Performance Evaluation of Food-Processing Wastewater Treatment Facility in a Small-Scale Sanjai Industry

Reni Desmiarti [a,1,] , Maulana Yusup Rosadi [b,2*], Lisa Aprilia [a,3], Adrian Zaki Zayyan [a,4]

[a] Department of Chemical Engineering, Universitas Bung Hatta, Jl. Gajah Mada No. 19, Padang 25173, Indonesia
[b] Department of Civil Engineering, Universitas Borobudur, Jl. Laksamana Malahayati No. 1, Jakarta 13620, Indonesia
[1] desmiarti@bunghatta.ac.id; [2] mrosadi@borobudur.ac.id*; [3] lisaaprilia548@gmail.com; [4] adrianzaki@gmail.com
* corresponding author

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ABSTRACT

Payakumbuh, Indonesia, is renowned for its traditional cassava chips known as sanjai, which are a significant part of the local economy. The production process, primarily operated by small-scale industries, generates approximately 1.5 tons of sanjai per day, resulting in a substantial discharge of wastewater—about 3,300 liters daily. To mitigate the environmental impact, a dedicated wastewater treatment facility was developed, incorporating a trickling filter system as its core treatment component. This system utilizes an attached growth process with a fixed medium, enabling microorganisms to degrade organic pollutants effectively. The objective of this study was to evaluate the operational performance of this facility by monitoring key wastewater quality parameters, including pH, chemical oxygen demand (COD), biological oxygen demand (BOD), and total coliform count. Over a monitoring period of 145 days, the influent COD and BOD levels averaged 2,504 mg/L and 1,587 mg/L, respectively. The treatment system achieved significant pollutant reductions, with removal efficiencies of 65% for COD, 79% for BOD, and 87% for total coliform. The results indicate that the trickling filter system can effectively support microbial growth capable of degrading organic matter even at slightly acidic to neutral pH levels (5–7). Overall, the study demonstrates that trickling filters offer a practical, efficient, and environmentally sustainable solution for managing wastewater in small-scale food processing industries such as the sanjai industry in Payakumbuh.

1. Introduction

The food-processing industry developed massively in Payakumbuh, Indonesia, in 2022, primarily for cassava products called sanjai. Sanjai is a traditional chip made from sliced cassava deep-fried with coconut oil until crispy. A small-scale sanjai industry with a production capacity of 500–1500 kg/day produces 1,100–3,300 L/day of liquid waste as sanjai wastewater, which is left untreated and discharged to the open channel. Meanwhile, untreated wastewater contains contaminants, such as organic matter, nutrients, and pathogens that harm public health and the receiving ecosystem [1].

Food-processing wastewater generally contains high chemical oxygen demand (COD) (20,000–50,000 mg/L), biological oxygen demand (BOD) (10,000–30,000 mg/L), and total suspended solids (2,000–10,000 mg/L) [2], [3]. A large amount of untreated wastewater from the food-processing industry is released into the environment, deteriorating the water quality in the surface water bodies. Biological treatment is considered a cost-effective method to treat wastewater and has been extensively used for various types of sewage origins [4]. However, the problems that arose from biological treatment were clogging and a low hydraulic loading rate, thus decreasing the effectiveness of biological therapy. Trickling filters are perhaps the most feasible and cost-effective process for removing and reducing organic and inorganic compounds from food-processing wastewater [5]. Previous researchers investigated wastewater treatment from craft breweries. They found satisfactory removal efficiency for BOD and COD of 76% and 80%, respectively, from a laboratory-scale model with a trickling filter operating with 100% recirculation [6]. The sequential vertical follow trickling filter removed COD 92.1% with an initial concentration of 960 mg/L from decentralized domestic wastewater [7]. It also showed the elimination of specific microorganisms caused by organic loading degradation. However, there is less information on how a trickling filter can successfully eliminate the wastewater discharged from the sanjai industry.

