A Low Cost Wastewater Reclamation Unit comprising a Lamella Settler for reducing Fresh Water Usage in Carwash Stations

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ABSTRACT

A low-cost carwash wastewater reclamation unit comprising a lamella settler and filtration unit was designed and fabricated in the laboratory. A newly designed lamella settler, Reflux Lamella Settler (RLS), consisting of two inclined sections, was incorporated for the first time in the reclamation unit with the objective of enhancing the sedimentation process. Furthermore, organoclay was employed as a component of the filtration unit to remove oil contents. The analysis of the reclaimed water demonstrated a notable reduction in the Total Suspended Solids (TSS), from 821 mg/L to 98 mg/L, in turbidity from 253 Nephelometric Turbidity units (NTU) to 2.70 NTU, and in the oil content from 26 mg/L to zero. This implies a substantial removal of the above substances of 88%, 98.9%, and 100%, respectively. Similarly, the concentration of hardness was reduced by 62.8%, from 321.6 to 120 mg/L, that of Chemical Oxygen Demand (COD) by 65.3%, from 274 mg/L to 95 mg/L, that of total solids by 65%, from 1590 mg/L to 543

mg/L, and that of total dissolved solids by 47.9%, from 769 mg/L to 400 mg/L. These results indicate that the reclaimed water was suitable for car washing. Moreover, a study on the RLS demonstrated a reduction in turbidity from 253 NTU to 175 NTU, 150 NTU, 130 NTU, and 10 NTU, respectively, after 0.5, 1, 1.5, and 24 hours. The RLS is an effective method for the removal of solid particles/sludge as a primary treatment step in carwash reclamation.

Keywords-boycott effect; inclined channel; recycling; sediment; segregation; wastewater

I. INTRODUCTION

Population growth and the evolving lifestyles in the developed and developing countries have increased the use of personal vehicles, which has subsequently resulted in a surge in the demand for car and vehicle washing facilities. Consequently, carwash stations have become a significant fresh water consumer, with the primary purpose of washing cars, buses, and vehicles. It has been estimated that the consumption of fresh water for the washing of a single car in a carwash station ranges from approximately 45 L to 450 L, depending on the washing method involved, either manual or automatic [1-8]. It can be reasonably assumed that a carwash station will spend about 22,500 L of wastewater per day in order to wash 50 cars. However, the precise volume will depend on the number of cars washed daily and the number of carwash stations in operation in a given suburb. In developing countries, the lack of planning and awareness has resulted in water discharge without treatment. The wastewater contains a number of harmful contaminants, including sand and dust, surfactants, oil content, grease, waxes and dissolved solids. These pollutants have the potential to contaminate surrounding water sources, including rivers and lakes. Moreover, such practices lead to the inefficient utilization of fresh water resources [1-3, 6, 9]. The reclamation, recycling and reuse of carwash wastewater are vital steps for ensuring the sustainable future of fresh water resources and the carwash industry. Furthermore, the treatment of carwash wastewater ascertains compliance with environmental protection regulations [1, 3, 8, 9]. In developed countries, the mandatory ratio of the reclaimed fresh water used for car washing is 75:25 [1, 2, 10]. In numerous European countries, there are stringent regulations pertaining to fresh water consumption in carwash facilities [1, 3]. However, in developing countries, there is a notable absence of awareness regarding wastewater reclamation and reuse in carwash stations [9, 10]. Overall, the global attention towards wastewater reclamation from carwash industries is relatively limited.

