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Effectiveness of Solar Distillation System in Treating Direct Discharge of Car Wash Wastewater

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Abstract

Car wash facilities offer simple alternatives for automobile owners, but by discharging highly contaminated wastewater into rivers, they contribute to environmental degradation. For this study, three different solar still distillation models were developed to treat car wash wastewater, including a standard solar still (Model 1), a painted solar still (Model 2), and a painted solar still combined with sand (Model 3). The objectives of this study included designing and evaluating the effectiveness of these models in producing treated carwash wastewater, as well as assessing the quality of both treated and untreated water in terms of pH, turbidity, COD, BOD, nitrites, nitrates, and zinc. The volume of treated water collected was measured hourly from 9:00 a.m. to 6:00 p.m., and the temperature of both the water and the surroundings was also recorded. The findings indicate that Model 3, which was painted with black paint and sand, performed better in terms of producing effectiveness and water purification. In addition, Model 3 outperformed the other models in terms of effectiveness by producing the highest volume of water and exhibiting the greatest % removal rates for a variety of pollutants, is turbidity (96.0 5%), COD (96.42%), BOD (97.65%), nitrate (60.75%), nitrite (83.33 %) and zinc (93.78 %). The improved thermal mass and heat absorption capabilities of Model 3 were responsible for its higher evaporation rates and overall effectiveness in eliminating contaminants. Car wash wastewater is effectively treated by solar still distillation systems, especially the more efficient ones, such as the painted still with sand. The processed water quality meets the accepted standard, demonstrating the effectiveness and ecological responsibility of solar distillation technology in wastewater treatment.

1. Introduction

Water supplies are becoming increasingly scarce worldwide, and by 2025, approximately 2.7 billion people are expected to face water shortages [1]. This indicates that the water shortage issue will impact one in three people worldwide. Other than that, the growth in urbanisation, agriculture, and industrial production has negatively impacted the quality of our water supply [2]. Therefore, recycling wastewater has become crucial to finding a solution to the water shortage issue [3]. The car wash is a typical public service that has a significant impact on municipal operations, as it is a major consumer of water resources. Significant quantities of car wash wastewater have been generated due to the increased demand for car wash services resulting from the rapid expansion of the human population. The total number of registered vehicles in the country in 2022 was 33.3 million, while the corresponding human population was 32.6 million [4]. Based on research, a single car wash consumes 100 to 200 litres of water [5]. On the other hand, the washing of trucks and buses demands a larger quantity of water, ranging from 400 to 600 litres [6], [7]. Numerous contaminants, including oil and grease, nutrients, heavy metals, organic matter, and suspended solids, are present in the wastewater from car washes [8]. Pollutants in car wash wastewater have an influence on the qualities of the wastewater, such as chemical oxygen demand (COD), temperature, biochemical oxygen demand (BOD), turbidity, and pH, all of which are harmful to the aquatic ecosystem and human health [3], [7].

The growing number of car washing facilities and the shortage of water have made it increasingly important to use efficient methods for treating wastewater, especially due to the pollutants generated by these activities. From past research, carwash wastewater can be treated by various methods, including filtration treatment, coagulation and flocculation treatment, and adsorption treatment, among others. However, there are limited studies that use solar distillation systems to treat car wash wastewater. One of the developing techniques that shows promise for cleaning up polluted water, such as industrial wastewater effluent, is solar still distillation.

Fundamentally, the contaminated feed water is placed in the still, where sunlight passes through a glass surface, causing the water to heat up due to the greenhouse effect and eventually evaporate. As the water evaporates, it leaves behind all the pollutants and bacteria from the basin below. The purified water vapour then condenses on the underside of the glass, flows into a collection basin, and is stored in a closed container [9]. A solar still is a sealed container that comes in various shapes, including tubular, hemispherical, trapezoidal, pyramidal, and triangular. Its primary feature is a basin that contains polluted water, and it features a transparent top that allows sunlight from the sun to enter and heat the water inside.

