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Sludge accumulation pattern on the plate settlers and the optimum washout

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ABSTRACT

The sludge accumulation pattern on the inclined plate settlers has been observed and studied for several large-scale water treatment plants. Further, air, water, and electrical techniques were investigated to clean up the accumulated sludge on the plate settlers. This technique allows the plate settlers to operate at shallow angles resulting in faster and reliable clarification compared with conventional plate settler. It was found that nonmetal plate settlers can be washed out effectively using compressed air or compressed water of 6 bars with efficiency up to 60% and 70%, respectively. However, metal plate settlers were washed out effectively using electrical separation having a little potential difference of 10, 20, and 30 V with a high efficiency up to 75%, 85%, and 93% respectively, after 5 min. Increasing the pH value up to 8.7 and the losses from the plates are the main side effects of electrical separation. Compared with the present methods of washout, the new techniques can achieve a high removal efficiency of washing in short retention time, less than few minutes, with the little amount of disposed water. Further, it can be applied to upgrade the present plants to operate the plate settlers with a shallow slope, which means increasing its efficiency and reducing the waste in a washing process.

Keywords: Inclined plate settlers; Sludge; Accumulation; Air; Water; Electrical discharge

1. Introduction

Generally, inclined plate settlers are used to remove particles from liquids in domestic and industrial water treatment [1–3]. They are often employed in several places such as primary water treatment in place of conventional settling tanks as well as can be found in wastewater treatment as primary, secondary, or tertiary settling tank [4,5].

The main advantages of the plate settlers are that they do not need the power to work, provide small depths by increasing the separation efficiency [6], do not require pumps, valves, or blowers, do not contain moving parts, and have very low maintenance [4]. So, inclined plate settlers are used to compress the large conventional clarifiers into compact economical units [7] and reduced required area for most clarifiers [8,9].

Compared with the conventional clarifiers, plate settler clarifiers are more compact unit which require only 65%–80% of the area of conventional clarifiers [10]. Further, plate settler clarifiers can be optimized by the addition of flocculants and coagulants [11,12]. These chemicals optimize the settling process and cause a higher purity of overflow water by ensuring that all smaller solids are settled into the sludge underflow [13].

Generally, several materials can be used as plate settlers, but metal or plastic plates, which are commonly arranged as arrays at an angle of 55°–60°, are the most widely used [10,14].

Despite all of these advantages of plate settlers, there is difficulty in washing them after the settling process [14,15]. In spite of this, operating the inclined plate settlers at shallow angles is the necessity for all designers and practitioners [8], but fine solids cannot be washed out easily and flow down to shallow sloped plate surface [16]. So, large amounts of sediments stick and accumulate on the plates, leading

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to clogging and growth of algae on these plates. Clogging due to the accumulation of fine particulates and some types of algae reduces the removal efficiency and causes odor problem when the machinery is outdoors [14].

Today most washing process and cleaning are done by manual methods, two or three times a week for about 45 min each [17]. These methods waste a large amount of water as well as need much time for tank recovering [18]. On the other hand, the main principle of the electrocoagulation process states that when direct current passes through the metal plates, metal ions dissolve and leave the outer surface of the metal to the water [19,20]. This process cleans the metal surfaces from all the accumulated sludge.

So, the main aim of this research is to apply the electrocoagulation principle for only a few minutes to wash the accumulated sludge from the inclined plate settlers irrespective of its slopes and to discuss the use of compressed air and compressed water via additional pipes between the plate settlers. Efficient and rapid removal of the accumulated sludge enables the designers and operators to operate the plate settlers with a shallow slope, which means increasing its efficiency and reducing the waste in a washing process.

2. Experimental methods

The present experiments contain field observation and laboratory experiments. The field observations included the sludge accumulation patterns on the plate and tube settlers as well as the sludge accumulation along the clarifier bed. These observations were carried out inside several water treatment plants (WTP) that are located in north Egypt. However, the laboratory experiments were carried out inside Mansoura University to identify the properties of the sludge accumulated on the plates. Finally, the laboratory experiments included three different methods to remove the accumulated sludge from the plates. Three different methods included washing the accumulated sludge using compressed air, compressed water, and electrical separation.

Figs. 1 and 2 show the schematic diagram and the real photograph of the experimental setup that were used for the present work. This setup included three steel plates inside a Plexiglas clarifier of capacity 80 L with surface area of 50 cm × 40 cm and water depth of 40 cm. Real sludge was accumulated on the steel plates by placing these plates at the outlet zone inside a large scale. So, a natural sludge was accumulated on steel plates inside a large-scale WTP, and natural raw water of mean turbidity of 20 NUT was used. The steel plates containing the accumulated sludge were placed inside the bench-scale setup with an angle of 60°. In this clarifier, three systems for sludge washing were used separately, which includes compressed air, compressed water, and electrical separation.

