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The Effect of Distillation on Several Types of River Water on Clean Water and Drinking Water Quality Standards

Adi Permadi [a,1,*], Arief Syamsuddin [b,2], Totok Eka Suharto [a,3], Mutiara Wilson Putri [a,4], Rachmadian Wulandana [c,5]

[a] Department of Chemical Engineering, Faculty of Industrial Technology, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[b] Department of Automotive Technology Vocational Education, Faculty of Teacher Training and Education, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[c] Mechanical Engineering Program at the State University of New York (SUNY) New Paltz, New York, USA
[1] adi.permadi@che.uad.ac.id*; [2] arief.syamsuddin@pvto.uad.ac.id.; [3] totok.suharto@che.uad.ac.id; [4] 2300020037@webmail.uad.ac.id;
[5] wulandar@newpaltz.edu
* corresponding author

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ABSTRACT

This research was conducted to evaluate the effectiveness of a distillation device in producing clean water from five major rivers in Yogyakarta, namely the Progo, Oyo, Opak, Gajah Wong, and Code Rivers. The distillation process utilizes an organic waste combustion system as a heat source to generate water vapor from river water, which is then condensed into liquid form. This method not only aims to produce clean water but also to promote sustainable practices by utilizing readily available organic waste as fuel. The study analyzed the resulting distilled water based on physicochemical and microbiological parameters in accordance with the clean water quality standards set by the Indonesian Ministry of Health. Parameters such as pH, turbidity, mineral content, total dissolved solids (TDS), and microbial contamination were measured. The results indicated that the distillation device was capable of producing water that met several clean water criteria, though variations in distillation efficiency were observed across river sources. These inconsistencies were mainly attributed to factors such as leakage in the device, fluctuations in combustion temperature, and differences in the initial water quality of each river. Furthermore, the distillation process significantly altered certain chemical characteristics, including a reduction in mineral content and shifts in pH values. In conclusion, while the distillation method shows potential as a viable alternative for clean water production, especially in rural or resource-limited areas, further improvements in system stability and design optimization are needed to enhance its consistency and overall effectiveness.

1. Introduction

Water is essential to all biological and human activities, including industrial processes, agriculture, and production [1]. Water is generally accepted as an unlimited natural resource available [2]. Although freshwater is often considered an unlimited resource due to the hydrological cycle, freshwater availability is unevenly distributed. Over 70% of the Earth's surface is covered by water, but over 97% is saltwater, leaving less than 0.007% of freshwater accessible for domestic use [3], [4].

Natural water sources contain dissolved minerals, organic matter, and various contaminants, including NO_2^- and NO_3^- from agricultural and domestic waste [5]. Household wastewater, including used bathing and laundry water, contributes to pollution, rendering water unsafe for consumption [6]. Treatment processes are necessary to ensure safe drinking water. Raw water, sourced from surface or groundwater, undergoes purification to meet quality standards set by regulations such as Permenkes No. 492/2010 and PP No. 122/2015 [7], [8].

Various purification methods produce potable water, including chemical, physical, and bacteriological treatments [9], [10]. Distillation is a widely recognized technique miming the natural water cycle by evaporating and condensing water to remove impurities. Solar water distillation offers a sustainable approach to wastewater treatment, effectively producing clean drinking water [11], [12]. Other technologies that have been developed include multiple-effect evaporation, membrane distillation, and hybrid desalination systems [13]. MSF, widely used in large-scale desalination, is often integrated with power plants for efficiency, while RO and EDI provide high-purity water for industrial and domestic applications [14], [15].

Alternative distillation technologies, such as Multi-Effect Distillation (MED) and hybrid desalination systems, are gaining prominence due to improved efficiency and sustainability [16]. MED, in particular, is expected to play a more significant role in future desalination due to its lower energy requirements than MSF [17], [18], [19]. Water quality is strongly influenced by chemical factors, such as pH, ammonia, sulfate, hardness, metals, and nitrate or nitrite compounds, as well as other physical factors, including current speed, brightness, depth, color, turbidity, salinity, and TDS (Total Dissolved Solids) or TSS (Total Suspended Solids) [20], [21].