A single-slope conventional solar still design and successfully treated stormwater and greywater [10] . However, conventional solar stills without a heat absorber typically exhibit lower efficiency in converting solar energy into distilled water due to inefficient heat transfer mechanisms. Consequently, several studies have improved solar stills by incorporating a heat absorber. The single-slope solar distillation works efficiently by maintaining high temperatures and pressures inside a well-insulated system. They used units made from plywood and painted them black to absorb heat, while rubber, silicon, and exterior paint helped with insulation and humidity control [11]. Heat-absorbing materials addition, such as sand, soil, and paraffin wax, to a solar still can increase its efficiency [12]. They compared a conventional solar still (case 1) with one using these materials (case 2). The solar still with heat-absorbing materials was more efficient and had a shorter payback period. This approach is promising for cost-effective and efficient water distillation, especially in areas with limited access to clean water. The utilization of sand as the heat absorber, and a comparative examination of second-law performance revealed that the system's energy consumption is 30% higher than that of a typical single-slope solar still without thermal preservation [13].

Furthermore, numerous research projects have been conducted on the use of solar energy to treat wastewater, aiming to meet the drinking water quality parameters set by Malaysia's Ministry of Health (MOH). standards for taste, odour, colour, pH, and organic and inorganic matter. The effectiveness of a solar water distiller in purifying stormwater and greywater found that the treated water met the standards set by the Ministry of Health Malaysia for drinking water, with contaminant removal rates ranging from 94% to 100% [10]. Therefore, it is possible to measure the quality of water using its physicochemical characteristics and ensure it is safe and pure to consume. The objective is to calculate the solar water distiller's effectiveness in treating car wash effluent water and determine if the resultant water meets the standard for the parameter limit of effluent set by the Environmental Quality (Sewage and Industrial Effluent) Regulation 1974 and the drinking water quality standards established by Malaysia's Ministry of Health (MOH).

This study examines sustainable and eco-friendly methods for treating wastewater from car washes, addressing significant environmental concern. With the growing number of car wash facilities, there is a need for innovative technologies to minimise environmental harm. Properly treated car wash wastewater can be recycled for everyday activities, such as washing, thereby reducing the need for freshwater. This aligns with global efforts to promote responsible water usage. In rural areas with limited access to clean water, solar distillation offers a sustainable solution by harnessing solar energy to purify water through the process of evaporation and condensation. Other than that, the effectiveness of two solar still distillation designs namely, a black-painted solar single-slope basin and a solar single-slope basin with a sand still was compared in this study.

2. Methodology

In this study, three different design models for solar stills were created and evaluated. The first model is a conventional single-slope still distillation, referred to as Model 1. Model 2 is a painted solar still, which features a black paint layer added to enhance heat absorption. Model 3 was designed with a black-painted body and added sand underneath the still basin component. This research focuses on designing and comparing models for treating carwash wastewater. The primary goal is to evaluate the effectiveness of these models in treating and purifying wastewater, thereby ensuring cleaner and safer water. Key assessments involve measuring water quality parameters, such as pH, turbidity, COD, BOD, nitrites, nitrates, and zinc, which will be examined at the Environmental Laboratory, UiTM. The study aims to identify the most effective methods for wastewater treatment, thereby contributing to sustainable water management and environmental protection.

2.1 Study Area

The car wash, named The Car Laundry, located in Section 20, Shah Alam, Selangor, was chosen as the study area for the car wash wastewater sample. The wastewater from the car wash in this study may contain detergent, oil, grease, and other contaminants that could potentially pollute the water supply. To learn more about the research location, a site investigation and local area observation were done to determine the flow pattern and effluent condition. Six litres of car wash effluent wastewater samples were collected at the outlet discharge using polyethene containers. The collected sample was preserved by keeping it in a cold chamber at 4°C or lower without freezing it. The study area is shown in Fig. 1.