Authors in [9, proposed different carwash wastewater reclamation systems comprising sedimentation, clarification, filtration, and membranes, which are capable of removing pollutants to such an extent that the reclaimed water can be reused or discharged into water bodies. Authors in [11] put forth a system comprising nanofiltration, which was observed to retain surfactants and reduce organic components. Similarly, authors in [1] introduced a carwash wastewater recycling and reuse system comprising a settling tank, an oil separator, and filters. Authors in [2, 4] proposed a system consisting of a flocculation column, flotation, sand filtration, and chlorination for the treatment of wastewater from car wash stations. Authors in [12, 13] employed membranes for the treatment of car wash wastewater. Authors in [14] put forth a cost-effective wastewater treatment system comprising a sedimentation tank and a filtration unit. Site visits to 29 car wash stations in Peshawar city were made and wastewater samples were collected. It was estimated that 351,250 liters of fresh water were consumed daily for car washing purposes. Researchers reduced the level of contaminants to a degree that rendered the treated water suitable for reuse as a car wash solution. In response to the growing interest in the reclamation, recycling, and reuse of carwash wastewater, authors in [5-7] published comprehensive review articles on carwash wastewater treatment technologies. They provided valuable insights into the significance of carwash wastewater reclamation and the technologies that had been employed up to that point. The majority of the technologies utilized, involve processes, such as sedimentation, filtration, nano-filtration, membranes, and chemical treatment. However, the use of membranes and chemicals renders the reclamation process expensive, which is an unattractive proposition for carwash station owners. Similarly, treatment units comprising large settling tanks are not always feasible, given that carwash stations occupy limited land and have small-scale operations. Consequently, there is a need for low-cost, high-efficient treatment processes for carwash stations.

It is evident that carwash wastewater has a higher concentration of Suspended Solids (SS), detergents, oil, and grease [5, 15], rendering conventional sedimentation tanks and simple filtration units ineffective. The sedimentation process is inherently time-consuming, necessitating the use of expansive settling tanks to accommodate the wastewater volume and allow the requisite settling time for solid particles to achieve equilibrium [16]. Nevertheless, the rate of solid particle settling can be accelerated through the use of inclined channels. The latter operate based on the principle of the Boycott Effect [17], which posits that inclined channels provide a significantly larger settling area for solid particles than that offered by vertical channels [17-20]. This enhanced settling area is evidenced in Figure 1 and results in a higher settling rate. Furthermore, inclined channels have a high capacity per unit volume, enabling the handling of relatively large fluid volumes [19-21]. The enhanced settling rates in inclined channels, as predicted by the Ponder, Nakamura and Kuroda (PNK) theory [16, 22-23], are given by:

$$S_t = v_t\left(\frac{L}{b}sin\theta + cos\theta\right) \quad (1)$$

where S_t is the settling rate, v_t is the vertical settling velocity, b is the channel width, L is the channel length, and θ is the inclination angle.

Settling tanks incorporating inclined channels are referred to as lamella settlers and are used in wastewater treatment and as thickeners in a range of industrial contexts. A lamella settler has the capacity to enhance the sedimentation process, accommodate high flow rates, and requires less space [19]. Nevertheless, the use of lamella settlers in car wash wastewater reclamation systems has yet to be proposed. This work represents an extension of the research conducted in [14], which was designed to develop a low-cost carwash wastewater treatment unit comprising a sedimentation tank and a filtration unit. The sedimentation tank has been replaced with a newly designed lamella settler consisting of two inclined sections. The principal objective of utilizing a lamella settler was to accelerate the rate of solid particle settling, thereby producing a more clarified water stream for conveyance to the filtration unit. Organoclay was employed in the filtration unit to effectively remove oil contents. The primary objective of this research is to propose a carwash wastewater reclamation system that is both efficient and cost-effective, in which carwash wastewater is treated and subsequently reused for car washing.

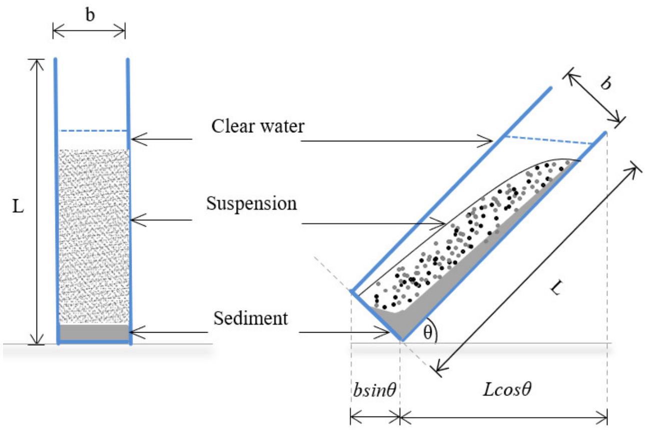

Fig. 1. Settling of solid particles in a vertical and inclined channel.