Various water treatment methods ensure clean and safe drinking water, with distillation being one of the most effective techniques [22], [23]. Given the growing demand for clean water and the uneven distribution of freshwater resources, distillation offers a viable solution, especially in regions with limited conventional water treatment facilities. This study explores the effectiveness of distillation in producing clean water from river sources, emphasizing its potential for sustainable water purification in underserved areas [24], [25].In regions lacking adequate clean water access, distillation remains a viable solution. This study aims to evaluate the effectiveness of a distillation device in producing clean water from five different rivers, namely the Progo, Oyo, Opak, Gajah Wong, and Code Rivers.

2. Research Methodology

2.1. Materials

This study uses river water from 5 different types of rivers, namely the Progo River with the collection coordinates (-7.841223,110.225090), the Oyo River with the coordinates (-7.945905,110. 426776), Opak River with coordinate point (-8.010091,110.291764), elephant wong river with coordinate point (-7.847882,110.395759), and Code river with coordinate point (-7.892624,110.388313).

2.2. Procedures

Research procedures are written in this part.

1) Water Sample Collection

This study collected water samples from five rivers: Progo, Oyo, Opak, Gajah Wong, and Code. Each sample was taken in a volume of 10 liters and stored at a temperature of 4°C to prevent microbial growth and contamination before testing.

2) Distillation Process

The distillation process uses a combustion system fueled by organic waste, as shown in Fig. 1. The setup includes a boiler, combustion chamber, condenser, and distillate collection system. Raw water is heated in a sealed boiler using controlled combustion of materials like wood shavings and agricultural residues, with a fuel-to-water ratio of 1 kg per 3 liters evaporated. As the water heats above 100°C, it turns to steam, separating from contaminants such as dissolved solids, heavy metals, and microbes. The steam is then cooled in a condenser using river water, forming purified water that is collected for further analysis.

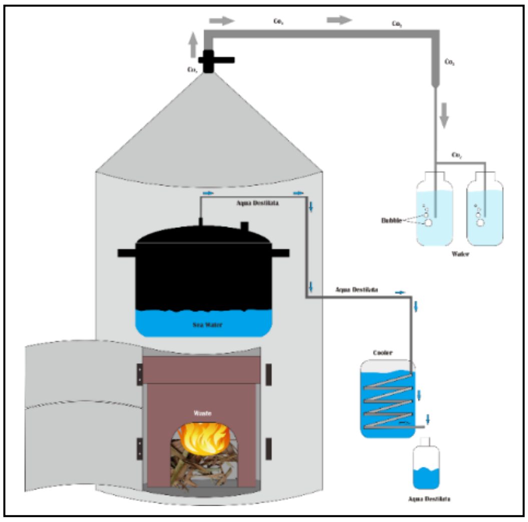

Fig. 1. Design of distillation apparatus. Process design of the Distillation model (left) and the organic waste combustion-based distillation equipment unit (right)

3) Water Quality Testing

After distillation, the purified water undergoes comprehensive quality testing to ensure its safety and compliance with drinking water standards. The testing is conducted at the UPT Health Laboratory in Yogyakarta, Sisingamangaraja Street No. 21, Brontokusuman, Mergangsan, Yogyakarta. The analysis includes physico-chemical and microbiological parameters based on PERMENKES RI No. 32 Tahun 2017. The physicochemical analysis evaluates parameters such as pH, turbidity, total dissolved solids (TDS), nitrate (NO_3^-), nitrite (NO_2^-), iron (Fe), manganese (Mn), cyanide (CN), and other chemical contaminants. The methods used for this testing follow Indonesian National Standards (SNI), APHA, and other established analytical techniques in Table 1.

Table 1. Parameters and methods used in physicochemical testing

Chemical, Physical, and Biological Tests	
Parameter Test	***Methods***
Odor	Organoleptic
pH	Potentiometry
Iron (Fe)	SNI 6989.4-2009
Manganese (Mn)	SNI 6989.5-2009
Fluoride (F)	SNI 06-6989.29-2009
Nitrate (as NO_3-N)	APHA 2017. Section 4500-NO3 B
Nitrite (as NO_2-N)	SNI 06-6989.9-2004
Total Hardness ($CaCO_3$)	SNI 06-6989.12-2004
Flavor	Organoleptic
Color	Photometry
Turbidity	SNI 06-6989.25-2005
Temperature	SNI 06-6989.23-2005
Total coliform	APHA 2017. Section 9222 -J
E-Coli	APHA 2017. Section 9222 -J
TDS	Potentiometry
Cyanide (CN)	002/SOP.V/LK-KY/VII/2022
Detergent	001/SOP.V/LK-KY/VII/2022

Additionally, microbiological testing is performed to determine the presence of harmful microorganisms. This includes Total Coliforms and *Escherichia coli* (*E. coli*). The microbial tests adhere to APHA, SNI, and ISO standards, ensuring that the distilled water meets national health regulations for safe consumption.