2.1. Washing the accumulated sludge using compressed air

In the first case, the experimental clarifier was equipped with perforated pipes of internal diameter of 1.0 inch having holes of diameters 3.0 mm each 1.0 cm. The perforated pipes were placed parallel to the plate settlers between them as well as connected to the air blower having compressed air adjustable to 6 bars and discharge up to 10.0 L min^{-1}. The air velocity in each washing pipe was about 10.0 m s^{-1}. In each case, the plate settlers were washed for about 10 min with compressed air of 2, 3, and 6 bar. The washing efficiency of the accumulated sludge was observed as well as the turbidity of water during washout.

2.2. Washing the accumulated sludge using compressed water

In the second case, the perforated pipes were connected to water pump that has a variable head up to 6.0 m and discharge of 1.0 L min^{-1}. The water velocity inside each washing pipe was about 1.0 m s^{-1}. In each case, the plate settlers were washed for about 10 min with compressed water of 2, 3, and 6 bar. The washing efficiency of the accumulated sludge was observed as well as the turbidity of water during washout.

2.3. Washing using electrical separation

In the third case, the perforated pipes were removed from the clarifier and the plates were alternately (positive and negative) connected with a direct electrical potential difference of 10, 20, and 30 V. In each case, the plate settlers were washed for about 7 min with an electrical potential difference of 10, 20, and 30 V. The washing efficiency of the accumulated sludge was observed as well as the turbidity of water during washout. Also, the pH value of the water and the losses of the plates were also observed. The losses of the plates were estimated as the [(original weight of plate – final weight of plate)/original weight of plate] × 100.

3. Results and discussion

The first part of the present results describes the field observation of the sludge accumulation patterns inside those clarifiers containing plate and tube settlers. Further, the second part presents three methods to remove the accumulated sludge from the plate settlers, using compressed air, compressed water, and electrical separation.

3.1. Sludge accumulation pattern of plate and tube settlers

The sludge accumulation was observed for several water clarifiers having similar operational parameters. The pattern of sludge deposition in plate and tube settlers was strongly influenced by the method of sludge removal in the settling tank. It has been observed that settling tanks with continuous sludge removal have minimum solid deposition in the first plates. The sludge begins to accumulate on the first plates at the beginning of the tank and begins to increase gradually until reaching the maximum value at the end plates in the tank.

Figs. 3(a) and (b) show the sludge accumulation patterns on such clarifiers containing tube and plate settlers. Further, Fig. 3(c) shows a schematic diagram for the accumulation pattern on plate settlers and the tank bottom as well as the sizes of the cumulated sludge. From Figs. 3(a) and (b), it is clear that the sludge accumulation pattern for both tubes and plates are similar. For tube and plate settlers, maximum sludge accumulation is found on those last plates at the clarifiers' outlet. Conversely, no accumulation of sludge

