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Performance Analysis of Ceramic Membranes in Clean Water Treatment on River Water Quality

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Abstract

The clean water treatment process changes the physical, chemical, and biological properties of water so that it meets the requirements for use as drinking water or daily needs. The purpose of this research is to examine the performance of ceramic membranes in the process of converting river water into clean water through an environmentally friendly microfiltration-adsorption-ceramic membrane integrated process. The results showed that each filter is able to improve the quality status of the water quality of the Kelekar River sample. The final concentration value of BOD_5 17.0 mg/L with rejection percentage (%R) 1.16%; COD 14.3 mg/L with %R of 32.55%; manganese (Mn) 0.030 mg/L with a %R of 29.41%; nitrate (NO_3-) 0.013 mg/L with a %R of 13.33%; nitrite (NO_2-) 0.50 mg/L with a %R of 16.67%; iron (Fe) 0.12 mg/L with %R of 29.41%; ammonia (NH_3-N) 0.10 mg/L with %R of 37.50%; and biological parameters in the form of total coliform 21 total/100 mL with a %R of 40%. Based on the analysis of river water quality parameters, such as BOD_5, iron (Fe), manganese (Mn), nitrate (NO_3-), ammonia (NH_3-N), and total coliform bacteria after water treatment were within environmental quality standards. Meanwhile, COD and nitrite (NO_2-) were still not meeting the environmental quality standards set by Government Regulation This is presumably due to the filter arrangement, which places the microfiltration filter first before adsorption, resulting in an inefficient water treatment process in the filter.

Keywords: Water treatment, Kelekar River, microfiltration–adsorption–ceramic membrane integrated process

Abstrak (Indonesian)

Penelitian ini ditujukan untuk menganalisis kinerja membran keramik dalam proses pengolahan air di sungai menjadi air bersih menggunakan proses terpadu mikrofiltrasi–adsorpsi-membran keramik yang ramah lingkungan. Hasil analisa menunjukkan bahwa masing-masing filter mampu meningkatkan status mutu kualitas air sampel Sungai Kelekar. Nilai konsentrasi akhir parameter BOD_5 17,0 mg/L dengan persentase rejeksi (%R) sebesar 1,16%; COD 14,3 mg/L dengan %R sebesar 32,55%; mangan (Mn) 0,030 mg/L dengan %R sebesar 29,41%; nitrat (NO_3^-) 0,013 mg/L dengan %R sebesar 13,33%; nitrit (NO_2^-) 0,50 mg/L dengan %R sebesar 16,67%; besi (Fe) 0,12 mg/L dengan %R sebesar 29,41%; amoniak (NH_3-N) 0,10 mg/L dengan %R sebesar 37,50%; dan parameter biologi berupa total *coliform* 21 jumlah/100 mL dengan %R sebesar 40%. Berdasarkan analisis parameter kualitas air sungai, nilai konsentrasi BOD_5, besi (Fe), mangan (Mn), nitrat (NO_3^-), amoniak (NH_3-N), dan total bakteri coliform setelah pengolahan telah sesuai standar baku mutu lingkungan. Sedangkan nilai konsentrasi COD dan nitrit (NO_2^-) masih belum sesuai standar baku mutu lingkungan yang ditetapkan oleh Peraturan Pemerintah. Hal ini diduga karena susunan filter yang menempatkan filter mikrofiltrasi terlebih dahulu sebelum adsorpsi, sehingga mengakibatkan tidak efisiennya proses pengolahan air di dalam filter.

Kata Kunci: Pengolahan air, Sungai Kelekar, proses terpadu mikrofiltrasi–adsorpsi-membran keramik

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INTRODUCTION

The clean water treatment process changes the physical, chemical, and biological properties of water to meet the requirements for use as drinking water or daily needs. The purpose of this clean water treatment activity is to improve water quality by reducing the level of turbidity of the water, reducing odor, taste, and color, eliminating and killing microorganisms, reducing levels of materials dissolved in water, reducing hardness, and improving acidity (pH) water [1].

