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EFFECTIVENESS OF RAW WATER POLLUTANT REMOVAL BY AERATED PLASTIC HONEYCOMBS AND QUARTZ SAND BIOFILTERS

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ABSTRACT

River water is widely used as raw water for drinking water supply although it sometimes does not meet the quality standard of raw water. Such condition leads to an increased water treatment cost and health risks to the community. Technological innovation of biofiltration process can be an effective solution to solve such problems, in which the pollutant elimination is caused by a combination of biological oxidation, adsorption and filtration. This research aimed to determine the effectiveness of biofilters for the pre-treatment of raw water for drinking water supply. Quartz sand and plastic honeycombs were tested as filter media. Continuous air supply was done to maintain an aerobic condition of the biofilter system. Special attention was given to the eliminations of organic pollutants and physical parameters (total suspended solids, turbidity, and color). In addition, the biofilters were tested by using detergent loading. The quartz sand biofilter could reduce organic pollutants (measured as chemical oxygen demand/COD) of approx. 80% that was higher than the COD reduction of approx. 70% by using plastic honeycomb biofilter. The study indicates that the biofiltration system is also able to eliminate the pollutant detergents. The increased raw water quality can reduce water treatment cost and the risk to public health.

Keywords: Biofilter; Drinking water supply; Organic matters; Polluted river water

1. INTRODUCTION

Surface water is one of the main raw water sources used to meet the water needs in the various regions of Indonesia. Unfortunately, the river water is often polluted heavily and does not meet the minimum requirement as raw water for drinking water supply. The low quality of raw water leads to higher water treatment costs due to a higher chemical consumption in the water treatment plants. In addition, the low quality of raw water increases the risks of public health. Therefore, technical efforts are required to improve the raw water qualify. An alternative for the pre-treatment of the polluted raw water as drinking water supply is a biofiltration process.

The main pollutants of the river water are organic matter and physical contaminants such as suspended solids, turbidity and color. Organic matter in raw water increases the use of chemicals (coagulant/flocculants) in the drinking water treatment (*Matilainen* and Sillanpää, 2010). Furthermore, the remaining organic matter in the processed water can form byproducts, such as compounds trihalomethane ($CHCl_3$), which is carcinogenic compounds that trigger cancer (WHO, 2015; Hsu et al., 2011). Although physical pollutants do not directly cause a negative effect on human health, the physical

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contaminants affect the aesthetics (taste and odor) and increase the cost of water treatment.

Surface water contamination by organic matter and physical pollutants is observed in various parts of the world, especially in developing countries. It tends to increase in some cases. Various methods are developed to eliminate organic matter from the raw water. These methods include oxidation with O_3/H_2O_2, O_3/UV, UV/H_2O_2, TiO_2/UV, H_2O_2/catalyst, Fenton and photo-Fenton process (Matilainen and Sillanpää, 2010). However, these processes require higher investment and operation costs, so that the application of these processes on a commercial scale is still limited due to the cost constraints.

Biofiltration is a prospective innovation for the removal of organic pollutants from polluted raw water. Biofiltration is defined as a process in which water is filtered through media populated with microorganism capable to treat water. The principle of biofiltration is to utilize bacteria and protozoa, which are attached to the surface of filter materials, to clean water from undesirable substance in drinking water (Juhna and Melin, 1985). The biofilters can be used for the removal of organic matters, ammonium, nitrate, iron, manganese, taste and odor-causing substances. Due to its low maintenance costs and effective removal of biodegradable organic matter, biofiltration is becoming an attractive drinking water treatment method. Biofiltration is expected to become even more common in the future as efforts intensify to decrease the presence of disinfection by-products in drinking water and disease-causing microorganisms in drinking water (Juhna and Melin, 1985). In the biofilters, physical-chemical-biological processes take place simultaneously such as filtration, adsorption and degradation of contaminants by the biological activity of the microorganisms forming biofilm (Horan 1990).