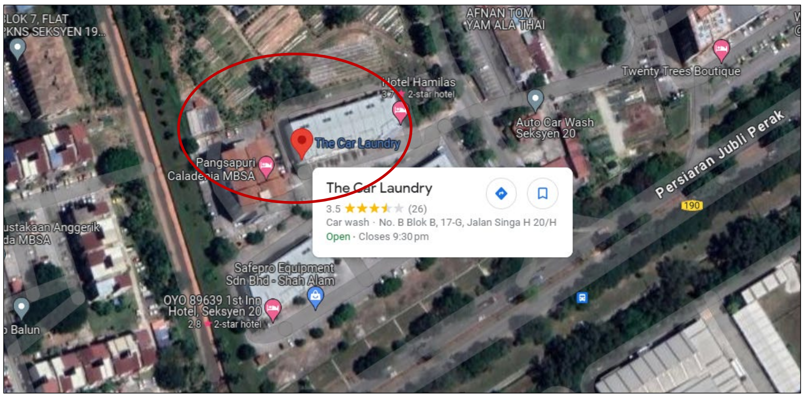


Fig. 1 *Study area location [14]*

2.2 Parameter of Water Quality

A laboratory experiment was conducted to evaluate the effectiveness of solar distillation in treating car wash wastewater, using pH, turbidity, chemical oxygen demand (COD), biological oxygen demand (BOD), nitrites, nitrates, and zinc as indicators. The experiment was performed before and after the treatment process, following standard experimental procedures. All parameters were measured in accordance with the Standard Method for the Examination of Water and Wastewater (2005) and have been compared with the parameter limits for effluent as specified in the Environmental Quality (Sewage and Industrial Effluent) Regulation 1974 and for drinking water quality as outlined by the Malaysia Ministry of Health (MOH). The experiments were conducted in the Environmental Laboratory at UiTM Shah Alam.

2.3 Data Collection

As shown in Fig. 2, three different model designs were employed in this study for treating car wash wastewater through solar still distillation. The fundamental model used in this study is the conventional single-slope solar still, referred to as Model 1. Although the traditional solar still is simple to operate, low heat absorption and the requirement for direct sunlight are two common factors that limit its efficiency. Understanding the drawbacks of Model 1 and Model 2, the painted solar still provides innovation by covering the basin's exterior with a black-coloured paint, which acts as a heat absorber. Lastly, Model 3 is designed with a black-painted body and features added sand underneath the still basin component.

Every solar still model was filled with 500 ml of carwash water every cycle and put in the same exact surroundings which is in open area in Section 20, Shah Alam, Selangor, and hourly measurements of purified water volume were taken between 9:00 a.m. and 6:00 p.m. Environmental conditions, such as temperature of water in solar still and surrounding temperature, were recorded at each hourly interval to account for their potential impact on performance. The procedure was also run in 2 days to minimise the reading error. Fig. 3 illustrates the process of treating car wash wastewater using solar still distillation.