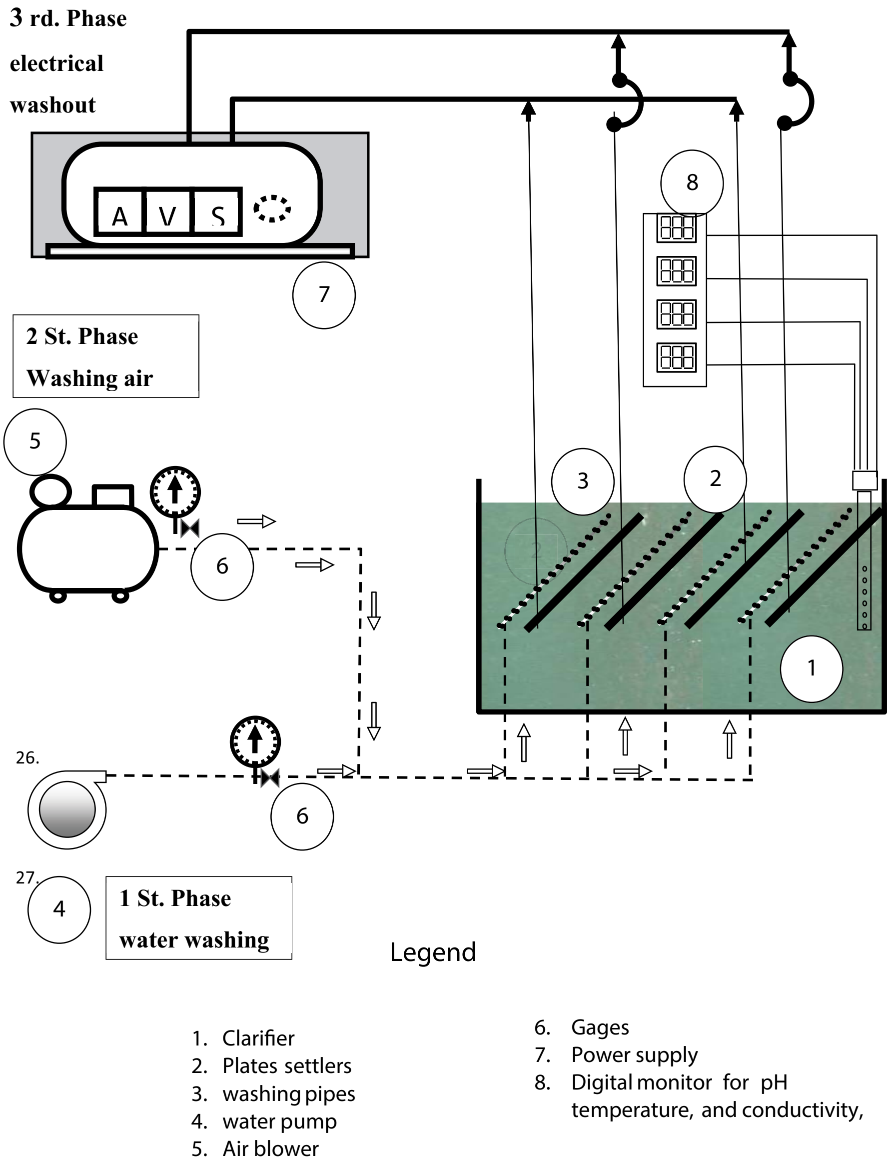

Fig. 1. Schematic diagram of the experimental setup.

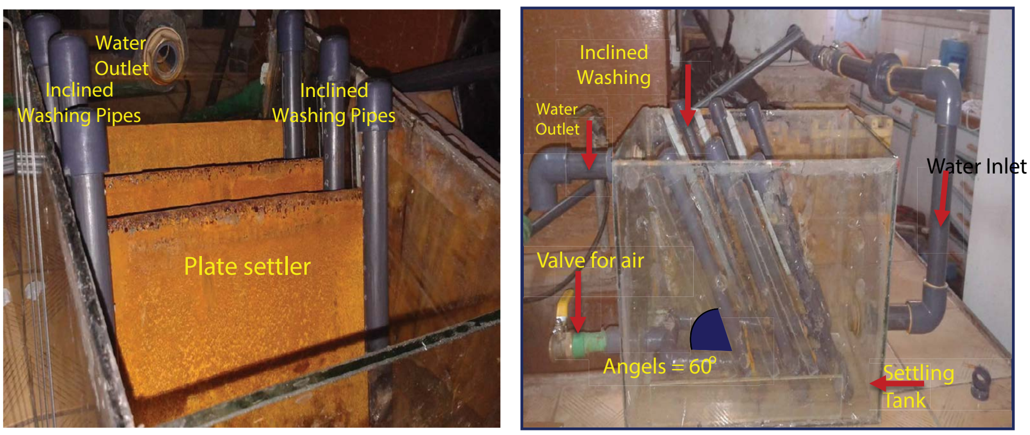

Fig. 2. Experimental setup.