Establishing the wastewater treatment plant for a small-scale food industry considers the wastewater generated and the complexity of contaminants in wastewater to estimate the proper treatment units, thus reducing the installation cost [8], [9]. Trickling filters only require a small area for installation, are easy to operate and maintain, have low construction costs, are energy-saving, and are cost-effective methods for wastewater treatment. The installed media filter provides a suitable location for biofilm development on the media's surface, where treatment is done with the degradation of organic and inorganic materials by microorganisms [10]–[12]. In Indonesia, wastewater treatment for the food industry is rarely established, resulting in the direct discharge of wastewater into the environment. The Ministry of Environment of the Republic of Indonesia has established the effluent standards for food-processing wastewater under Regulation No. 5 of 2014. These guidelines are based on the performance capabilities of wastewater treatment and control technologies. Accordingly, treatment facilities within the food-processing industry must comply with these standards and continuously improve their treatment technologies, regardless of the potential risk or impacts on the receiving waters. Therefore, this study aims to evaluate the food-processing wastewater treatment plant established in the small-scale sanjai industry. The plant consists of a pre-treatment tank, receiving well, trickling filter, and clarifier. The trickling filter was operated at 25–30℃ at atmospheric pressure to ensure low energy consumption. The media filter was constructed using plastic media due to its low weight, high specific surface area, and high void ratio (>90%). The performance evaluation of Sanjai wastewater treatment is evaluated by the changes in pH, COD concentration, BOD concentration, and total coliform after treatment from each unit.

2. Research Methodology

2.1. Wastewater Used in This Study and Water Quality Parameters

A sampling campaign was conducted from October 2022 to February 2023 in a sanjai industry in Payakumbuh, Indonesia. Table 2 shows that a 1 L pre-soaked chlorine glass bottle collected the wastewater from each treatment unit. pH, COD, BOD, and total coliform were measured according to standard methods [13]. The initial characteristics of Sanjai wastewater are shown in Table 1.

Table 1. Initial wastewater characteristics obtained from this study

Parameters	Value	Maximum levels required by the Indonesian Government	Method and standard used [13]
pH	4	6–9	APHA 4500-H+ (calibrated portable digital pH meter)
COD (mg/L)	2,504	100	APHA 5220 B (dichromate reflux method)
BOD (mg/L)	1,587	50	APHA 5210 B (incubation at 20°C for 5 days)
Total *coliform* (MPN/100 mL)	110,000	10,000	APHA 9221 B (Most probable number (MPN) method)

2.2. Wastewater Treatment Plant Design

Fig. 1. shows the process flow of the Sanjai wastewater treatment plant. Wastewater generated from *the sanjai industry was collected in a receiving well in which a pre-sedimentation process was*

performed to settle the large particulate matter, *such as soil and sand from the washing process of raw cassava*, *as well as the suspended solids*, before entering the trickling filter. In the trickling filter unit, wastewater was allowed to contact the plastic media to form biofilm. The generated biofilm will further develop on the surface of the media filter to assist the biodegradation process. The clarifier is the final treatment unit for the final sedimentation process. The clarifier was installed with plastic media called biofoam to enhance the separation of the release of suspended solids in the effluent on the trickling filter and further settle in the clarifier. Each treatment unit's initial influent and effluent will be examined for pH, COD, BOD, and total *coliform*.

Table 2. Summary of the sampling campaign schedule and conditions

Sampling campaign (day)	Date	Condition	Measured parameters	Number and point of samples collected
1	3 October 2022	Initial day of technology operation	pH	
4	6 October 2022	Fourth day of technology operation	pH, COD, BOD, total *coliform*	
8	10 October 2022	Acclimation period	pH	
12	14 October 2022	Acclimation period	pH, COD, BOD, total *coliform*	
13	15 October 2022	Acclimation period	pH	
15	17 October 2022	Acclimation period	pH, COD, BOD, total *coliform*	
18	20 October 2022	Acclimation period	pH, COD, BOD, total *coliform*	
23	25 October 2022	Acclimation period		4 (influent, receiving well, trickling filter, clarifier)
26	28 October 2022	Biofilm generation	pH, COD, BOD, total *coliform*	
33	4 November 2022	Biofilm generation	pH, COD, BOD	
41	12 November 2022	Biofilm generation		
48	19 November 2022	Biofilm generation	pH, COD, BOD	
54	25 November 2022	Optimum operation condition	pH, COD, BOD	
107	17 January 2023	Optimum operation condition	pH, COD, BOD	
119	29 Januari 2023	Optimum operation condition	pH, COD, BOD	
131	10 February 2023	Optimum operation condition	pH, COD, BOD	
145	24 February 2023	Optimum operation condition	pH, COD, BOD	