Biofilm (the basic principle of biofiltration) has been proven for effective water and waste water treatment for a variety of purposes, such as advanced treatment of wastewater (Pleha, 1987; Bever et al., 1995; Luebbecke and Dickgreber, 1997; Banjenbruch, 1998; Jou and Huang, 2003), elimination of pesticides (Timmer et al., 1993), and elimination of toxic substances (Eker and Kargi, 2010; Sheth and Dave, 2010; Lie et al., 2011). These studies emphasized the elimination of the relatively high concentration of pollutants from wastewater or on the advanced treatment of wastewater to eliminate nutrients (nitrification, denitrification and phosphate elimination). Development of biofiltration for the removal of organic matter, suspended solids and other pollutants with relatively low concentrations has not been widely reported. It is necessary to look for an effective removal of pollutants in low concentrations, for example to remove pollutants from polluted river water. The pre-treatment of raw water for drinking water supply with biofilters can improve the quality of raw water leading to an improved quality of the produced drinking water, lower processing costs, and a lower risk of public health.

This study aimed to examine the performance of biofiltration in the removal of physical pollutants and organic matter from polluted raw water. Two types of filter media were tested in this experiment, namely quartz sand and plastic honeycombs. The main attention was given to the temporal course of the pollutant removal with an increased operating time, the percentage of pollutants elimination, and the quality of the treated water.

2. METHODOLOGY/ EXPERIMENTAL

The main equipment used in this study was two biofilter units and their accessories, equipment and instrumentation for laboratory analysis, such spectrophotometer, COD reactor, pH meter, sample bottles, as well as standard laboratory glasswares.

The principle of biofiltration is to utilize bacteria and protozoa, which are attached to the surface of filter materials, to clean water from undesirable substance in water (Juhna and Melin, 1985). Biofilter with filter media of quartz sand (Biofilter 1) was directly compared with biofilter with plastic honeycombs (Biofilter 2) in terms of their abilities to remove pollutants from river water. Quartz sand was selected as filter media in this study because of its ability to provide physical filtration effect, whereas plastic honeycombs were chosen because the physical form is structured, light, as well as commercially available. Each biofilter unit was equipped with an aerator for air supply, air and water flow regulator valves, and piping systems. Figure 1 shows the experimental set up. Each biofilter unit had a total volume of 1000 L (working volume of 700 L). The media volume was 500 L. The biofilter units were operated up flow in which the water flowed from the bottom upwards.

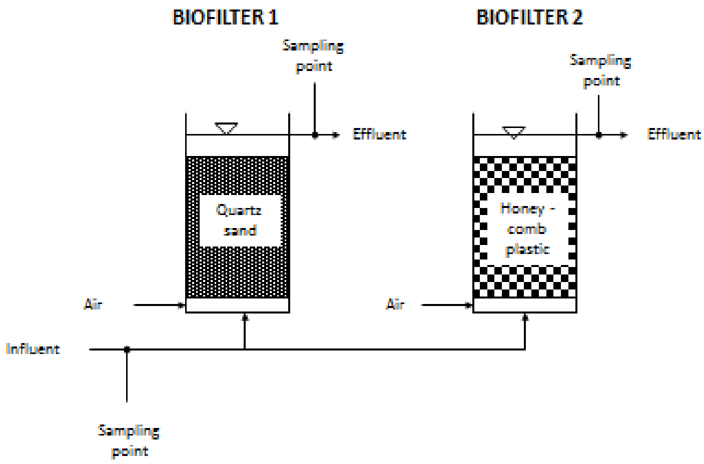


Figure 1 Set up of experimental apparatus

The study consisted of three phases, namely the characterization of the raw water, process start-up and load test. The raw water used for this study was taken from Cihideung River, Bogor Agricultural University (IPB) Darmaga Campus, Indonesia. At the beginning of the experiment, the raw water was characterized by a laboratory analysis of physical parameters. Sampling was done on two conditions, namely sunny condition (no rain) and rainy condition. The laboratory analysis was conducted in accordance with the standard procedures: organic matter was COD (APHA ed. 21th 4500-H^{+} B, 2005), and the physical properties (total suspended solids / TSS, turbidity and color) were measured by using spectrophotometer DR 2000.

The start up for the acclimatization of microorganisms was done naturally by flowing raw water continuously through the biofilter system to allow the forming of biofilm on the surface of the filter media. The biofilters were operated with a hydraulic residence time of 2 hours to reach a steady condition. The hydraulic residence time of two hours was selected based on the previous study. The steady state condition was determined by analyzing the color, turbidity, TSS and COD removal efficiencies.