II. LAB SCALE CARWASH WASTEWATER RECLAMATION UNIT

A laboratory-scale wastewater reclamation unit was constructed for experimental purposes, comprising a lamella settler, a filtration unit, and a water collecting tank. The unit was fabricated using acrylic sheet. The actual and schematic images of the carwash reclamation unit are shown in Figure 2.

A. *Reflux Lamella Settler*

A recently developed lamella settler comprising two inclined sections, RLS, was constructed in the laboratory, as observed in Figure 3. The RLS comprised a vertical section, 0.30 m (1 ft) in length, and two inclined sections, each 0.30 m (1 ft) in length and inclined at 60 degrees. The vertical section was placed in the center, with the two inclined sections being incorporated as the upper and lower sections of the device. A series of five parallel inclined channels, with a distance of 0.01 m (10 mm) between them, was incorporated into the lower inclined section. The width of the RLS was 0.15 m. The vertical section provides even feed distribution, while the inclined sections operate as high-classification zones, offering a substantial settling area for solid particles. Upon entering the device, the solid particles within the feed are initially subjected to settling in the lower inclined section. The presence of inclined channels results in a higher rate of solid particle settling, which ultimately leads to the formation of a sediment at the base.

(a)

(b)

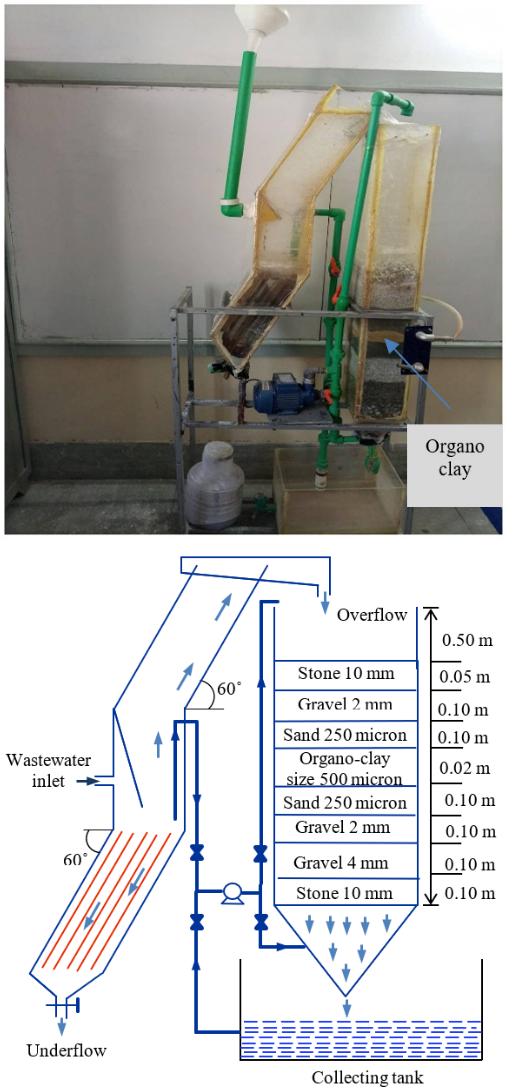

Fig. 2. Carwash wastewater reclamation unit: (a) photo, (b) schematic.

As the quantity of wastewater increases, the device will begin to fill. The water will flow in an upward direction, and some of the solid particles will be carried along with it and enter the second inclined section of the device. In this section, the particles will settle once more on the upward-facing wall. Subsequently, the particles will slide back in a downward direction, thereby becoming incorporated into the sediment at the bottom of the apparatus. Once the concentration of solid particles in the lower section of the device reaches a specified level, the discharge valve will be opened to remove them. In contrast, the feed comprising a lower concentration of solids overflows from the device. The RLS is suitable for both batch and continuous processes.