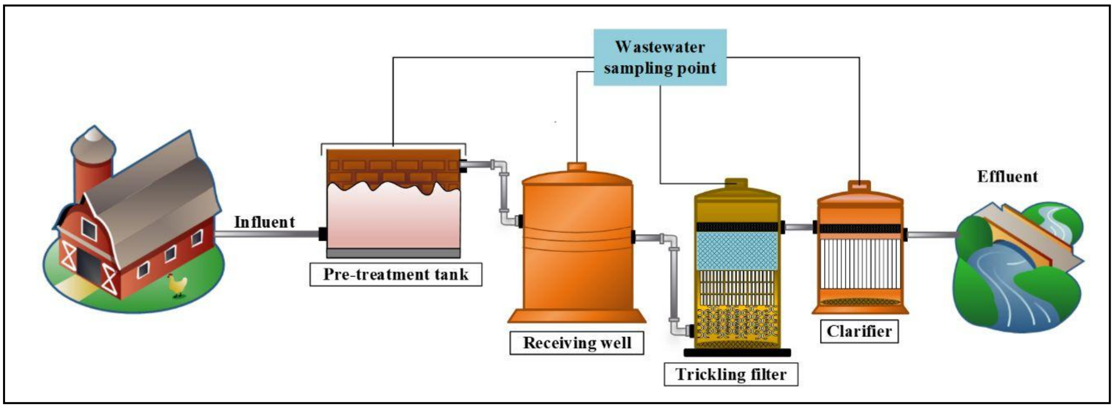

Fig. 1. Process flow of Sanjai wastewater treatment plant

3. Results and Discussion

3.1. Changes in pH Value Across the Wastewater Treatment Process

Fig. 2. shows the pH value of the effluent from each treatment, and a noticeable increase in pH value of 7 was observed in the final effluent. The influent of wastewater had a pH value of 4, indicating the influent contained acid-based compounds. Using food coloring materials to produce *sanjai* affected the pH value of the wastewater influent. Redbill dye contains tartrazine compounds ($C_{16}H_9N_4Na_3O_9S_2$), which are a mixture of phenol compounds, polycyclic hydrocarbons, and heterocyclic acids, which are acidic, thus lowering the pH value in the influent.

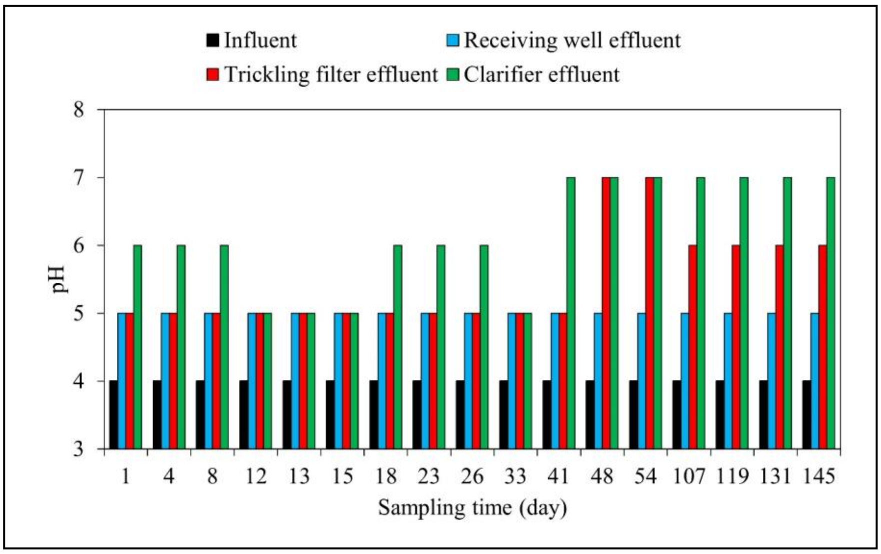

Fig. 2. Changes in pH of wastewater effluent from each treatment

The increase in pH value across treatment units could be due to microorganisms' decomposition of organic materials [14]. However, the pH value in the effluent of the trickling filter remained constant until day 33 and sharply increased to 7 on day 41. The constant pH value in the effluent of the trickling filter demonstrated that the activity of the microorganisms in the biofilter was not fully acclimated, resulting in no degradation processes occurring [15], [16]. Microorganisms will degrade the accumulated organic materials in the biofilter into smaller fractions of organic matter that metabolizing microorganisms will efficiently utilize. The anaerobic process in the trickling filter decreased ORP, thus increasing the pH value. Additionally, the soluble Na acted as a reductant that might increase the pH value in the effluent of trickling filters (ORP -185 mV on day 48). The increased pH value is also caused by the accumulated organic nitrogen in wastewater converted into ammonia by ammonification [17], [18]. The pH in the final effluent reached seven and met the pH standard of wastewater effluent.