In this experiment, a loading test was conducted by adding a solution of detergent into the influent stream and then the concentrations of the detergent in the influent and effluent were observed. The detergent which was added to the influent stream resulted in a detergent concentration of 0.1-1.6 mg/L. The abilities of microorganisms in eliminating the detergent were seen by testing the detergent concentrations in raw water before and after treatment with biofilter unit. The detergent concentration analysis was conducted in accordance with the standard procedure of APHA (APHA Ed 21th 4500-S2-D, 2005).

3. RESULTS AND DISCUSSION

3.1. Raw water characteristics

Table 1 shows the physical characteristics of the raw water at sunny and rainy conditions. The measurement results show that the river water becomes more turbid at the rainy condition. The dirts on the soil surface in the watershed are carried away by the flow of rainwater into the river. On the other hand, the sediment on the riverbed can be mixed and lifted up by the turbulent flow of the river water and washed by the river stream causing the river water to be more turbid, and the TSS and color of raw water become higher. The measurement results show that the water quality does not meet the quality criteria as raw water (Class I, the Indonesian Government Regulation/IGR No. 82/2001), especially when it rains. In accordance with the standard, the TSS and turbidity shall not be more than 50 mg/L and 5 FTU. The color of raw water is not set in the regulation.

Table 1 Physical characteristics of raw water at sunny (not rain) and rainy conditions

Condition	Color (PtCo)	Turbidity (FTU)	TSS (mg/L)
Sunny	20	3	7
Rainy	419	88	77
Quality standard, Class I (IGR No. 82/2001)	-	5	50

3.2. TSS removal

All contaminants may contribute to the levels of solids in water, except dissolved gases. Solids in water can be classified based on the size, form, chemical properties, and size distribution. Based on its size, solid materials in water are classified into two groups for practical purposes, namely the suspended solids and dissolved solids. The solids in water are differentiated by using a filter (0.45 μm in pores diameter). Particles passing through the filter (0.45 μm in diameter) are classified as dissolved solids, and the particles retained by the filter are classified as suspended solids.

TSS is an important parameter of raw water quality, in addition to other physical parameters such as turbidity and colour. Biofilter can significantly reduce the levels of TSS. Figure 2 shows the TSS influent and effluent, as well as TSS removal efficiency (bottom) during biofiltration using the media of quartz sand and plastic honeycombs. The TSS removal efficiencies were still low at the beginning of the operation, at the level of approx. 20% both for the quartz sand biofilter and the plastic honeycomb biofilter. At the initial phase of the biofilter operation, microorganism growth on the media surface was still relatively few. The longer the time of operation, the more biofilm was formed leading to the more TSS elimination. The mechanism of the elimination of suspended solids is likely due to the mechanism of physical-chemical-biological process, i.e. filtration by the filter medium, adsorption by filter media (and microorganism) and degradation by microorganisms in the biofilm.

With an increase in the length of operation time, TSS removal efficiency increased. The increased TSS removal efficiency is an indication that the microorganisms on the filter media surface have grown and multiplied, forming a thicker biofilm layer than before, resulting in a higher TSS removal. The TSS removal efficiency began to show a maximum level on day 20 i.e. 65% for the plastic honeycomb biofilter and 80% for quartz sand biofilter.

On the 25th day, the TSS removal efficiency of the plastic honeycomb biofilter dropped dramatically due to an increased TSS level in effluent. The increased TSS level in the effluent is probably as result of biofilm release (death of microorganisms) so carried away by the effluent and contributed to an increase in TSS. The death of biofilm biomass can occur due to biomass age or sudden environmental changes (Schuner and Jarvis 2009).

The TSS removal efficiency reached a virtually steady state condition at the operating time of approx. 15 days with TSS removal efficiency of around 80% for the quartz sand biofilter and about 70% for plastic honeycomb biofilter. As shown in Figure 2, the two types of biofilter can reduce a high TSS load fluctuation. Despite a highly fluctuated TSS content in influent, TSS effluent was relatively stable. This biofilter effect is very important in maintaining the stability of the subsequent water treatment plant units. The TSS removal efficiency was slightly better in the media of quartz sand biofilter than in plastic honeycomb biofilter.

