceramic membrane functions as a filter, thanks to the inclusion of 20 mesh zeolite in its composition, which is proficient at absorbing water. Additionally, the ceramic membrane serves as an adsorbent due to the presence of bentonite, which readily absorbs certain organic molecules present in the borehole water. This is evident in the ceramic membrane's pore size, which is considerably smaller than the size of suspended solids with a diameter exceeding 1 micron. Consequently, the ceramic membrane proves highly effective in reducing TSS concentrations.

4 Conclusion

From the various research procedures conducted above, the application and testing of ceramic membranes with zeolite and bentonite compositions aimed at improving the quality of borehole water yield the following results:

1. Ceramic membranes with a zeolite and bentonite composition of 25% and 15%, respectively, demonstrate the ability to significantly reduce E. Coli levels by up to 98%.
2. Ceramic membrane A, with a zeolite and bentonite composition of 25% and 15%, respectively, shows a notable reduction in TSS levels by 65%.
3. The effective timeframe for reducing the concentration of E. Coli and TSS in borehole water falls within the range of 120-150 minutes.

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