3. Results and Discussion

3.1. Organoleptic Test

Organoleptic tests were conducted on the odor and taste of pure river water and distillate water samples. Based on the test results, river and distillate water showed colorless and odorless characteristics. These results are based on the applicable clean and drinking water quality standards. Drinking water quality standards in SNI 01-3533-2006 and PP Number 12 of 2015. Table 2 shows the results of organoleptic tests conducted on river and distillate water.

Table 2. An organoleptic test was conducted to check the odor and taste of river water and distillate water

River Water Type	Parameter	Test Result		Quality Standard	
		Before	*After*	*Clean Water*	*Drinking Water*
Gajah Wong		No Odor	No Odor		
Code		No Odor	No Odor		
Progo	Odor	No Odor	No Odor	No Odor	No Odor
Oyo		No Odor	No Odor		
Opak		No Odor	No Odor		
Gajah Wong		Flavorless	Flavorless		
Code		Flavorless	Flavorless		
Progo	Taste	Flavorless	Flavorless	Flavorless	Flavorless
Oyo		Flavorless	Flavorless		
Opak		Flavorless	Flavorless		

Distillation does not alter the taste or odor of water because it effectively removes dissolved impurities, such as minerals, organic compounds, and contaminants, through phase separation. Since only pure water vapor is condensed into liquid form, volatile substances responsible for taste and odor are left in the boiling chamber [26].

3.2. pH Test

Based on the test results, it can be concluded that the pH of river water conditions before distillation shows that it is within the quality standards of clean water in the form of 6.5-9.0 and drinking water in the form of 6.5-8.5. Instead, the results are inversely proportional when the water has been distilled and tends to have a pH below the quality standards of clean water and river water, which is below 6.5, which means that this is not by existing standards. The distilled water's pH below the clean water quality standard is caused by the distillation process, which can produce a lower pH. This is because the distillation process removes impurities and dissolved solids, which can sometimes cause the pH to be slightly acidic if the distilled water absorbs carbon dioxide from the air, forming carbonic acid.

This is reflected in the analysis, where the pH value varies and can be lower than the standard [27].To raise the pH of water that has dropped, several methods can be used, including the addition of chemicals such as sodium bicarbonate to neutralize acidity [28], aeration to reduce dissolved carbon dioxide (CO_2) gas that causes low pH, and the use of alkaline filters that can add minerals such as calcium and magnesium to the water. The selection of these methods needs to be tailored to the condition of the water and its intended use [29]. Distilled water is highly pure and lacks dissolved minerals, making it more susceptible to absorbing carbon dioxide (CO_2) from the air. When CO_2 dissolves in water, it reacts to form carbonic acid (H_2CO_3), slightly lowering the pH of the distilled water [30], [31].

3.3. Iron Content Test (Fe)

Humans need iron to form hemoglobin, which can damage the intestinal wall if consumed in large amounts. If the iron level in water is more than 1 mg/l, it will irritate the eyes and skin. The water will smell like rotten eggs if the iron level exceeds 10 mg/l [32]. Iron levels in river water and distillate water.

The iron content test is conducted to see how much iron is dissolved in water. Based on quality standards, iron content in clean water is a maximum of 1 mg/L, while in drinking water, it is a maximum of 0.3 mg/L. After distillation, iron content decreases because Fe primarily exists in water as dissolved ions or particulate matter, which do not evaporate during the process. Instead, these impurities remain as residue in the boiling chamber, preventing them from being carried into the distilled water. Based on the test results obtained in Table 3, distillate water has Fe levels below the quality standards for clean water and drinking water listed in PERMENKES RI NO.32 TAHUN 2017.