3.3. Turbidity removal

Turbidity is an important characteristic that is easily detected visually. Water will be turbid if it contains colloidal or suspended particles. The principle of turbidity measurement is to measure the light transmission using standard light sources. The test is useful in determining water quality in drinking water treatment. Turbidity removal efficiency during the startup of the biofilter is presented in Figure 3. At the beginning of the biofilter operation, turbidity removals were relatively low with an average of 10-20%. TSS removal efficiency began to increase in the second week and reached a stable value at an operating time of 30 days. In the virtually steady state conditions, the turbidity removal efficiency is approx. 75% for biofilter quartz sand and 55% for plastic honeycomb biofilter. Like the TSS parameters, the biofilter is also able to reduce a high fluctuation in the influent turbidity. Despite the dramatic increase in influent turbidity, the effluent turbidity is relatively stable and low.

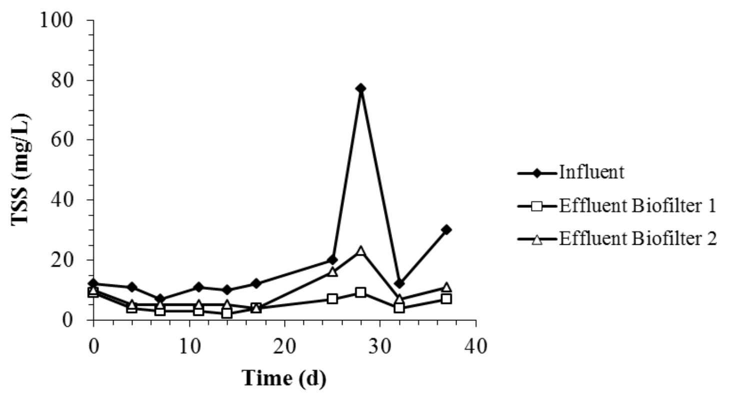


Figure 2 TSS influent and effluent during biofiltration with filter media of quartz sand filter media (Biofilter 1) and plastic honeycomb (Biofilter 2)

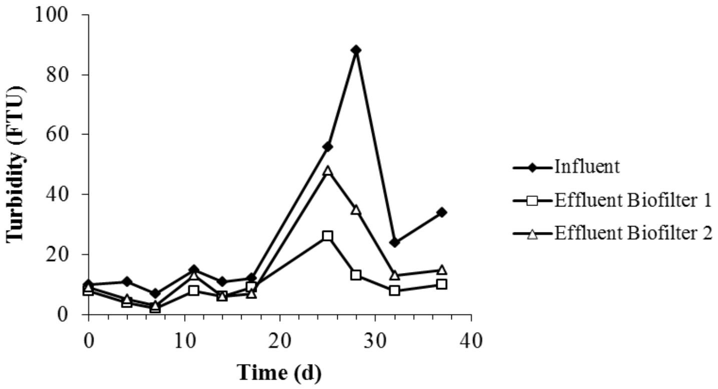


Figure 3 Turbidity influent and effluent during biofiltration with filter media of quartz sand (Biofilter 1) and plastic honeycomb (Biofilter 2)

4.4. Color removal

Color is a physical parameter of water quality indicating suspended materials and dissolved materials in water. Various colors can join in the water, but the true color of the water is caused by dissolved materials that usually originate from the decay of organic materials, such as plant biomass. Some types of industrial waste water can also contribute to the color of the water if the waste water is discharged into the river without appropriate handling. Various causes the dissolved material can be degraded color microbiologically in biofiltration systems. Figure 4 shows the influent and effluent color during biofiltration with quartz sand filter and plastic honeycomb media.

In the second week, the color removal efficiency began to increase. On day 25, there was a surge of water color causing an increase in the color of the effluent. However, the color removal efficiency increased again in the following days. Color removal efficiency was relatively fluctuating due to a lower physical filtration effect of either sand or plastic honeycomb against water color. In general, color removal efficiency is relatively low, only about 60% for the quartz sand biofilter and 20% for the plastic honeycomb biofilter. In addition, the color removal of the quartz sand biofilter is slightly higher than that of the plastic honeycomb biofilter. The principle of both biofilters is similar, namely the capturing of pollutants in water using filter material and microorganisms that grow on the surface of the filter material degrades the captured pollutants into elements or simpler compounds. However, quartz sand biofilters have additional effects in the form of physical filtration due to lower void filter material, causing the arrest is better and the degradation of pollutants. This resulted in a higher removal of pollutants and better quality of treated water.