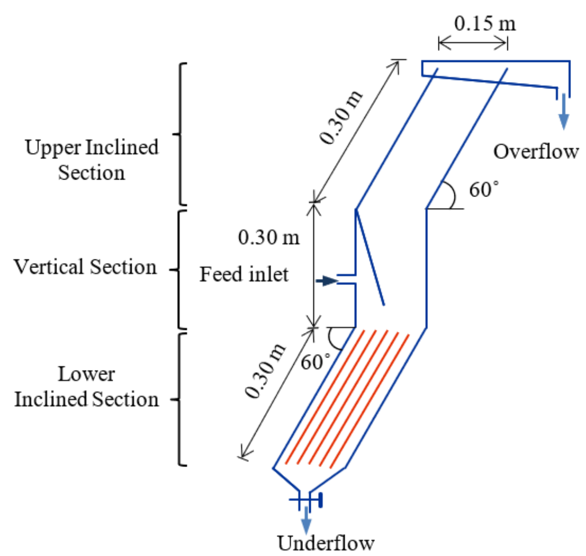

Fig. 3. Schematic diagram of Reflux Lamella Settler.

B. Filtration Unit

A filtration unit of 1.25 m and a conical bottom are depicted in Figure 4.

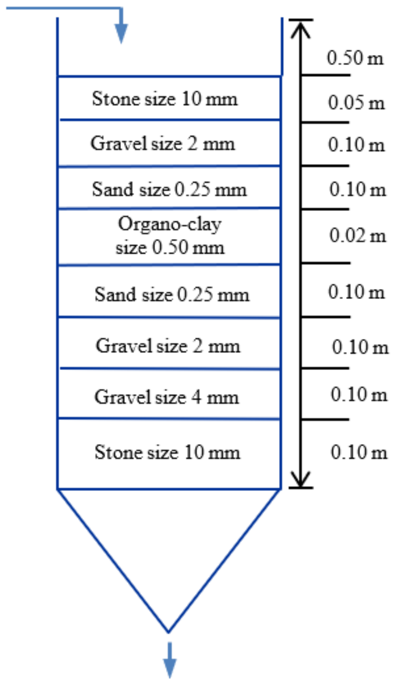

Fig. 4. Schematic diagram of the filtration unit.

A wire gauge was positioned within the filtration unit in order to secure the filter media. At the top of the filtration unit, a 0.50 m void was created to allow for the accumulation of water. The filter media comprised multiple layers. The initial layer, situated at the uppermost portion of the filtration unit, consisted of stone particles, with a diameter of 0.01 m and extending to a depth of 0.05 m. The objective of this layer was to regulate the velocity of the water undergoing filtration. The second layer comprised gravel, with a particle size of 0.002 m and 0.1 m depth. The purpose of this layer was to retain small solid particles. The third layer contained sand particles, with a size of 0.25 mm and 0.1 m depth, which is used to retain fine particles. The fourth layer consisted of organoclay, a fine-grained clay mineral, known as Multani Mitti or bentonite, with a particle size of 0.50 mm and a depth of 0.02 m. The composition of the substance is: hydrated aluminum silicates, magnesium chloride, and calcium bentonite. Its chemical formula is $Al_2H_2O_{12}Si_4$ and it was employed for the removal of oil and grease from car wash wastewater. The clay is readily accessible in Pakistan. The depth of the fifth layer is 0.1 m and consists of sand particles, with a size of 0.25 mm. The sixth and seventh layers are both made of gravel, with a size of 2 mm and 4 mm, respectively, and a depth of 0.1 m in each case. The final layer consisted of stones, with a particle size of 10 mm and a depth of 0.1 m.

C. Reclaimed Water Collecting Tank

The objective of the reclaimed water collecting tank was to facilitate the accumulation of the filtrated/reclaimed water produced by the unit. Samples of reclaimed water will be collected and tested from this tank. A pump is also installed to transfer water from the RLS to the filtration unit if the settler does not become filled due to slow wastewater accumulation. The rate at which water transfers to the filtration unit is 23.3 L/min. A backwashing system is also provided for the purpose of cleaning the filtration unit, with a suitable valve arrangement.