Table 3. Iron levels in river water and distillate water

River Water Type	Parameter	Test Result		Quality Standard	
		Before	*After*	*Clean Water*	*Drinking Water*
Gajah wong	Iron (Fe)	0.034	<0.009	1	0.3
Code		0.038	<0.009		
Progo		<0.009	<0.009		
Oyo		<0.009	<0.009		
Opak		0.043	<0.009		

3.4. Manganese Content Test

The manganese (Mn) content test was conducted, and the results showed the level of manganese dissolved in river water and distillate water. Based on the quality standards listed in PERMENKES RI No. 32 of 2017, the maximum level of manganese in clean water is 0.5 mg/L, while for drinking water, it is 0.4 mg/L. This test also shows a decrease in manganese levels after the water distillation process, which is caused by some dissolved manganese precipitation. Based on the data in Table 4, manganese levels in river and distillate water were obtained and compared with the quality standards. Generally, river and distillate water have manganese levels that meet the quality standards for clean water and drinking water listed in PERMENKES RI NO.32 TAHUN 2017.

Table 4. Manganese levels in river water and distillate water

River Water Type	Parameter	Test Result		Quality Standard	
		Before	*After*	*Clean Water*	*Drinking Water*
Gajah wong	Mangan (Mn)	0.027	0.005	0.5	0.4
Code		<0.001	<0.001		
Progo		0.002	0.006		
Oyo		0.016	0.006		
Opak		0.08	0.034		

3.5. Nitrate Content Test (as NO_3-N)

One of the most common types of nitrogen found in natural waters is nitrate (NO_3^-), not nitrite (NO_2^-). Ammonium entering waterways through sewage and agricultural runoff undergoes nitrification, where microbial activity oxidizes ammonium to nitrite and then converts it into nitrate. If the highest nitrite concentration is found in the same river as the highest nitrate concentration, this suggests active nitrogen cycling, likely due to continuous ammonium oxidation. Excessive nitrate in water can indirectly harm aquatic ecosystems by promoting algal blooms, which deplete dissolved oxygen and disrupt marine life.

Table 5. Nitrate (NO_3-N) levels in river water and distillate water

River Water Type	Parameter	Test Result		Quality Standard	
		Before	*After*	*Clean Water*	*Drinking Water*
Gajah wong	Nitrate (as NO_3-N)	2.420	<0.006	50	50
Code		2.206	<0.006		
Progo		0.341	<0.006		
Oyo		0.530	<0.006		
Opak		0.234	<0.006		

Therefore, nitrate levels in the river and distillate water were tested, as shown in Table 5, to determine nitrate concentrations before and after distillation. After distillation, the overall nitrate level drops below 0.006 mg/L, demonstrating the effectiveness of the distillation process in reducing nitrate concentrations. Generally, river and distilled water comply with the quality standards for nitrate in clean and drinking water, which is set at a maximum of 50 mg/L according to PERMENKES RI No. 32 of 2017.

3.6. Nitrite Content Test (as NO_2-N)

Nitrite (NO_2-N) levels in the water consumed or used daily can harm the surrounding environment [33]. As a result, tests had to be conducted to determine the nitrite level in the river and distillate water, as shown in Table 6. The ambient environmental conditions, or surface water, led to the highest nitrite level of 0.240 mg/L in the Elephant Wong River water sample.

Table 6. Test results for nitrite levels in river water and distillate water

River Water Type	Parameter	Test Result		Quality Standard	
		Before	*After*	*Clean Water*	*Drinking Water*
Gajah wong	Nitrite (as NO_2-N)	0.240	0.008	1.0	3
Code		0.167	<0.002		
Progo		0.017	<0.006		
Oyo		0.009	<0.002		
Opak		0.042	0.005		

In the distillate water samples, the highest nitrite levels were in the distilled Elephant Wong River water, although there are effective distillation methods that lead to lower nitrite levels. Based on the test results, it can be concluded that all river water and distillate water samples have met the nitrite concentration quality standards set in PERMENKES RI No. 32 of 2017.