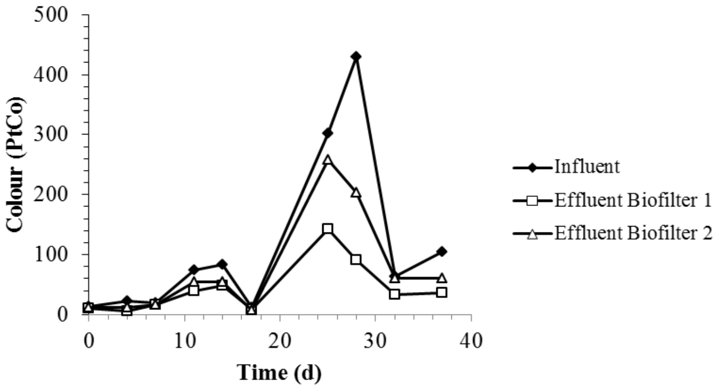
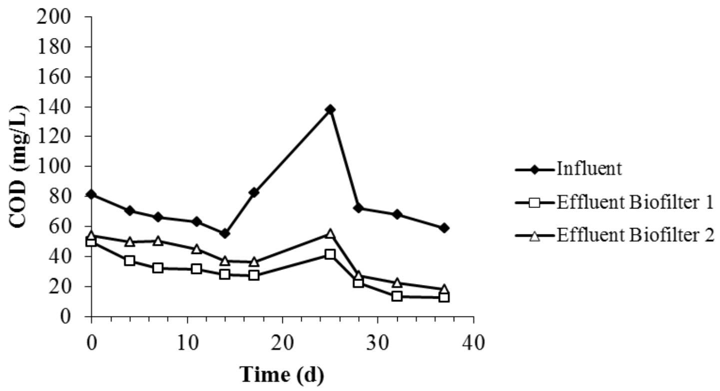


Figure 4 Color influent and effluent during biofiltration with filter media of quartz sand (Biofilter 1) and plastic honeycomb (Biofilter 2)

4.5. Organic matter removal

Various dissolved materials can be degraded biologically in the biofilter system. Figure 5 shows the influent and effluent COD during the biofiltration process. The increase of COD removal efficiency with the increased operation time is also presented in the figure. At the beginning of the biofilter operation, there is still few microorganisms' growth on the surface of the filter media resulting in a relatively low COD removal. Microorganism needs time for adaptation and growing on the surface of the media, often referred to as the acclimatization process. In the experiment, the process was realized by continuous flowing of raw water through the biofilter media bed to low microorganism forming a biofilm attached on the surface of the media. A steady state condition can be reached after acclimation process of approx. 30 days in the view point of COD removal.



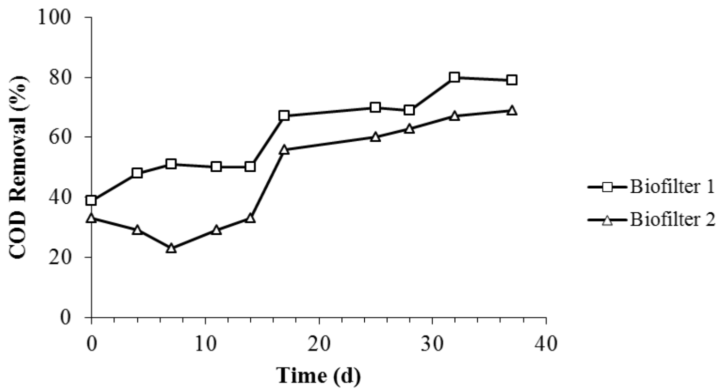


Figure 5 COD influent and effluent (top) and COD removal efficiency (bottom) during biofiltration with filter media of quartz sand and honeycomb plastic

The biofilter systems are supplied with sufficient oxygen continuously to support the growth of microorganisms. Raw water and oxygen will be in contact with microorganisms attached to the surface of the media, so that the process of organic material decomposition occurs. The formation of biofilm on the surface of the media can be seen visually. Widayat et al. (2010) identified *Bacillus subtilis*, *Clostridium*, and *Proteus sp.* as the most dominant decomposers of organic compounds in the biofiltration system. The increasing water pollutant removal efficiency during biofiltration start up is also an indicator of the acclimatization process. The COD in the effluent decrease with an increased operation time (from day 0 to 13). On day 25, there was a surge COD load in the influent due to a heavy rain. Although the surge COD in the influent was up to 140 mg/L, COD in the effluent was relatively stable at a value of about 40-50 mg/L. This indicates that the surge COD in the effluent does not significantly affect the COD in effluent both for quartz sand biofilter and plastic honeycomb biofilter.