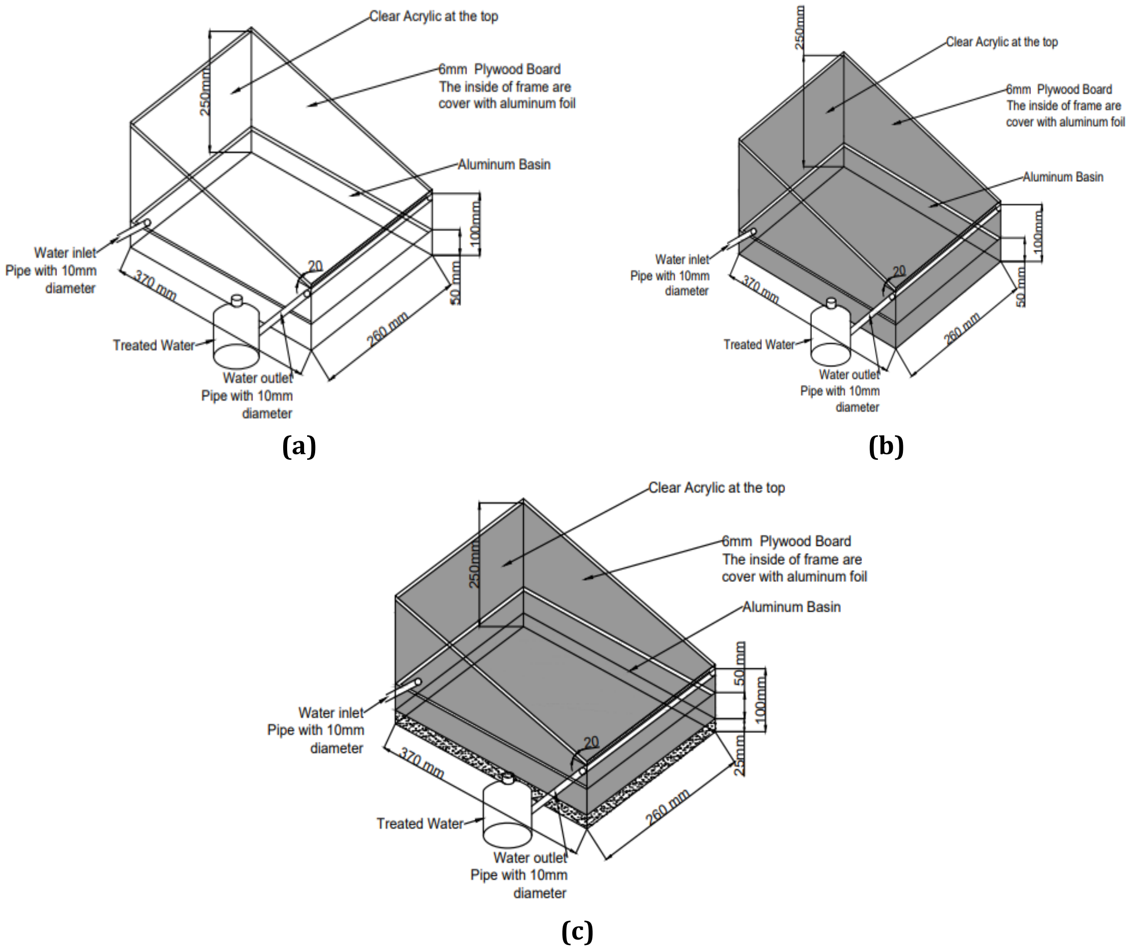


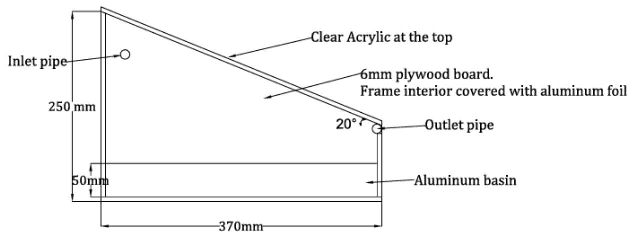
Fig. 2 *(a) Schematic diagram of a conventional solar still (Model 1); (b) Schematic diagram of a painted solar still (Model 2); and (c) Schematic diagram of a painted solar still with sand (Model 3)*

Fig. 3 *Process of treating carwash wastewater using 3 different models of solar still distillation*

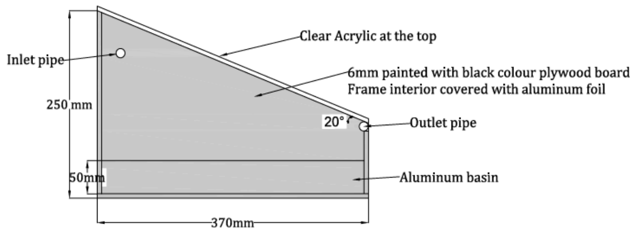
3. Results and Discussions

Three different solar still distillation models have been designed and developed to assess their effectiveness in treating carwash wastewater, as shown in Fig. 4. Model 1 features a clear acrylic top for maximum sunlight penetration, a 6 mm plywood frame with an aluminium foil interior for heat retention, and an aluminium basin.

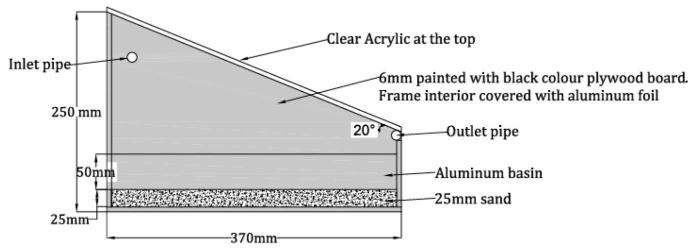
Model 2 enhances this design by painting the plywood black, increasing solar radiation absorption and boosting evaporation rates. Model 3 adds a 25 mm sand layer beneath the aluminium basin, acting as a thermal storage medium to maintain consistent temperatures and extend distillation periods. By comparing these models, the study aims to identify the most effective design enhancements for optimising the solar distillation process and developing a sustainable solution for car wash wastewater treatment. This iterative design and testing process highlights the potential of solar still systems in achieving efficient and eco-friendly water purification.



(a)



(b)



(c)

Fig. 4 *Cut Section of solar still distillation model*

The untreated and treated water quality of car wash wastewater for parameters pH, turbidity, chemical oxygen demand (COD), biological oxygen demand (BOD), nitrites, nitrates, and zinc were determined and compared with the Environmental Quality (Sewage and Industrial Effluent) Regulation 1974 and the Drinking Water Quality Standard (MOH) in this study. Table 1 presents the parameter results in comparison to both standards.