Membrane technology is one of the high-performance water treatment technologies [2]. Ceramic membranes are an inorganic membrane composed of metals and nonmetals combined to form oxides, nitrides, or carbide. Ceramic membranes are very efficient for water treatment because they can separate liquid mixtures or gas perforation while also reducing hardness. Furthermore, this technology has no negative environmental consequences [3, 4]. Ceramic membranes containing clay, activated carbon from empty fruit bunches of oil palm (C-active TKKS), and iron powder can improve river water quality [5].

The problem of converting river water into clean water is extremely complex and intertwined. As a result, in this study, the authors limit the problems associated with converting Kelekar River into clean water by using the an environmentally friendly microfiltration – adsorption – ceramic membrane integrated process. The purpose of this study is to analyze the performance of ceramic membranes in the process of purifying water from the Kelekar River.

MATERIALS AND METHODS

Materials and Tools

1 unit 300 L PVC tank, 1 water pump, PVC pipe ½ inch, 4 membrane housings, 1 sponge filter with 0.5 m pore diameter, 1 sponge filter with a diameter of 10 m, 1 activated carbon, 1 pieces of ceramic membranes made in this study (with a material ratio of 87.5% clay: 10% C-active TKKS: 2.5% iron powder) [6], 1 measuring cup, 1 beaker, and a bottle. While the sample material used at this stage is the water from the Kelekar River.

Water Treatment Procedure

A sampling of water from the Kelekar River for preliminary analysis (pretreatment) in the laboratory to determine the quality of the water. We loaded the River water sample into a storage tank with a capacity of 300 liters before we filtered the water through a ceramic membrane. The water from the storage tank flows from housing-1 to housing-5 using one bar pressure pump. Housing-1 (F1) contains a filter cartridge with a pore diameter of 3 m, housing-2 (F2) contains a sponge filter with a pore diameter of 1 µm, housing-3 (F3) contains an activated carbon filter (carbon black), housing-4 (F4) contains a manganese ferollite 8x16 mesh, and housing-5 (F5) contains a ceramic membrane. Every time the river water passes through the filter, a sampling is taken and stored in a container to be analyzed in ISO-certified laboratories. The parameters that are being analyzed, such as BOD_5, COD, manganese (Mn), nitrate (NO_3-), nitrite (NO_2-), ammonia (NH_3-N), iron (Fe), and total coliform bacteria.

Analysis Data

Evaluation of membrane performance is carried out by measuring rejection or perm selectivity, namely the ability of the membrane to pass certain species and retain other species. Rejection (R) shows the value of the concentration fraction of solutes retained by the membrane which can be calculated by the following formula [7]:

$$R = \left(1 - \frac{C_p}{C_f}\right) \times 100\% \quad (1)$$

Information:
R = Rejection coefficient (%)
Cp = Concentration of solute in permeate
Cf = Concentration of solute in the feed

RESULTS AND DISCUSSION

The performance of membranes in water treatment with an integrated process of microfiltration–adsorption–ceramic membranes gave significant results in reducing the concentration of several water quality parameters in the Kelekar River, including BOD_5, COD, iron (Fe), manganese (Mn), nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3-N), and total bacteria coliform (**Table** 1).

Table 1. The results of a performance analysis of a water treatment filter using microfiltration-adsorption-ceramic membrane on water samples from Kelekar River

Parameter	Unit	Early	End (F5)	%R	EQS
BOD_5	mg/L	15.5	17.0	1.16	2
COD	mg/L	24.5	14.3	32.5	10
Fe	mg/L	0.45	0.12	29.41	0.3
Mn	mg/L	0.033	0.030	67.03	0.1
NO_3^-	mg/L	0.013	0.013	13.33	10
NO_2^-	mg/L	1.10	0.50	16.67	0.06
NH_3-N	mg/L	1.30	0.10	37.50	0.1
Total Coliform	Count/ 100 mL	1500	21.0	40	1000

The Environmental Quality Standards used in this study are based on Government Regulation of the Republic of Indonesia No. 22 of 2021 on Environmental Protection and Management Implementation. These water quality standards serve as the basis for determining whether water samples are satisfactory or safe for use [8, 9].