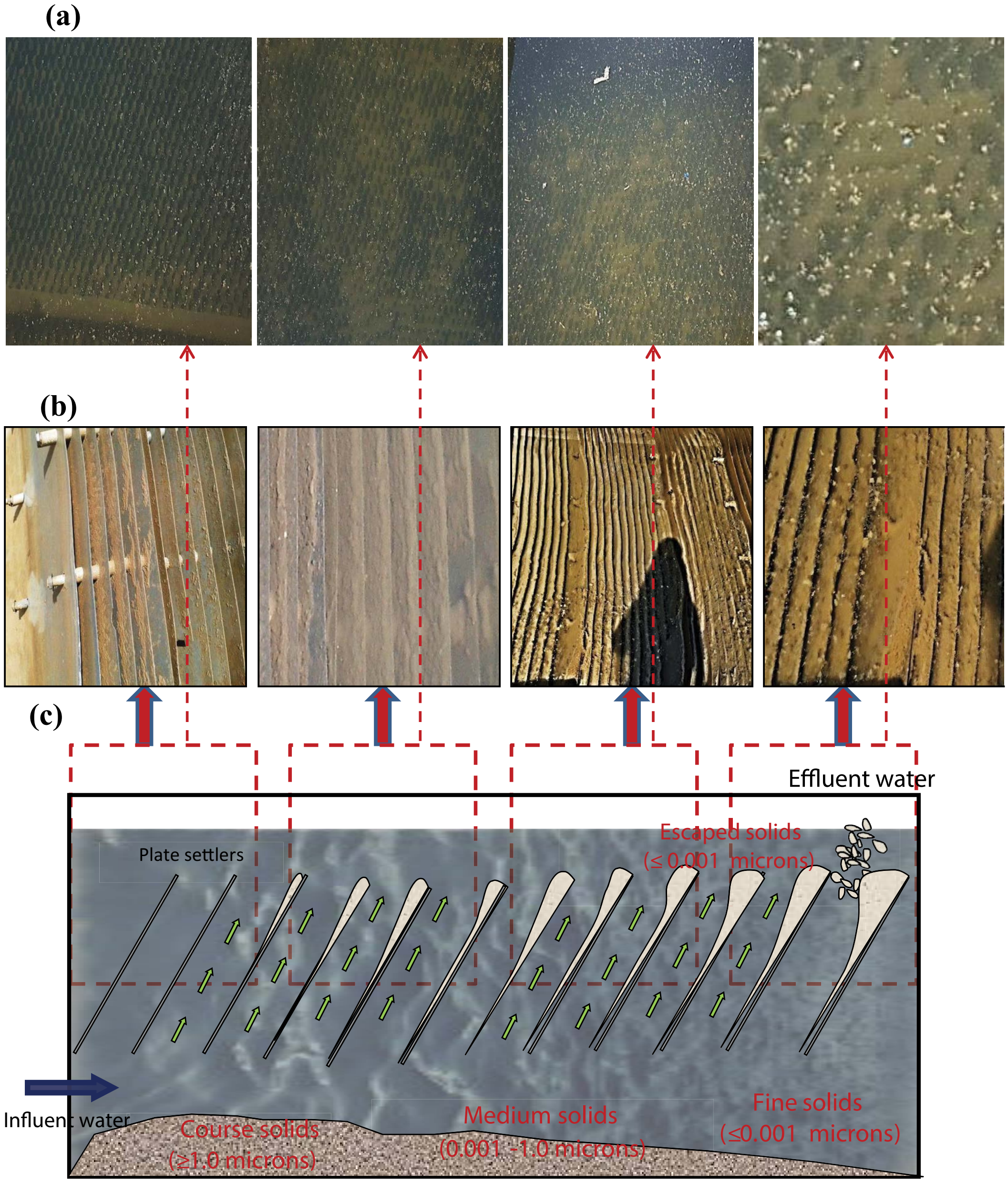

Fig. 3. (a) Real photographs of solid accumulation pattern on the tube settlers, (b) real photographs of solid accumulation pattern on the plate settlers, and (c) a schematic diagram for solid accumulation on plates and tank bottom.

is found on those plates or tubes that are located at the clarifiers' inlet. The particles collected from the accumulated sludge were characterized with a hydrometer analysis of soil which measures the fine particles that are less than 0.01 mm (according to standard methods) [21]. According to the analysis of the accumulated sludge, the accumulated sludge has a size range between 0.01 and 0.001 mm.

These results can be illustrated easily; most particles having size range between 0.01 and 0.001 mm stick on the plate settlers that have a slope of 45°–60°, respectively, and do not slide from the plates based on their own weight. After these particles attach to the plate or tube settlers, clogging occurs between these final plates, and other fine particles start to accumulate gradually on the preceding plates in the tank. Sludge accumulates on each plate in the form of a wedge prism that has an initial point of 0.0 cm and a final point of 8.0 cm at the plate's inlet and outlet, respectively. Sludge accumulation on the plate settlers decreases the clearance between those plates and increases the stream velocity causing most particles to escape with the effluent water. Escape of flocculated particles among the plates decreases the removal efficiency of the plates and the mean removal efficiency of the clarifier. For a real clarifier, the removal efficiency at specific distance along a clarifier length with time is shown in Fig. 4(a), while Fig. 4(b) shows the mean removal efficiency and clogging with time after washing. The daily observations