Table 1 *Parameter results compared to the parameter limit of effluent by Environmental Quality (sewage and industrial effluent) regulation 1974 and Drinking Water Quality Standard (MOH)*

Parameter	Untreated	Model 1	Model 2	Model 3	Standard A (Environmental Quality Act 1974 (Sewage))	Drinking Water Quality Standard (MOH)
pH	5.46	6.575	6.63	6.84	5.5 – 9.0	6.5 – 9.0
Turbidity (NTU)	50.55	5.585	2.655	1.995	5	5
COD (mg/L)	2023.5	78.5	74	72.5	50	-
BOD (mg/L)	248.95	12.76	28.355	5.86	20	-
Nitrites (mg/L)	0.0535	0.0325	0.027	0.021	-	-
Nitrates (mg/L)	0.15	0.05	0.035	0.025	-	10
Zinc (mg/L)	2.41	0.18	0.155	0.150	1	3

The evaluation of solar still distillation methods for treating car wash wastewater shows significant improvements in water quality. The untreated wastewater, with parameters such as pH 5.46, turbidity 50.55 NTU, COD 2023.5 mg/L, BOD 248.95 mg/L, nitrites 0.0535 mg/L, nitrates 0.15 mg/L, and zinc 2.41 mg/L, greatly exceeds the acceptable limits of 5 NTU for turbidity, 50 mg/L for COD, 20 mg/L for BOD, and 1 mg/L for zinc in the effluent standard. This indicates that the data collected were inconsistent with the previous findings due to differences in the types of detergent used, environmental conditions, and the dirt from the vehicles [7], [8]. The drinking water standards are even stricter, requiring a pH range of 6.5-9.0, a turbidity of 5 NTU, and a zinc level of 3 mg/L, with no specified limits for COD and BOD. The conventional solar still (Model 1) reduces these contaminants, adjusting the pH to 6.575, and lowering turbidity to 5.585 NTU and BOD to 12.76 mg/L, meeting some effluent standards but exceeding the drinking water turbidity standard. The solar still with black paint (Model 2) further improves water quality, achieving a turbidity of 2.655 NTU and a pH of 6.63; however, it slightly increases the BOD to 28.355 mg/L, which exceeds the effluent standard. The most effective method, the solar still with black paint and sand (Model 3), achieves substantial improvements, reducing turbidity to 1.995 NTU, COD to 72.5 mg/L, and BOD to 5.86 mg/L, making the water compliant with the effluent standards and aligning better with drinking water quality for pH and zinc at 0.150 mg/L. Model 3 also achieves the lowest levels of nitrites (0.021 mg/L) and nitrates (0.025 mg/L), and maintains zinc at 0.150 mg/L, which is well within both the effluent standard and the drinking water standard. These outcomes demonstrate that Model 3 offers the most effective treatment, potentially making car wash wastewater suitable for non-potable reuse and closer to meeting strict drinking water standards.