3.2. Changes in COD Concentration and Its Removal

The COD concentration in the influent of wastewater varied across the sampling time, which ranged from 1.325–2.504 mg/L, and the highest COD concentration was observed on day 4 (Fig. 3). The initial COD concentration sharply decreased on day 33 and remained stable until day 54, and continued to increase until day 145. This suggests that the production amount of sanjai on the corresponding days affected the COD content in the wastewater influent. The pre-sedimentation caused a decrease in COD concentration, and the maximum removal by pre-sedimentation was recorded at 59% on day 4, owing to the high concentration in the influent of wastewater. The removal of COD ranged from -23 to -22%, with the highest COD removal observed on day 145. The negative COD removal indicates the enhancement of organic material concentration. On days 4 and 12, the enhancement of COD might be due to the unsuccessful acclimation of microorganisms to degrade organic materials further [19]. Also, the flocculation of dissolved COD could be the reason for the enhancement of COD. At this point, we considered that the start-up period did not reduce COD by the trickling filter. Instead, the flocculation of dissolved COD perhaps led to the enhancement of COD in the effluent of the trickling filter.

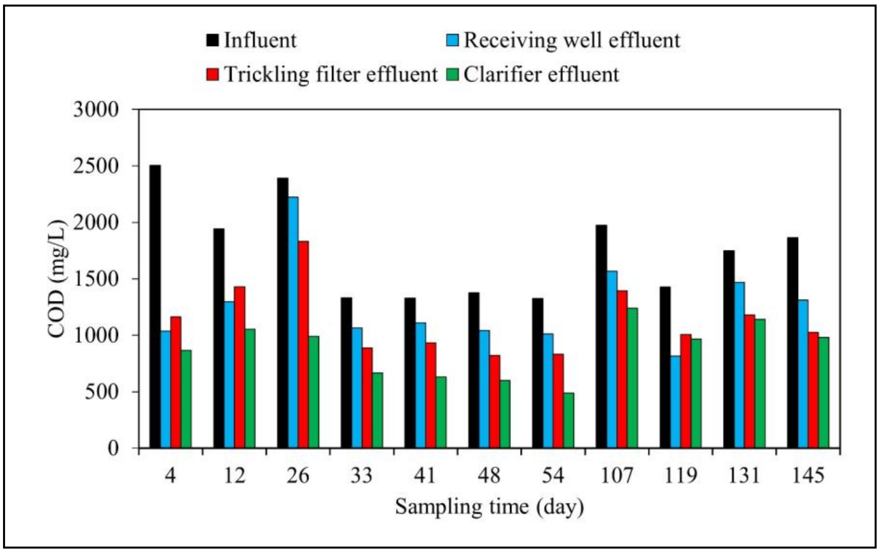

Fig. 3. Changes in COD of wastewater effluent from each treatment

Meanwhile, a similar trend of decreasing COD concentration by the trickling filter was observed from day 26 until the end of the investigation. This indicates the acclimation of appropriate biomass capable of degrading this type of wastewater. However, an increase in the COD concentration was observed on day 119. The reason could be that the sloughed biofilm is detached from the media filter and enters the water. A previous study reported that the highest COD removal by trickling filter was obtained at 95.4%, demonstrating that the maximum acclimation was achieved during the last acclimation phase of the trickling filter [20]. Nevertheless, the trickling filter in this study only reached 22% of COD removal, which is unsatisfactory for reducing contaminants. This could be due to the small number of active microorganisms in the biofilter degrading the newly added organic materials [21]. It can be concluded that the start-up period was not completed, and the filter was not ready for the whole operation. Clarifier decreased COD concentration with the highest reduction in COD of 46% on day 26, while the lowest COD concentration (3%) was observed on day 131. The lowest COD removal on day 131 might be attributed to biofilm release from filter media in the trickling filter, which enhanced the amount of dissolved organic materials in the influent of the clarifier. Moreover, the residual COD, which was unable to settle, resulted in the lowest COD removal by the clarifier.