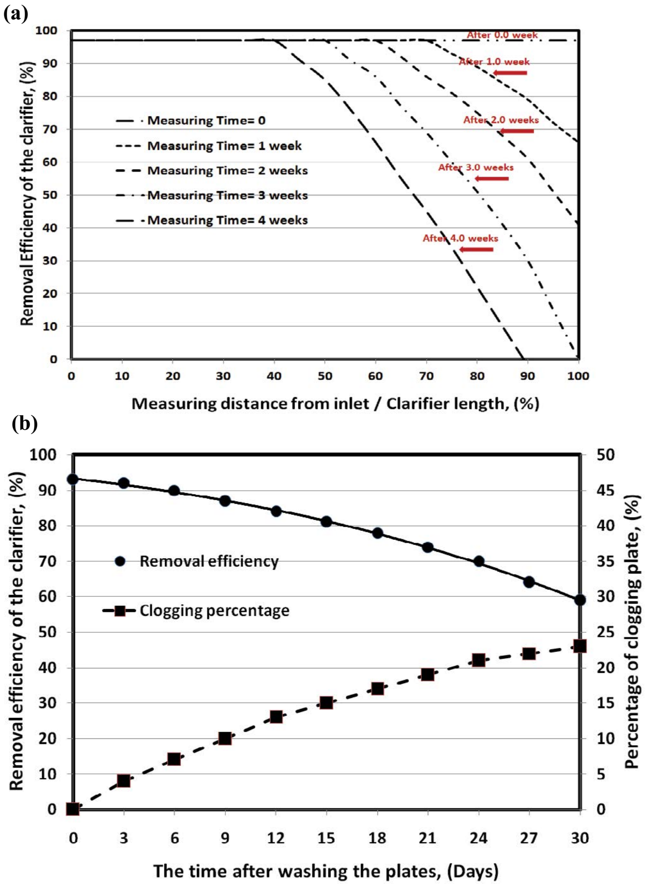

Fig. 4. (a) Removal efficiency at specific distance along the clarifier length with time and (b) the mean removal efficiency and clogging with time after washing.

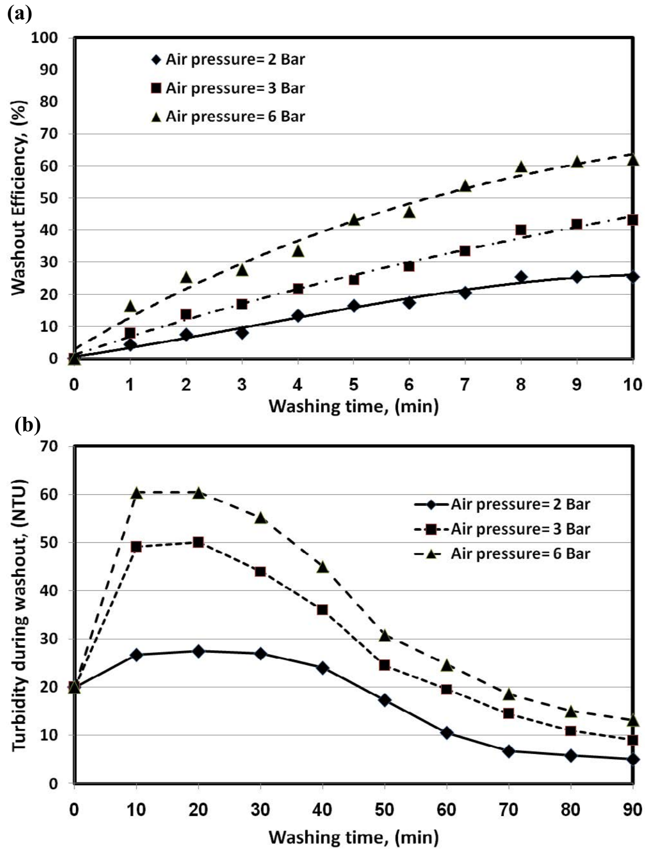

Fig. 5. (a) Washing efficiency using compressed air and (b) turbidity values during washing using compressed air.

were carried out for more than 3 months. The removal efficiency was estimated as (influent – effluent)/influent × 100 [22]. However, the clogging percentages were estimated as (final clearance between the plates/initial clearance) × 100 [23].

3.2. Washing the accumulated sludge using compressed air

Figs. 5(a) and (b) show the results for washing accumulated sludge using compressed air by perforated pipes that supported the plates. From Fig. 5(a), it is clear that the maximum removal efficiency of washing with air is limited, which did not exceed 60% after using compressed air of 6 bars for 10 min. Further, the washing efficiency was decreased from 60% to 42% and to 25% by reducing the compressed air from 6 to 3 and to 2 bar, respectively. Fig. 5(b) shows the increases in water turbidity from 20 to 60 NTU during washing by air due to the full mix of the entire content of the tank. The water in the tank needed about 60 min to return to the same turbidity before washing process. The washout efficiency was estimated with the following equations:

$$\text{Washout efficiency} = \frac{\left(W_F - W_I\right)}{\left(W_F - W_o\right)} \times 100 \quad (1)$$

W_F = total weight of unwashed plate with the accumulated sludge before washing, W_I = total weight of washed plate and residual accumulated sludge after washing, and W_O = original weight of the cleaned plate settler.

3.3. Washing the accumulated sludge using compressed water

Figs. 6(a) and (b) show the results of washing the accumulated sludge using compressed water via the same perforated pipes that supported the plates. It is clear that the compressed water achieved better washing efficiency more than the compressed air. The compressed water achieved washing efficiency of 70% after using compressed water of 6 bars for 10 min (Fig. 6(a)). Further, the washing efficiency was decreased from 70% to 60% and to 52% by reducing the compressed air from 6 to 3 and to 2 bar, respectively. Fig. 6(b) shows the increases in water turbidity from 20 to 70 NTU during washing by water due to the full mix of the entire content of the tank. The water in the tank needed about 70 min to return to the same turbidity before washing process.