BOD_5 and COD Concentration

The concentration of BOD_5 during the water treatment process did not fluctuate too significantly (**Figure** 1). In contrast to the concentration of COD parameters, which continued to decrease until the end of the filtration (**Figure** 2). The concentration of BOD_5 produced from water treatment with an integrated microfiltration – adsorption – ceramic membrane process is by class I environmental quality standards based on Government Regulation of Republic Indonesia (GRRI) No. 22 of 2021.

The increase in BOD_5 value is thought to be caused by the arrangement of the filtration model used in this study. Housings 1 and 2, which serve as microfiltration, should be placed after housings 3 and 4, which serve as adsorption. Because previous research has shown that filtration using a combination of adsorbents is effective in significantly reducing BOD levels. The use of a combination of adsorbents such as activated charcoal, zeolite, silica sand, anthracite, and ferrolite demonstrates multipurpose capabilities that can carry out filtration, adsorption, and ion exchange processes concurrently to decompose and reduce levels of organic pollutants in waste. [10, 11].

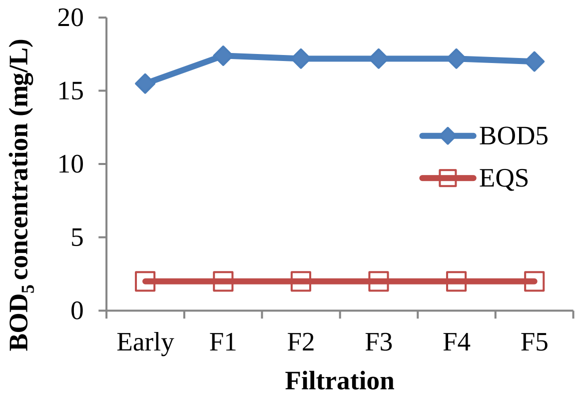

Figure 1. BOD_5 Concentration in Kelekar River Water in Water Treatment Process

Meanwhile, the COD concentration has not been able to reach the specified quality standard, which is 10 mg/L. The high concentration of COD is thought to be caused by the presence of divalent and monovalent compounds that cannot dissolve completely during the water treatment process [12]. Although it can be seen from the graph (**Figure** 2), there has been a significant decrease in COD concentration during the water treatment process.

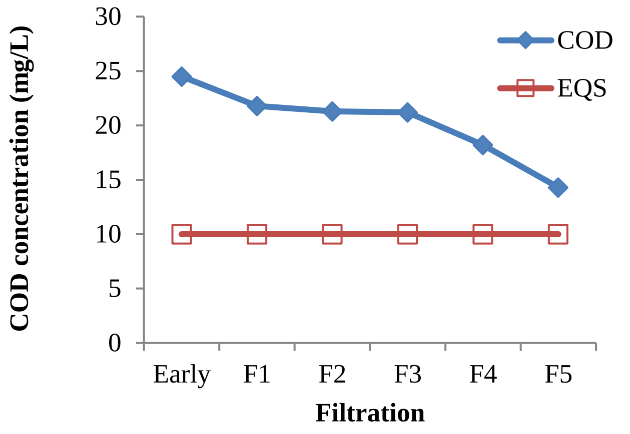

Figure 2. COD Concentration in Kelekar River Water in Water Treatment Process

The rejection percentage of ceramic membranes made of clay, C-active empty palm oil frugs, and iron powder can reduce the COD concentration value by 32.5%. This value is higher than the BOD rejection percentage of 1.16 percent. However, this percentage is insufficient to reduce COD concentrations by environmental quality standards.