D. Survey

In this study, wastewater samples were collected from six distinct carwash facilities operating within the city of Peshawar, located within the Khyber Pakhtunkhwa (KP) province of Pakistan. Names, addresses and the volume of water consumed by these car wash stations are provided in Table I. Moreover, wastewater samples were collected from the Shinwari Carwash Station in buckets for the purposes of carrying out the experimental work. The water samples were initially collected in small bottles of 0.5 L, from the wastewater exit system of the car wash stations. Similarly, 5 L buckets were used to collect wastewater samples for the experiments.

TABLE I. CARWASH STATIONS VISITED IN PESHAWAR CITY

Carwash station	Location	Cars washed per day	Total water consumption (L/day)
Shinwari Carwash Station	Hayatabad Peshawar	25	11250
Abaseen Service Station	Abaseen University Peshawar	35	15750
Smart Car Wash Ring Road	Ring Road Peshawar	20	9000
Gulf Car Wash	Ring Road Peshawar	30	13500
Shah Service Station	Charsadda Road district Peshawar.	20	9000
Qazi Brothers Service Station	University Road Peshawar	25	11250

E. Experimental Procedure

Wastewater was thoroughly mixed in order to prevent the accumulation of solids within the buckets. The samples were obtained and subjected to analysis to determine the types and quantities of contaminants present. Subsequently, 0.2 g of alum was added to the buckets before running each experiment, as a coagulant, with the objective of reducing the COD. The wastewater was initially placed in the RLS and was allowed to rest for 30 min during which the initial settling of solid particles occurred. Subsequently, the wastewater was conveyed to the filtration unit and proceeded through, wherein it completed the initial settling of solid particles. The treated water was collected in the reclaimed water tank. The filtrated/treated water was collected at a rate of 13.49 L/min in the reclaimed water tank. The experiments were carried out at 25 ºC ambient temperature and each experiment lasted 45 min. The treated water samples were collected from the tank, tested and analyzed for contaminants.

III. RESULTS AND DISCUSSION

A. Laboratory Analysis of Wastewater Samples

Initially, wastewater samples were collected from six carwash stations and subjected to analysis to ascertain the pH, alkalinity, turbidity, TSS, Total Dissolved Solids (TDS), COD, hardness, and oil content levels. To ascertain the presence of contaminants, the wastewater samples were subjected to analysis in the laboratories of the Pakistan Council for Scientific and Industrial Research (PCSIR). Table II presents the aforementioned analysis results. The findings demonstrated that the water samples were contaminated due to the presence of dust particles, soap and detergents, as well as oil contents derived from lubricants. They also disclosed that the type and concentration of contaminants present in the wastewater samples from all six carwash stations were largely similar. Consequently, the sample from the Shinwari Carwash Station was selected as a reference for the subsequent experiments.

B. Laboratory Analysis of Reclaimed Water

Three experiments were initially carried out in the reclamation unit on wastewater samples collected from the Shinwari car wash station. To ensure consistency in the experimental results, the filtration unit was backwashed after each experimental run. The samples of treated/reclaimed water collected in the reclaimed collecting tank were taken and analyzed for their Total Solids (TS), TSS, TDS, turbidity, oil content, and other parameters.

a) Treatment of Turbidity and TSS

The turbidity of the carwash wastewater was very high due to the presence of detergents, diesel, and silt/dust particles. In the present study, a lamella settler was used as a primary settler with the objective of enhancing the settling rate of particle species, thereby ensuring that the water entering the filtration unit is relatively clear. Furthermore, 0.20 g of alum was initially added, which resulted in coagulation and facilitated the settling of larger particles. The wastewater was permitted to settle in the RLS for a period of 30 min. Following a 30-min period, a sample was collected from the top of the RLS using a pipette for the purpose of checking the turbidity. It was determined that a 30-min retention period in the RLS, resulted in a 58% reduction in turbidity, from an initial value of 253 NTU to 175 NTU. Subsequently, the wastewater was conveyed through the filtration unit for further treatment. The treated water collected in the reclaimed water tank was subjected to analysis. Following the completion of the treatment process, which involved the passage of the wastewater through both the RLS and the filtration unit, a notable reduction in turbidity, from 253 to 2.70 NTU was observed. In addition, TSS were found to decline from 821 mg/L to 98 mg/L.