3.4. Washing using electrical separation

Figs. 7 and 8 show the results of separation of the accumulated sludge using electrical current after connecting the plates alternately with a direct electrical current of 10, 20, and 30 V. From Fig. 7(a), it is clear that the electrical separation achieved better washing efficiency more than both the air

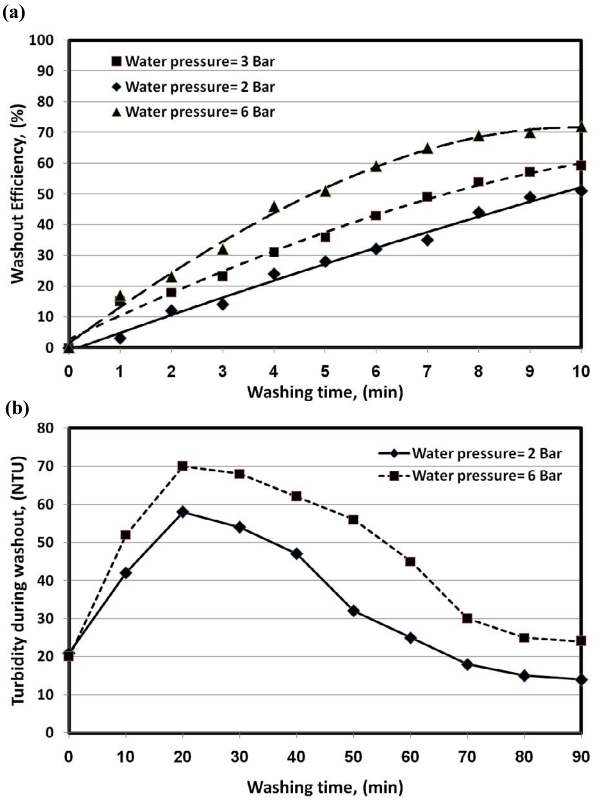

Fig. 6. (a) Washing efficiency using compressed water and (6) turbidity values during washing using compressed water.

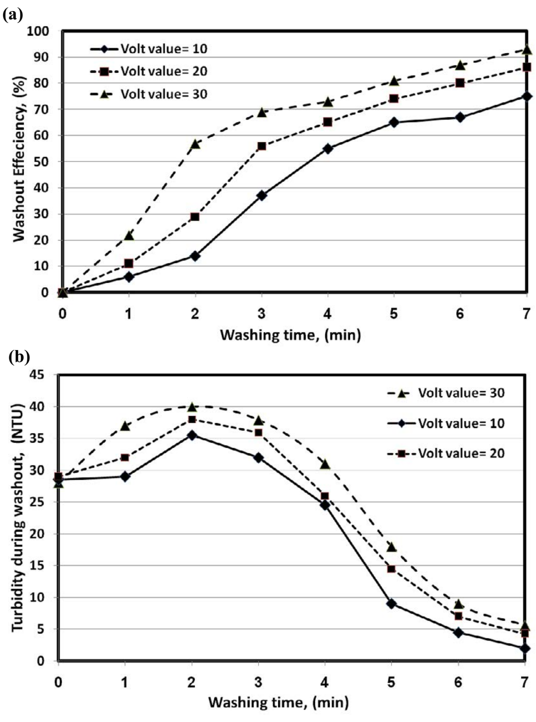

Fig. 7. (a) Washing efficiency using electrical iron plates and (b) turbidity values during washing using electrical iron plates.