3.7. Total Hardness Test

Water hardness occurs when the lime content in water is too high, primarily due to cationic elements such as Na, Ca, and Mg. Freshwater sources, especially those flowing through limestone areas, often exhibit high hardness levels exceeding 200 ppm, which can impact household appliances and, over time, pose health risks, particularly for individuals with kidney conditions. In this study, river water samples met the clean and drinking water standards (≤500 mg/L); however, hardness levels exceeded the specified limits in distillate water from rivers such as Code, Progo, and Opak. This anomaly likely results from the concentration effect, where the distillation process removes most minerals and organic compounds, but residual minerals become more concentrated, as shown in Table 7.

Table 7. Spike in hardness levels in distillate water

River water	Before (mg/ml)	After (mg/ml)
Gajah wong	153	8.16
Code	142.8	591.6
Progo	157.08	1527.96
Oyo	142.8	234.6
Opak	193.8	612

Because of this, the water produced after distillation tends to have a relatively higher hardness than the water from its source before distillation. The distillation process removes minerals that contribute to the hardness of the water. Therefore, distilled water tends to be purer and possibly harder. One method that can be used to reduce water hardness is electrocoagulation. This method has received much attention due to its simplicity and ability to remove various ions and organic matter from water [34].

3.8. Color Test

Color tests on water are generally conducted to evaluate the clarity of the water. Clear-colored water indicates that it is free of solid particles that can affect its quality. Unusual or different colors than expected may indicate the presence of contaminants in the water, both organic and inorganic. Color tests can also reveal the presence of certain substances, such as heavy metals or certain organic compounds, which can harm human health if present at high levels. Based on the quality standard of clean water and drinking water, it is 0 (zero). In this experiment, river and distillate water obtained results that met the quality standards.

3.9. Turbidity Test

Turbidity measures water cloudiness and serves as a standard for various water types. According to PERMENKES RI No. 32 of 2017, clean water turbidity should be ≤25 NTU, and drinking water ≤5 NTU. The highest turbidity was found in the Oyo River (13.2 NTU), and the lowest in the Progo River (2.32 NTU), with all river samples meeting the clean water standard. Progo and Gajah Wong Rivers also met drinking water turbidity standards. However, some distillate samples exceeded the drinking water limit, possibly due to recontamination during collection, storage, or handling, or measurement errors like calibration issues.

3.10. Temperature Test

Temperature is a crucial physical factor affecting an organism's growth, reproduction, and metabolism, influencing viscosity, chemical reactions, evaporation, and gas solubility in water. The highest temperature was recorded in Progo River water at 26.2°C, while the lowest was in Code River distillate at 25.4°C, all within the optimal range for phytoplankton growth (20–30°C) and bacterial decomposition activity (25–35°C). These values comply with PERMENKES RI No. 32 of 2017, which limits deviations to ≤3°C from natural temperatures. After distillation, temperatures decreased in Code, Progo, and Oyo Rivers but increased in Opak and Gajah Wong Rivers, though the overall difference remained minor (25–26°C).

3.11. Microbiology Test

1) *Total Coliform Test*

Before distillation, none of the river water samples met either drinking water or clean water standards, as evidenced by the high bacterial count, with results showing TNTC (Too Numerous to Count) or exceeding 200 CFU/100 mL.

After distillation, some samples met the clean water standard, as shown in Fig. 2.a., with Gajah Wong River at 46 CFU/100 mL and Oyo River at 43 CFU/100 mL. However, the other three river samples still exceeded the quality standards, with some remaining at TNTC levels, far from the acceptable threshold. This condition is influenced by several factors, including the high bacterial load before distillation and post-distillation treatment that was not entirely sterile.

2) *Escherichia Coli Bacteria Test*

As shown in the graph in Fig. 2.b., the number of Escherichia coli bacteria before distillation was too high, recorded as TNTC (Too Numerous to Count), meaning it exceeded 200 CFU/100 mL. However, no bacterial growth was observed after distillation, indicating that no viable Escherichia coli bacteria remained. This result confirms that the distilled water meets the quality standards for clean and drinking water.