TABLE II. TEST RESULTS OF WASTEWATER SAMPLES OF SIX CARWASH STATIONS

Tests	Wastewater sample (before treatment)					
	Shinwari car wash station	**Abaseen service station**	**Shah service station**	**Smart car wash**	**Gulf car wash**	**Qazi brothers carwash**
TS (mg/L)	1590	2667	1321	877	2234	965
TSS (mg/L)	821	1967	567	222	1341	241
TDS (mg/L)	769	700	754	655	893	724
Turbidity NTU	253	697.97	983	379	451	347
COD (mg/L)	274	263	270	250	289	260
pH	7	7	7	7	7	7
Hardness (mg/L)	321.6	315.6	259	170	179	180
Alkalinity (mg/L)	250	297.5	346	342	290	532
Oil (mg/L)	26	20	18	22	32	23

b) Treatment of COD and TDS

An initial dose of 0.20 g was added to the wastewater buckets and the wastewater was subjected to partial aeration upon entering the filtration unit and during its accumulation in the upper region of the filtration unit, with the objective of reducing the COD. The final analysis of the treated water revealed a notable reduction in the COD level, from 274 mg/L to 95 mg/L. The TDS were reduced from 769 mg/L to 400 mg/L, while the TS were reduced from 1590 mg/L to 543 mg/L.

c) Treatment of Oil Contents

An organoclay layer was used in the filter to facilitate the removal of oil contents. Following the final treatment, the analysis of the reclaimed water demonstrated a significant reduction in oil content, from 26 mg/L to zero, which is a highly promising outcome. A comprehensive investigation into the long-term efficiency and effectiveness of organoclay has yet to be carried out and is anticipated to be conducted in the future. Similarly, the concentration of hardness and alkalinity was reduced from 321.6 mg/L and 250 mg/L to 120 mg/L and 220 mg/L, respectively. A comparison of the present results with those of [9] and [14], reveals a significant reduction in turbidity, from 43 NTU to 2.70 NTU. Similarly, authors in [14] were able to reduce the TSS to 200 mg/L, whereas in the current study, the TSS was reduced to 98 mg/L. Also, in [14], no analysis or reduction of COD were undertaken. In contrast, authors in [9] reduced COD to 70 mg/L. In the present study, the COD was reduced to 95 mg/L. Moreover, both in the present study and in [14], it was observed that the TDS remained at 400 mg/L, while in [9], a slightly higher value of 551 mg/L was reported. In [14] and [9], TS values of 600 mg/L and 538 mg/L were respectively reported. In the present study, TS were reduced to 543 mg/L, which is slightly higher. The oil content was reduced up to 14 mg/L and 3.1 mg/L, whereas in the current study, it has been almost completely removed. Table III presents a comparative analysis of the wastewater sample, as analyzed in [9] and [14] before and after treatment.

TABLE III. COMPARISON OF RECLAIMED WATER RESULTS

Tests	Reclaimed water (after treatment)	Wastewater (before treatment)	Treated water results in [14]	Treated water results in [9]
Total Solids (mg/L)	543	1590	600	538
TSS (mg/L)	98	821	200	-
TDS (mg/L)	400	769	400	551
Turbidity (NTU)	2.70	253	3.70	43
COD (mg/L)	95	274	-	70
pH	7.5	7	8.60	7.5
Hardness (mg/L)	120	321.6	120	-
Alkalinity (mg/L)	220	250	300	-
Oil (mg/L)	0	26	14	3.1

C. Laboratory Analysis of Five Carwash Stations

Wastewater samples obtained from five other carwash facilities were subjected to a single experimental treatment. Figure 5(a) demonstrates the characteristics of the wastewater collected from the carwash stations prior to reclamation, while Figure 5(b) presents the characteristics of the treated water.