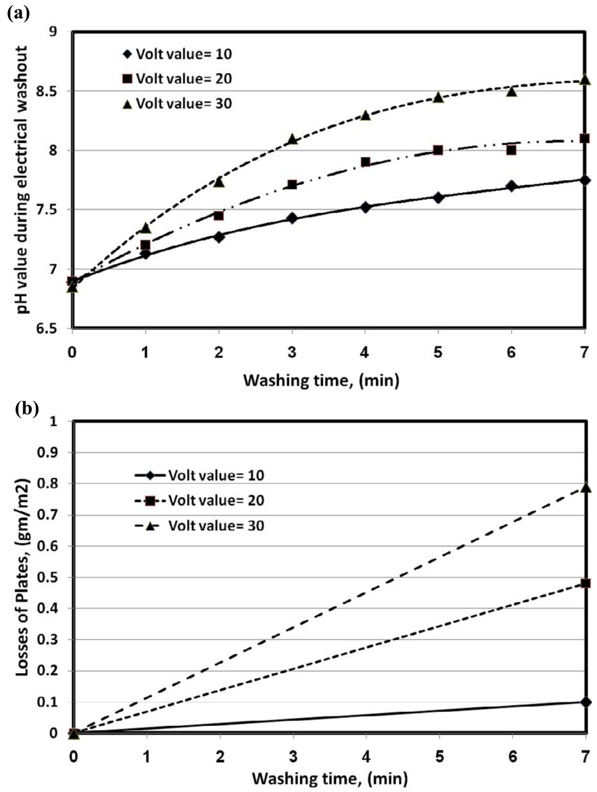

Fig. 8. (a) pH value with time during electrical washing and (b) loss of iron plates using electrical washing by 10, 20, and 30 V.

and water. The electrical separation achieved washing efficiency of 93% after 7 min by using 30 V for the iron plates. Further, the washing efficiency was only decreased from 93% to 85% and to 75% by reducing the potential difference from 30 to 20 V and to 10 V, respectively, in 7 min. It was useful to state that same washing efficiency was obtained after reducing the slope of the plate settler. So, electrical separation does not depend on the slope of the plate settler. Fig. 7(b) shows that there is a little increase in water turbidity from 20 to 40 NTU only during washing by electrical separation. The water in the tank needed only 7 min to return to the same turbidity before the washing process; so, the washing time is changed to 7 min when using electrical separation instead of 10 min.

Fig. 8(a) shows the change of pH value with time during the electrical washing while Fig. 8(b) shows the loss of iron plates using electrical washing by 10, 20, and 30 V. It is clear that increasing the pH value up to 8.7 and the losses from the plates are the main side effects of electrical separation (Fig. 8(a)). The maximum losses of the iron plates due to electrical separation were insignificant that did not exceed 0.0008 kg m^{-2} of plates (Fig. 8(b)). Increasing the pH value of the water from 6.9 to 8.7 during the electrical separation of the accumulated sludge, which was expected by several researchers [22,24–26], was the main disadvantage of this method.

4. Conclusion

The field study confirms that fine particles less than 0.01 and 0.001 mm stick on the plate settlers that have a slope of

45°–60°, respectively, and do not slide based on their own weight, but they need an external effect to remove them from the plates.

- There is a typical pattern for sludge accumulation on tube and plate settlers which have a maximum accumulation at the upper edges of the plates located on the tank outlet and decreased gradually to the plates on the tank inlet.
- Accumulation can reach up to 90% of the clearance between the plates resulting in decreasing removal efficiency below than zero for these plates while reducing the average removal efficiency of the clarifier.
- Nonmetal plate settlers were washed out using compressed air of 2, 3, and 6 bar but with a limited efficiency up to 25%, 40%, and 60%, respectively, after 10 min, but the clarifier needs about 70 min to recover again.
- Nonmetal plate settlers were also washed out using compressed water jet of 2, 3, and 6 bar but with a limited efficiency up to 50%, 60%, and 70%, respectively, after 20 min, but the clarifier needs about 90 min to recover again.
- Metal plate settlers were washed out effectively using electrical repulsion having a little volt of 10, 20, and 30 with a high efficiency up to 75%, 85%, and 93%, respectively, after 5 min, irrespective of their slope, and the clarifier needs only 7 min to recover again.
- Increasing the pH value up to 8.7 and the losses from the plates are the main side effects of electrical washout.

References

[1] S. Sarkar, D. Kamilya, B.C. Mal, Effect of geometric and process variables on the performance of inclined plate settlers in treating aquacultural waste, Water Res., 41 (2007) 993–1000.

[2] G. Galjaard, B. Martijn, E. Koreman, M. Bogosh, J. Malley, Performance evaluation SIX®-Ceramac® in comparison with conventional pre-treatment techniques for surface water treatment, Water Pract. Technol., 6 (2011) wpt20110066.

[3] A.M. Saleh, M.F. Hamoda, Upgrading of secondary clarifiers by inclined plate settlers, Water Sci. Technol., 40 (1999) 141–149.

[4] R. Tarpagkou, A. Pantokratoras, The influence of lamellar settler in sedimentation tanks for potable water treatment — a computational fluid dynamic study, Powder Technol., 268 (2014) 139–149.

[5] W.H. Chu, N.Y. Gao, M.R. Templeton, D.Q. Yin, Comparison of inclined plate sedimentation and dissolved air flotation for the minimisation of subsequent nitrogenous disinfection by-product formation, Chemosphere, 83 (2011) 647–651.

[6] Metcalf, Eddy, Inc., Wastewater engineering treatment and reuse, 4th Ed., McGraw-Hill, New York, 2003.