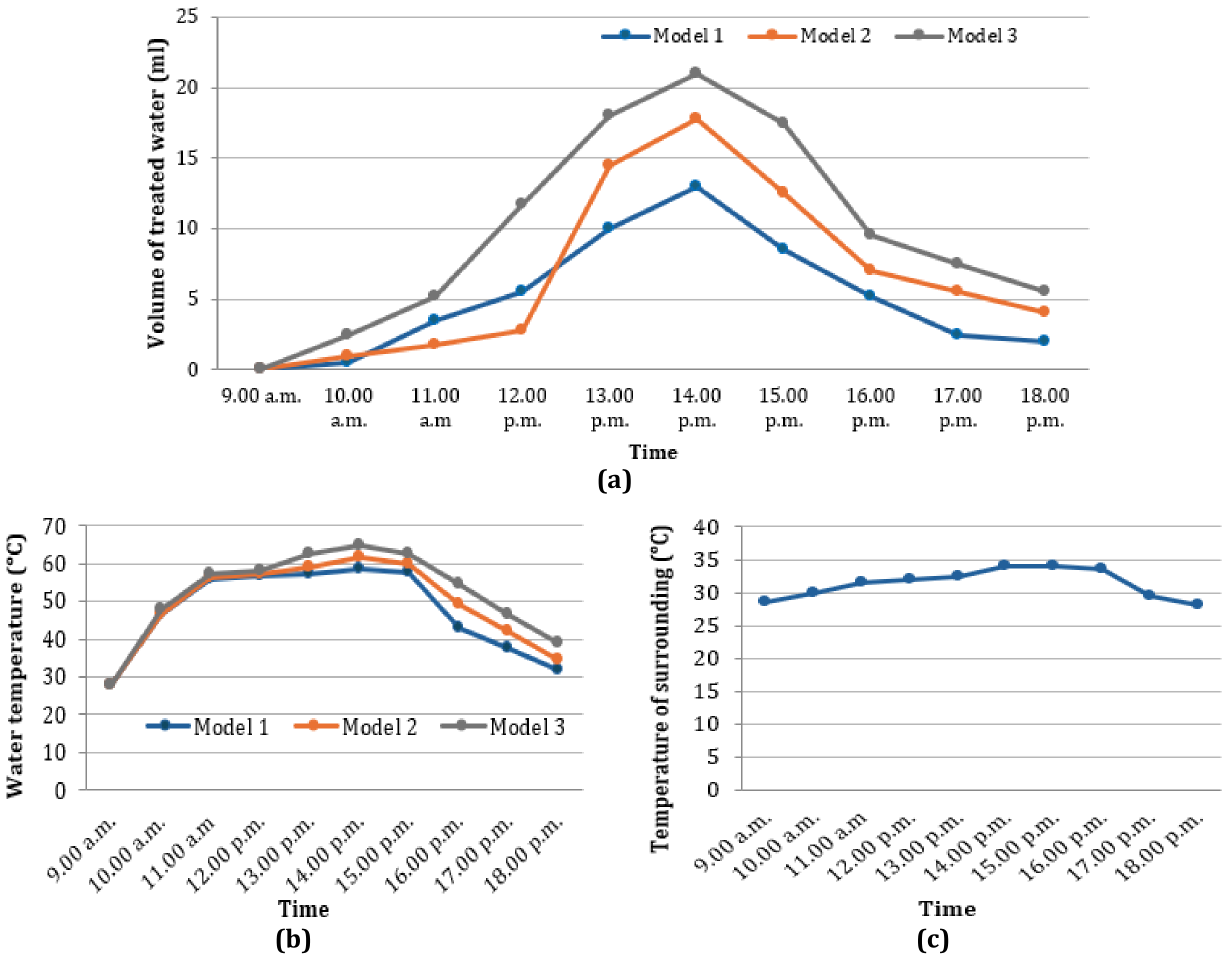


Fig. 5 *(a) The results of the volume of water produced against time; (b) Results of water temperature in the device against time; and (c) Results of the surrounding temperature against time*

The relationship between the volume of water collected from the three solar water distiller models, the time, and the surrounding and water temperatures which were recorded between 9:00 a.m. and 6:00 p.m is shown in Fig. 5. Model 1 shows the lowest effectiveness, water volumes increase from 0 ml at 9:00 a.m. to a peak of 13 ml by 2:00 p.m. with temperature of water 58.75°C, then decline to 2 ml by 6:00 p.m., indicating inadequate heat absorption and retention. Model 2 performed better, with volumes reaching a peak of 17.75 ml, likely due to the black paint enhancing heat absorption and increasing evaporation. The most effective, Model 3, combined black paint and sand, peaking at 21 ml, which significantly improved heat dispersion and retention. Fig. 5(b) shows that Model 3 achieves the highest peak temperature of 64.55°C at 2:00 p.m., thereby enhancing water evaporation and condensation. The findings aligned with the previous study whereas the temperature of both the water in the still and the surrounding air rises simultaneously, a greater volume of treated water is collected [10]. The steady rise in water temperature in all models corresponded with ambient temperature changes, peaking at 34.5°C, highlighting the impact of solar radiation on distillation efficiency. These findings demonstrate that design elements, such as black paint and sand, significantly enhance solar still efficiency, making them suitable for highinsolation areas and industrial applications, including car wash operations. This offers a cost-effective and environmentally friendly solution for wastewater treatment. This result supports previous findings indicating that the incorporation of heat-absorbing materials, such as sand, can enhance the efficiency of solar stills and reduce their payback period [12], [13].