The overall COD removal efficiency of the Sanjai wastewater treatment was 65%. This removal efficiency was acceptable compared to the previous studies that reported COD removal in the 60–75% range with the COD concentration above 5.000 m/L in the influent of their wastewater [20], [22]. However, looking into each wastewater treatment unit, the performance of the trickling filter was unsatisfactory owing to its unready operational period. The sedimentation process in the pre-treatment tank and clarifier seemed more prone to eliminate COD. Furthermore, this study's final COD concentration does not meet the standard quality for wastewater effluent regulated by the Indonesian Government (100 mg/L). Thus, improving Sanjai wastewater treatment is required to ensure that the effluent quality meets acceptable levels.

3.3. Changes in BOD Concentration and Its Removal

Like COD, the initial BOD concentration varied during the sampling period and decreased across the treatment stage, with the highest initial BOD concentration of 1.705 mg/L. The varied initial BOD concentration was also affected by the daily production capacity of Sanjai, which resulted in a low BOD concentration in the final effluent from Sanjai wastewater treatment. Pre-sedimentation in the pre-treatment tank was found to remove BOD with a maximum removal of 58%. It could be concluded that relatively high BOD removal efficiency by pre-sedimentation is due to the abundant suspended BOD contained in wastewater that easily settles.

The trickling filter showed a maximum removal efficiency of 30% of BOD. Yet, the enhancement of BOD was observed on days 12, 119, and 131 with the enhancement rate of 11%, 44%, and 68%, respectively. Like COD, 12 days was not significant enough for biofilm development, resulting in the undegraded organic materials flowing through the trickling filter. Like

COD, the increase in BOD concentration might be caused by the release of organic materials due to biofilm detachment. The maximum BOD removal efficiency was 30% on day 145, with the initial BOD concentration being 178 mg/L, because of the developed biological degradation of organic materials by microorganisms due to higher retention time. Higher BOD removal efficiency on day 145 was also probably due to higher oxygen availability for maintaining the aerobic zone in the outer portion of the biofilter, which causes the degradation of organic materials [23], [24]. In addition, high COD and BOD removal caused by the nitrification by microorganisms on the biofilter was observed in this study. The results further confirm the earlier studies on the efficiency of the trickling filter in eliminating organic materials in terms of COD and BOD [20], [25], [26].