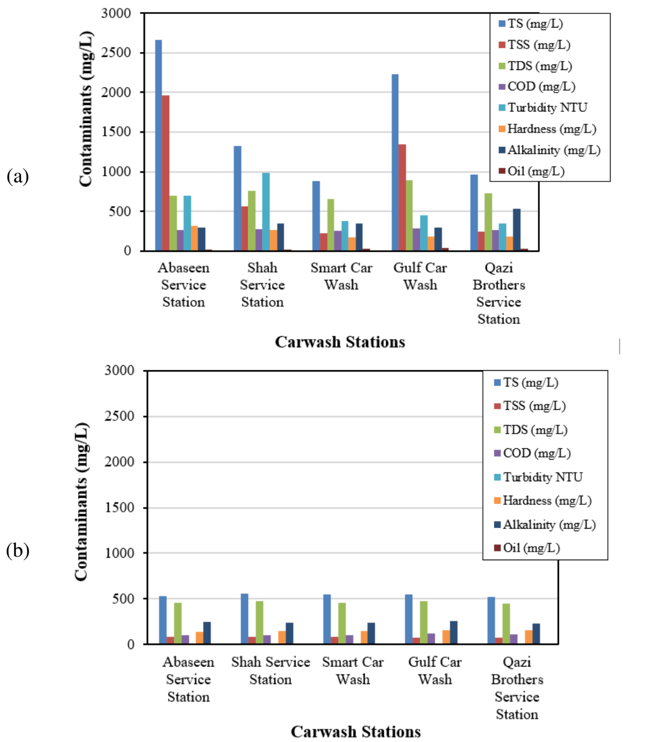

Fig. 5. Contaminants in carwash wastewater (a) before and (b) after water treatment.

The results display a substantial reduction in turbidity levels, with an average decrease of 99%. The TSS exhibited a notable decline, with an average reduction of 82%. Additionally, the oil content was found to be completely eliminated. Moreover, the average reduction in TS, TDS, COD, hardness, and alkalinity was 59%, 37%, 61%, 29%, and 30%, respectively.

D. Water Analysis in the RLS

A separate series of experiments was executed to evaluate the efficacy of RLS. The settler was filled with wastewater collected from the Shinwari car wash station and the turbidity and TDS were recorded at different time points. Figure 6 presents the outcome observed over a 24-hour period following the replenishment of the RLS with the wastewater sample. At the outset, the turbidity of the wastewater was recorded at 253 NTU, with a TDS of 769 mg/L. Following a period of 30 min during which sedimentation occurred within the RLS, the turbidity was reduced to 175 NTU, while TDS was noted to have been decreased to 741 mg/L. Similarly, after 60 min, the turbidity was reduced to 150 NTU and the TDS to 737 mg/L, and after 90 min, the turbidity to 130 NTU and the TDS to 683 mg/L. Subsequently, the wastewater was left to stand for 24 hours in the RLS, resulting in a reduction of turbidity to 10 NTU and a reduction of TDS to 497 mg/L. The results indicate that a 24-hour retention period causes a significant reduction in turbidity, which subsequently alleviates the burden on the filtration unit.