In the first week low, the COD removal was still low at only about 25-50% in both the quartz sand biofilter and plastic honeycomb media biofilter. Starting from the second week, the COD removal efficiencies increased to 60-70%. This indicates that the microorganism biofilm are already formed and capable to remove more organic materials. At the fourth week, the COD removal efficiency reached a relatively stable value of about 80% for the quartz sand biofilter and about 70% for plastic honeycomb biofilter. In this condition, it can be assumed that the microorganism are acclimated and adapted to the environment (Winkler 1981). As shown in Figure 5, at the condition the COD removal efficiency is approx. 80% for quartz sand biofilter and 60% for plastic honeycomb biofilter, with COD effluent of 13 mg/L for quartz sand biofilter and 20 mg/L for honeycomb plastic biofilter.

3.6. Detergent removal

At the end of the experiment, a preliminary study on biofilter loading with detergent was carried out to know the ability of the biofiltration system in eliminating detergent, a common pollutant of domestic wastewater. The loading test was conducted by adding a detergent solution into the influent stream, and measuring the concentrations of the detergent in the influent and effluent to determine a change in the detergent concentration. The detergent concentration in the influent ranged from 0.1 to 1.6 mg / L, while the concentration of the detergent in the effluent ranged from 0.6 to 1.1 mg / L. The detergent concentration in the effluent increased with the increased detergent concentration in influent, but the concentration of detergent in the influent concentration generally decreased after a treatment with biofilter (Figure 6). This indicates that biofiltration system is able to eliminate pollutant detergents. The quartz sand biofilter can eliminate detergent of approx. 55%, whereas the plastic honeycomb biofilter eliminates detergent of approx. 45%. In general, the detergent concentration in effluent tends to increase with the increasing concentrations of detergent in the influent.

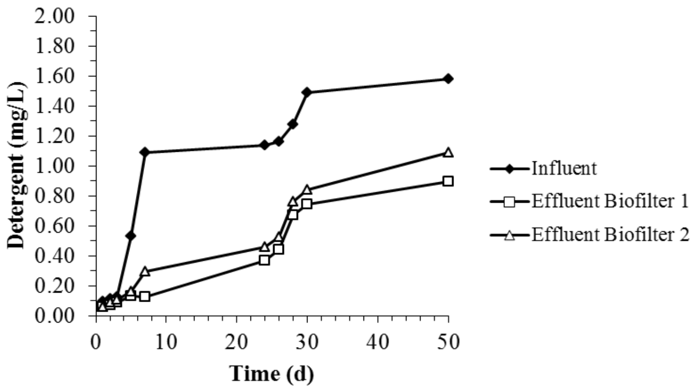


Figure 6 Detergent influent and effluent concentration during biofiltration with filter media of quartz sand filter and plastic honeycomb

5. CONCLUSION

Biofilter is able to remove physical pollutants (TSS, turbidity, and color) and organic matter (measured as COD) from polluted river water. Pollutant removal efficiency increases with an increased operating time, and achieves a stable condition (virtually steady state) after the operating time of about 20 days. Because of the additional effect of physical filtration in the quartz sand biofilter, the ability of the quartz sand biofilter is generally higher than that of the biofilter with plastic honeycomb. Both types of biofilters can reduce the high fluctuations of physical and organic pollutant load in the raw water, so that the shock load of the subsequent water treatment plant can be avoided. A preliminary loading test with detergent indicates that the biofilter can reduce detergent in the raw water. The increased raw water quality can reduce water treatment cost and the risk to public health.

Further research is still needed to optimize the biofiltration system, determine design and operating parameters, as well as analyze the techno-economical aspects.

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