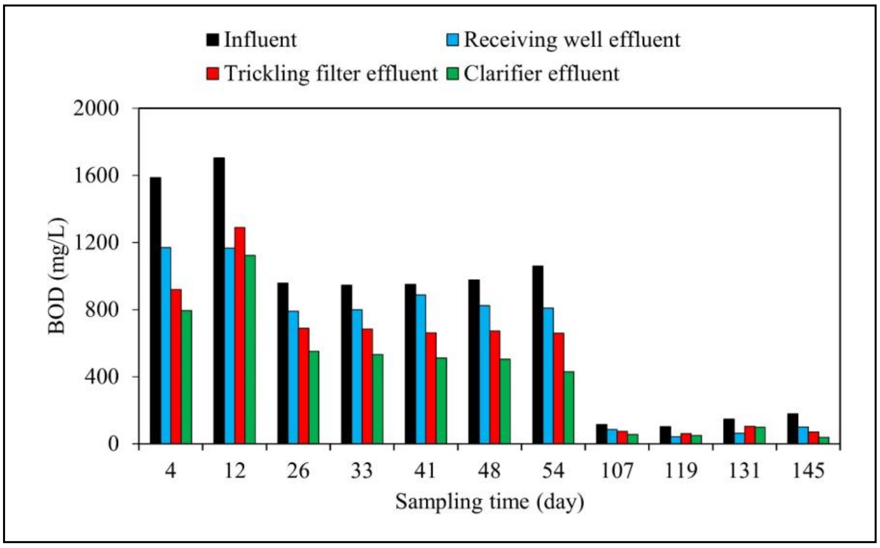

Fig. 4. Changes in BOD of wastewater effluent from each treatment

The overall BOD removal efficiency was 34–79% by the *Sanjai* wastewater treatment. It was observed that the BOD concentration in the initial wastewater decreased, and the BOD removal efficiency increased. This was due to variation in the initial BOD concentration because of the reduced retention time of wastewater to contact the biofilter to degrade the organic materials [23]. Furthermore, the residual BOD in the trickling filter effluent was settled in the clarifier, and the removal efficiency due to settling was unsatisfactory. It did not meet the standard quality for BOD of the wastewater effluent regulated by the Indonesian Government (< 40 mg/L). Since the *Sanjai* wastewater treatment is still under the optimization period, the performance of each treatment to remove BOD and COD is not acceptable compared to the earlier studies [19], [25], [26].

3.4. Changes in Total Coliform and Its Removal

According to Table 3, total *coliform* in the wastewater influent on day 4 was higher than on the following days. Again, the pre-sedimentation process is more prone to eliminating contaminants than the trickling filter. It was observed that pre-sedimentation caused a significant decrease in the total *coliform* by 99% on days 4 and 12, while only 59% of removal efficiency was obtained on day 26, due to the lowest initial concentration of total *coliform* in the wastewater. The higher removal efficiency on days 4 and 12 was probably due to more microorganisms forming flocs and attaching to the large particulate matter that is easy to settle. There were no significant changes in total *coliform* number in the effluent of the trickling filter on days 4 and 12. Obviously, the start-up period did not form biofilm immediately; thus, microorganisms had no metabolic activity to grow. A high increase in the total *coliform* number was observed on day 26. This indicated that the biofilm had already formed and led to the high metabolic activity by microorganisms to grow rapidly. The longer retention time in the trickling filter caused the biofilter to lose adsorption capability due to the accumulated particulate materials on the surface of the filter [27]. This could also be the reason for the increase in the total *coliform* concentration in the effluent of the trickling filter on day 26 by 15%. The finding is supported by researchers, who reported that the decline in the removal efficiency of total coliform was caused by the retention time that inhibited the interaction between wastewater and the media filter [28].

Total *coliform* was found to increase in the effluent of the clarifier with an enhancement rate of 8% and 53% on days 4 and 12. The high increase in the total *coliform* in the effluent of the clarifier was probably caused by the release of microorganisms due to the competition among microorganisms and the accumulation of organic and inorganic materials in the biofoam installed in the clarifier. The design of the clarifier with biofoam assisted in the additional removal of TSS, TDS, COD, and BOD before the settling. At the same time, it will release organic and inorganic materials into the water due to biofilm development on the biofoam surface. In plant designs, clarifiers should result in clearer and cleaner final effluent due to the settling mechanism of the sloughed biofilms and other solids [29], [30]. Therefore, it is surprising that the enhancement of total coliform was observed after settling in the clarifier. Thus, optimizing the operational efficiency of the treatment units is required to enhance the performance of *the Sanjai* wastewater treatment.

Table 3. Removal of total coliform by each unit in the Sanjai wastewater treatment facility

Parameters	**Removal (%)**		
	Day 4	***Day 12***	***Day 26***
Pre-sedimentation	99%	99%	59%
Trickling filter	99%	99%	-15%
Final sedimentation	-8%	-53%	90%

4. Conclusion

The study investigated the performance of *the Sanjai wastewater treatment plant in the initial operational period by examining the changes in pH, COD, BOD, and total coliform*, as well as their removal efficiency. The overall performance of *the Sanjai wastewater treatment was relatively satisfactory in removing COD, BOD, and total coliform, with a removal efficiency of 65%, 79%, and 99%, respectively, showing good performance of the Sanjai* wastewater treatment plant. However, the primary process of degrading the organic materials using the trickling filter was unsatisfactory in removing and reducing COD, BOD, and total *coliform*, resulting in water quality that does not meet the standard quality for wastewater regulated by the Indonesian government. The operational period was the main reason for the unsatisfactory removal of COD, BOD, and total coliform, in which there was no development of biofilm to perform degradation attached to the surface of the media filter. However, the sedimentation process in the pre-treatment tank and clarifier showed an acceptable maximum removal efficiency of 50%. Therefore, improving the existing wastewater treatment plant, especially for the trickling filter, is required to ensure that the effluent quality meets acceptable levels.

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