Iron (Fe) Consentration

The results of the analysis of the concentration of iron (Fe) contained in the water sample of the Kelekar River decreased significantly along with the ongoing water treatment process from filtration 1 to filtration 5. The initial concentration value before the water treatment process, which was 0.45 mg/L, decreased to 0.14 mg/L at the end of the water treatment.

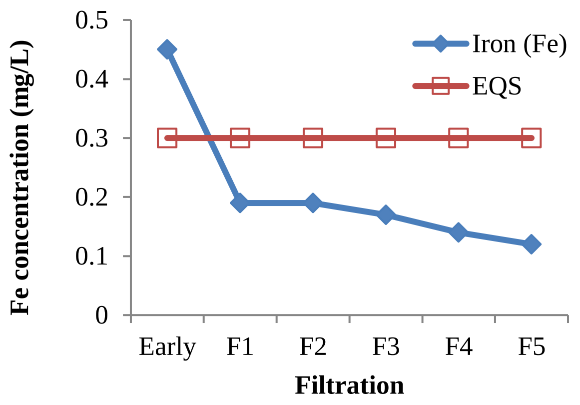

Figure 3. Iron Concentration (Fe) in Kelekar River Water in Water Treatment Process

The percentage value of Fe rejection was 29.41%. Based on these data, the concentration of iron (Fe) in water is in accordance with environmental quality standards class I, Government Regulation of Republic Indonesia No. 22 of 2021. It is further explained that the permissible content of iron in water is less than 0.3 mg/L and if it exceeds this value, it will cause the water to turn reddish in color due to the formation of deposits on metal pipes and the taste of the water becomes undesirable [3, 13].

Manganese (Mn) Consentration

In **Figure** 4, it can be seen that there was an increase in the concentration of manganese (Mn) at the beginning of the water treatment. Mn concentration previously was 0.033 mg/L and increased to 0.097 mg/L in F1. Then it decreased along with the water treatment process to 0.030 mg/L in F5, with a rejection percentage value (%R) of 67.03%. The increase in the concentration of Mn in water that occurs at the beginning of water treatment can be caused by several factors, including the low pH value concentration, the amount of oxygen dissolved in the water, the presence of aggressive CO_2 which causes the dissolution of ferrous metals, the highwater temperature that will dissolve the iron in the water, etc. [1].

Nevertheless, the value of Mn concentration still meets the environmental water quality book standard of class I, GRRI No. 22 of 2021 at 0.1 mg/L. If there is water with low oxygen content, then the concentration of Mn in the water is high because under anaerobic conditions, Mn in the water is in the form of Mn^{2+} and remains stable due to the low oxygen content, which can cause the oxidation of Mn^{2+} to Mn^{4+} [13, 14, 15].

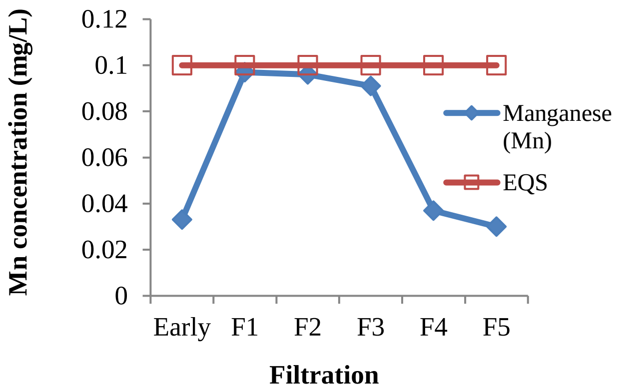

Figure 4. Manganese Concentration (Mn) in Kelekar River Water in Water Treatment Process

Nitrate (NO_3^-) and Nitrite (NO_2^-) Consentration

At the beginning of water treatment, the concentration of nitrate (NO_3-) increased from 0.013 mg/L before treatment to 0.015 mg/L in filter 1 (F1), then decreased along with the water treatment process to 0.013 mg/L and the value of the percentage of rejection (% R), i.e., 13.33%. The concentration of nitrate (NO_3-) in this study has met the environmental quality standard class I GRRI No. 22 of 2021 (**Figure** 5). It is said that nitrate-nitrogen levels in natural waters are almost never more than 0.1 mg/L [16].