[7] K. Fujisaki, Enhancement of settling tank capacity using a new type of tube settler, Water Sci. Technol., 62 (2010) 1213–1220.

[8] B.T. Smith, R.H. Davis, Particle concentration using inclined sedimentation via sludge accumulation and removal for algae harvesting, Chem. Eng. Sci., 91 (2013) 79–85.

[9] H. Guo, S.J. Ki, S. Oh, Y.M. Kim, S. Wang, J.H. Kim, Numerical simulation of separation process for enhancing fine particle removal in tertiary sedimentation tank mounting adjustable baffle, Chem. Eng. Sci., 158 (2017) 21–29.

[10] N.M.C. Saady, Effects of inclined plates and polyelectrolyte on the performance of settling tanks, J. Appl. Sci. Environ. Sanit., 7 (2012) 35–42.

[11] T. McKean, B. Bourke, W. Mitchell, L. Caplygin, R. McKeown, Novel application of a lamella clarifier for improved primary treatment of domestic wastewater, 73rd Annual Victorian Water Industry Engineers and Operators Conference, Exhibition Centre–Bendigo, 2010.

[12] C.H. Xing, K. Yamamoto, K. Fukushi, Performance of an inclined-plate membrane bioreactor at zero excess sludge discharge, J. Membr. Sci., 275 (2006) 175–186.

[13] G.M. Naja, B. Volesky, Treatment of Metal-Bearing Effluents: Removal and Recovery, In: Handbook on Heavy Metals in the Environment, L.K. Wang, J.P. Chen, Y.-T. Hung, N.K. Shammas, Eds., London, 2009, pp. 247–291.

[14] J. Hukkamäki, Intensification of Operation of Inclined Plate Settler at Fertilizer Plant, Master thesis, Lappeenranta University of Technology Lut, School of Engineering Science, Finland, 2015, pp. 14–21.

[15] R. Zhang, Z. Sun, B. Cui, P. Ren, Z. Du, X. Chai, J. Lu, Improvement on algae and turbidity removal in an integrated flotation and sedimentation unit using side flow-inclined plate settlers: evidence from a full-scale field experiment, J. Water Supply Res. Technol. AQUA, 67 (2018) 84–98.

[16] K. Takata, R. Kurose, Influence of density flow on treated water turbidity in a sedimentation basin with inclined plate settler, Water Sci. Technol. Water Supply, 17 (2017) 1140–1148.

[17] R.L. Roberts, U.S. Patent No. 8,317,036, U.S. Patent and Trademark Office, Washington, DC, 2012.

[18] C. Feng, N. Sugiura, S. Shimada, T. Maekawa, Development of a high-performance electrochemical wastewater treatment system, J. Hazard. Mater., 103 (2003) 65–78.

[19] M. Verma, R.N. Kumar, Coagulation and electrocoagulation for co-treatment of stabilized landfill leachate and municipal wastewater, J. Water Reuse Desal., 8 (2018) 234–243.

[20] K.S. De Moura, H.R.C. da Silva, L.P. Dornelles, L.C.B.B. Coelho, T.H. Napoleão, M.D.L. de Oliveira, P.M.G. Paiva, Coagulant activity of water-soluble Moringa oleifera lectin is linked to lowering of electrical resistance and inhibited by monosaccharides and magnesium ions, Appl. Biochem. Biotechnol., 180 (2016) 1361–1371.

[21] M. Fouad, A. El-Morsy, Sludge accumulation pattern inside oxidation ditch case study, Water Sci. Technol., 69 (2014) 2468–2475.

[22] M. Fouad, M. El Amrety, M. Mossad, Enhancement of electrocoagulation process efficiency using activated carbon, Desal. Wat. Treat., 114 (2018) 61–68.

[23] R.J. Xie, E.K. Tan, S.K. Lim, E. Haw, C.P. Chiew, A. Sivaraman, C.P. Teo, Pre-treatment optimisation of SWRO membrane desalination under tropical conditions, Desal. Wat. Treat., 3 (2009) 183–192.

[24] A. Mortadi, A. El Melouky, E. Chahid, H. Nasrellah, M. Bakasse, A. Zradba, R. El Moznine, Rheological and electrical properties to investigate the coagulation process during sludge treatment, Water Sci. Technol., 77 (2018) 196–203.

[25] S. Basra, Z. Iqbal, H. Ur-Rehman, M.F. Ejaz, Time Course Changes in pH, Electrical conductivity and heavy metals (Pb, Cr) of wastewater using Moringa oleifera Lam. seed and alum, a comparative evaluation, J. Appl. Res. Technol., 12 (2014) 560–567.

[26] S. Zhi, S. Zhang, Effect of co-existing ions on electrode behavior in electrocoagulation process for silica removal, Desal. Wat. Treat., 56 (2015) 3054–3066.