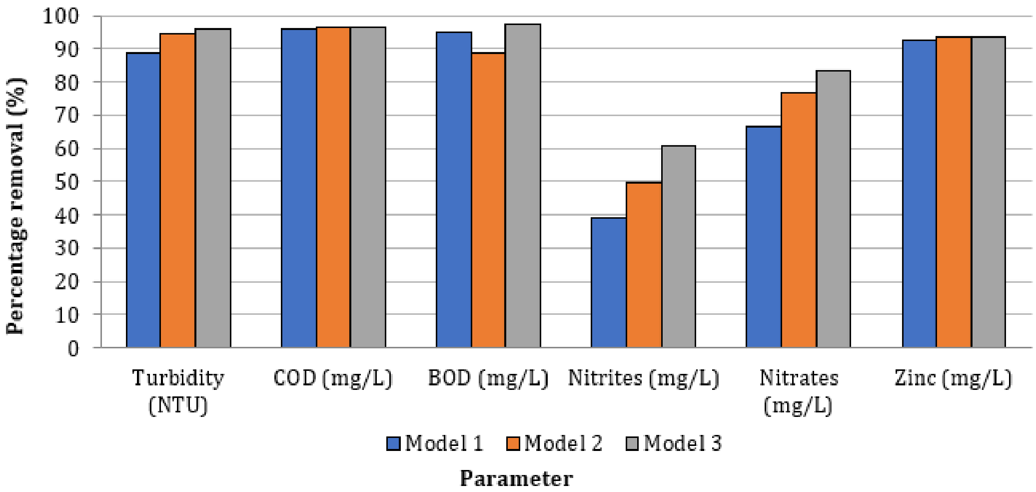


Fig. 6 *Removal percentage of contaminants*

Fig. 6 shows the percentage of contaminants removed by three different solar water distillation models. According to the figure, Model 1 removed 88.95% of turbidity, Model 2 improved this to 94.75%, and Model 3 achieved the highest removal at 96.05%, indicating that the combination of black paint and sand enhances both thermal efficiency and sedimentation. For COD removal, Model 1 achieved 96.12%, Model 2 improved slightly to 96.34%, and Model 3 reached 96.42%, indicating minor improvements with the addition of these features. In terms of BOD, Model 1 removed 94.87%, Model 2 slightly less at 88.61%, and Model 3 excelled with 97.65%, suggesting that the sand in Model 3 boosts biological degradation processes. For nitrites and nitrates, Model 1 removed 39.25% and 66.67%, respectively, while Model 3 outperformed, removing 60.75% and 83.33%, respectively, demonstrating superior chemical interactions. Zinc removal was consistently high across all models, with Model 3 achieving a rate of 93.78%. Overall, Model 3 proved to be the most effective, demonstrating that the enhancements of black paint and sand significantly improve the purification efficiency of solar stills, emphasising their potential for sustainable water treatment. A previous study (10) found removal rates of 94% to 100% for treated wastewater using solar distillers. The results of this study, including those for turbidity, COD, BOD, and zinc, are consistent with these findings, confirming the effectiveness of solar distillation in producing high-quality drinking water.

4. Conclusion

This study aims to design three different solar still distillation models, of which Model 1 is a conventional solar still, Model 2 is a painted solar still, and Model 3 is a painted solar still with sand. Additionally, water quality parameters for both treated and untreated water were determined, and the effectiveness of these designs in treating car wash wastewater was examined. Their effectiveness in producing treated water in terms of volume was also determined. The research objectives were effectively achieved through the use of detailed experimental techniques and in-depth analysis. Water quality tests revealed significant improvements in treated water, meeting most regulatory standards, including the Environmental Quality Act 1974 standard A for sewage and the Drinking Water Quality Standard, with the exception of slight deviations in COD and BOD for Models 1 and 2. The most effective model, Model 3, which incorporated sand to increase thermal mass, yielded the highest water volume and pollutant removal rates. As a result of this study, car wash wastewater can be effectively treated using solar stills, especially those with improved designs, such as the painted still with sand. Since the treated water quality follows substantial improvement standards, solar distillation is a practical and environmentally responsible method for treating wastewater. To improve both effectiveness and capacity for larger applications, future studies may investigate additional optimisation of solar still designs, including material and structural improvements.

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Conflict of Interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***Study conception and design:*** *Nur Fatin Syahirah Mohd Azli and Zaizatul Zafflina Mohd Zaki;* ***Data collection:*** *Nur Fatin Syahirah Mohd Azli;* ***Analysis and interpretation of results:*** *Nur Fatin Syahirah Mohd Azli and Zaizatul Zafflina Mohd Zaki;* ***Draft manuscript preparation:*** *Nur Fatin Syahirah Mohd Azli and Zaizatul Zafflina Mohd Zaki. All authors reviewed the results and approved the final version of the manuscript.*

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