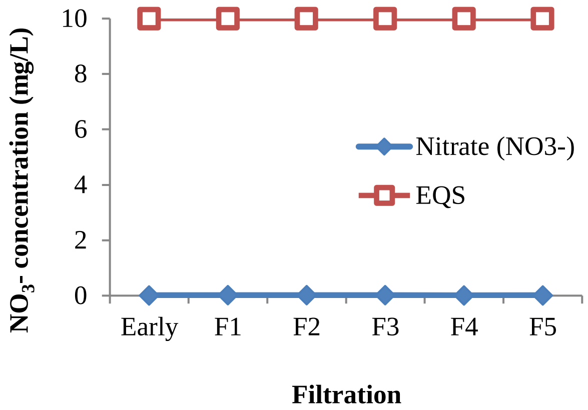

Figure 5. Nitrate Concentration (NO_3^-) in Kelekar River Water in Water Treatment Process

In contrast to the graph of a stable change in nitrate concentration, the nitrite concentration decreased along with the water treatment process, as shown in **Figure** 6. The value of the concentration of nitrite (NO_3^-) at the beginning of the study was 1.10 mg/L, then decreased gradually to 0, 60 mg/L with a rejection percentage (%R) of 16.67%. Although the concentration has decreased significantly, the concentration still exceeds the environmental quality standard limits for class I GRRI no. 22 of 2021, which is 0.06 mg/L. The concentration of nitrite in the water should not exceed 0.06 mg/L and natural waters contain nitrite at around 0.001 mg/L [16].

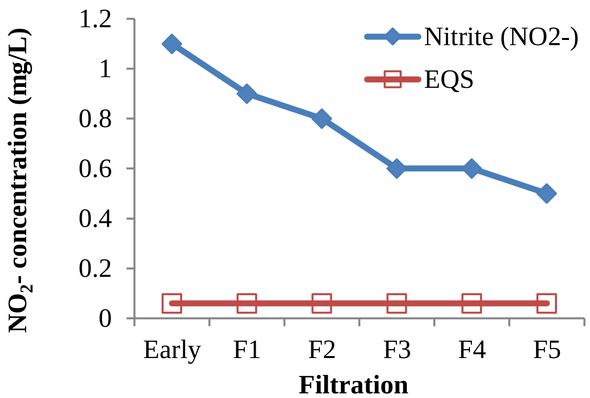

Figure 6. Nitrite Concentration (NO_2^-) in Kelekar River Water in Water Treatment Process

Ammonia (NH_3-N) Consentration

In **Figure** 7, it can be seen that there was a drastic decrease in ammonia concentration from 1.30 mg/L at the beginning of the study to 0.10 mg/L at the end of the water treatment, with a rejection percentage (%R) of 37.50%. The value of this ammonia concentration has met the environmental quality book standards for class I GRRI No. 22 of 2021. Pollution of organic matter in waters originating from domestic waste, industrial waste, and agricultural fertilizer runoff can be an indication of high levels of ammonia in these waters. Ammonia levels in natural waters are usually less than 0.1 mg/L [16].