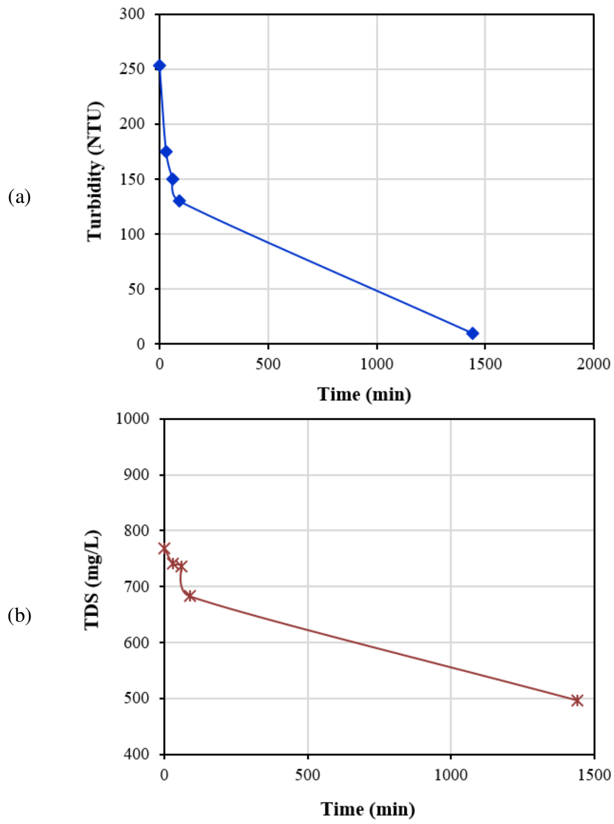

Fig. 6. (a) Turbidity and (b) TDS versus time.

E. Process Comparison

The proposed process has been compared with the work carried out by authors in [14] in order to gain insight into their similarities, changes, advantages and disadvantages. The wastewater treatment unit proposed in [14] and the new reclamation unit were constructed with a sedimentation and filtration unit. However, in [14], the sedimentation tank was a conventional settling tank, which allowed for the preliminary settling of solid particles at a slower rate. This process was time-consuming, as the wastewater had to remain in the tank for 24 hours. Moreover, the filtration unit was unable to remove oil contents from the wastewater. The modified carwash reclamation unit featured a settling tank RLS comprising two inclined sections, which facilitated enhanced solid particle settling and reduced the remaining time for wastewater in the tank. Furthermore, the incorporation of inclined sections enables the unit to accommodate high flow rates. Similarly, a layer of organoclay was added to the filtration unit, which removed oil contents from the wastewater.

The results obtained from the experimental unit were found to be promising, as they successfully removed the oil contents and improved the water quantity to a level that made it suitable for reuse for car washing purposes. The deployment of RLS in the reclamation unit indicated enhanced functionality of the treatment system in comparison to the preceding configuration proposed by authors in [14], accompanied by the additional advantages of accommodating substantial flow rates and minimal spatial requirements. Moreover, the objective of this study was to propose an efficient, low-cost wastewater reclamation unit that would be attractive to car wash station owners and educate them about wastewater reclamation, which would result in significant savings in fresh water.

IV. CONCLUSIONS

A low-cost carwash wastewater reclamation unit comprising a lamella settler and filtration unit was designed and fabricated in the laboratory. A recently developed settling device, Reflux Lamella Settler (RLS), was employed for the first time in the reclamation unit with the objective of improving the process of sedimentation by providing a larger settling area for solid particles and sludge. Similarly, organoclay was deployed in the filtration unit in an attempt to remove oil contents from wastewater. The analysis of the reclaimed water demonstrated a notable reduction in Total Suspended Solids (TSS) from 821 mg/L to 98 mg/L, in turbidity from 253 NTU to 2.70 NTU, and in the oil content from 26 mg/L to zero (i.e., 88%, 98.9%, and 100%, respectively). The reduction in hardness was 62.8%, from 321.6 to 120 mg/L, while the reduction in Chemical Oxygen Demand (COD) was 65.3%, from 274 mg/L to 95 mg/L. Similarly, the reduction in Total Solids (TS) was 65%, from 1590 mg/L to 543 mg/L, and the reduction in Total Dissolved Solids (TDS) was 47.9%, from 769 mg/L to 400 mg/L. The reclaimed water was deemed suitable for use in car washing. Moreover, an examination of the turbidity of the wastewater in the RLS revealed a notable decline from 253 NTU to 175 NTU, 150 NTU, 130 NTU and 10 NTU, respectively, at 0.5, 1, 1.5 and 24 hours. The RLS offers several advantages, including enhanced sedimentation, reduced space requirements and the ability to handle high flow rates.

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