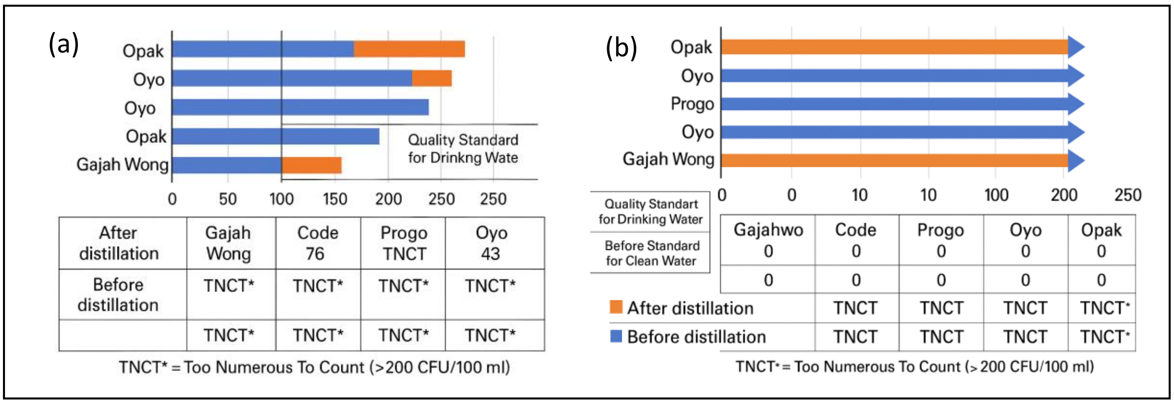

Fig. 2. Test results of (a) Total *Coliform* and (b) *E-Coli* bacteria content in river water and distillate water

3.12. TDS Test

TDS testing evaluates the concentration of dissolved inorganic and organic compounds in water, such as minerals, salts, and metals. High TDS can indicate contamination and affect water quality. In this study, TDS levels in river water ranged from 350 to 780 mg/L, while distilled water showed a significant reduction, averaging below 10 mg/L. This confirms that distillation effectively removes dissolved solids, ensuring compliance with clean water (≤1000 mg/L) and drinking water (≤500 mg/L) standards set by PERMENKES RI No. 32 of 2017.

3.13. Cyanide Content Test

Cyanide is a toxic chemical compound that can be naturally or artificially formed and found in various water sources, including drinking water, surface water, and wastewater. Therefore, it is necessary to test the cyanide content of river water and distillate water. Table 8 shows that the quality standard set for cyanide levels in clean water is 0.1 mg/L, while the results obtained for river water and distillate water are less than 0.002 mg/L, which means they meet the existing quality standards.

Table 8. Cyanide content test results in river water and distillate water

River Water Type	Parameter	Test Result		Quality Standard	
		Before	***After***	***Clean Water***	***Drinking Water***
Gajah wong	Cyanide	<0.002	-	0.1	3
Code		<0.002	<0.002		
Progo		<0.002	-		
Oyo		<0.002	<0.002		
Opak		<0.002	<0.002		

The quality standard is far below the standard for cyanide levels in clean water, which is 0.1 mg/L per PERMENKES RI No. 32 of 2017. Thus, these results show that river and distillate water have met the existing quality standards.

3.14. Detergent Content Test

Based on the test results in Table 9, detergent levels in Gajah Wong River water were 0.004 mg/L before treatment, well below the clean water quality standard of 0.5 mg/L. For other rivers—Code, Progo, Oyo, and Opak—detergent levels before and after treatment were recorded at less than 0.009 mg/L. These values are very low, near the detection limit of the testing equipment, and remain within the safe limits defined by the applicable quality standards.

Table 9. Detergent content test results in river water and distillate water

River Water Type	Parameter	Test Result		Quality Standard	
		Before	***After***	***Clean Water***	***Drinking Water***
Gajah wong	Detergent	0.004	-	0.5	3
Code		<0.009	<0.009		
Progo		<0.009	-		
Oyo		<0.009	<0.009		
Opak		<0.009	<0.009		

4. Conclusion

Based on the research conducted, it can be concluded that freshwater is a scarce resource, with less than 0.007% of the total global water available for household needs, so it is essential to maintain its sustainability. Distillation has been proven effective in producing clean water from various sources. However, physicochemical and microbiological parameters must be considered for the produced water to meet quality standards. While distillation effectively removes contaminants, some parameters such as pH, mineral content, and turbidity may change, requiring further testing to ensure the safety of the water produced. The availability of clean water is a significant challenge, especially in remote areas or those without access to adequate water sources, so further research and technology development are needed to ensure wider access to clean water.

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