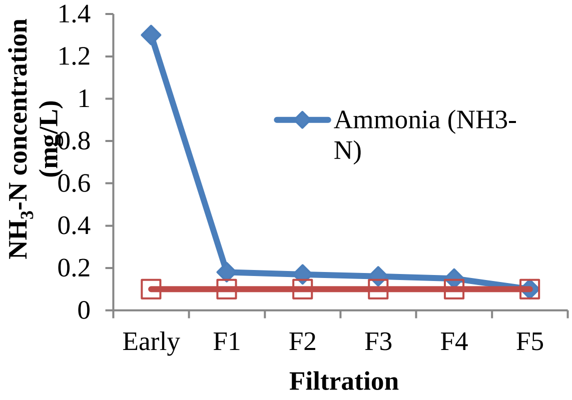

Figure 7. Ammonia Concentration (NH_3-N) in Kelekar River Water in Water Treatment Process

Total Coliform Bacteria Consentration

The analysis results showed a very significant decrease in total coliform bacteria after water treatment using an integrated microfiltration-adsorption-ceramic membrane process, from the total coliform bacteria at the beginning of the study of 1500 count /100 mL to 21 count/100 mL at the end of water treatment with a percentage value rejection (% R) of 40%. The total coliform bacteria concentration is in accordance with the environmental quality standard class I established by GRRI No. 22 of 2021.

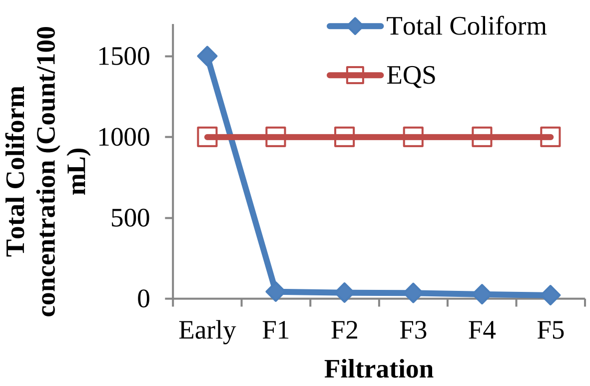

Figure 8. Total Bacteria Coliform in Kelekar River Water in Water Treatment Process

Coliform bacteria is an indicator of the presence of domestic sewage contaminants or poor sanitation, as well as fecal contamination from humans and warm-blooded animals [17, 18]. Coliform bacteria are more resistant to antibiotics than other pathogenic bacteria. Pathogenic bacteria are bacteria that can cause disease, so testing for coliform bacteria in water is critical [19, 20].

Based on the previous explanation, that water treatment using an environmentally friendly microfiltration – adsorption – ceramic membrane integrated process has been quite effective in improving the water quality of the Kelekar River samples. Water quality parameters such as manganese, nitrate, nitrite, iron, ammonia, and total coliform have met the requirements of environmental quality standards (BML) for clean water and drinking water.

CONCLUSION

The results of further analysis, it is known that each filter (F1-F5) is able to improve the quality status of the water quality of the Kelekar River sample. The final concentration value of BOD_5 17.0 mg/L with rejection percentage (%R) 1.16%; COD 14.3 mg/L with %R of 32.55%; manganese (Mn) 0.030 mg/L with a %R of 29.41%; nitrate (NO_3-) 0.013 mg/L with a %R of 13.33%; nitrite (NO_2-) 0.50 mg/L with a %R of 16.67%; iron (Fe) 0.12 mg/L with %R of 29.41%; ammonia (NH_3-N) 0.10 mg/L with %R of 37.50%; and biological parameters in the form of total coliform 21 total/100 mL with a %R of 40%.

The series of microfiltration-adsorption-ceramic membrane integrated process water treatment equipment can be used to treat river water into clean water. Based on the analysis of river water quality parameters, such as BOD_5, iron (Fe), manganese (Mn), nitrate (NO_3-), ammonia (NH_3-N), and total coliform bacteria after water treatment were within environmental quality standards. Meanwhile, COD and nitrite (NO_2-) were still not meeting the environmental quality standards set by Government Regulation of Republic Indonesia No. 22 of 2021 concerning the implementation of environmental protection and management. This is presumably due to the filter arrangement, which places the microfiltration filter first before adsorption, resulting in an inefficient water treatment process in the filter.

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