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A pilot study for rapid water clarification by V-shaped nested tubes

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ABSTRACT

The emergency water treatment technology supplies water when the quality of raw water becomes temporarily unpleasant due to an incident. Removing the factors producing turbidity is very important because of different issues, such as protecting microorganisms during disinfection. Thus, it is one of the priorities of water treatment in emergency conditions. The present study aimed at surveying the function of tube settlers in water treatment, especially for removing turbidity, in emergency conditions. This cross-sectional study was done by making a pilot using polyvinyl chloride material and a sedimentation tank as the control pilot. The performance of these settlers was surveyed during three different steps; without using any coagulants, using coagulants, and using coagulants and a slow sand filter. The efficiency of the tube and the control pilot were surveyed at three inlet turbidities (100, 200, and 300 NTU) at 10, 20, and 30 min retention times in each of the three steps. The samples were gathered from designated places according to the above-mentioned retention times. The best efficiency was gained at 300 NTU inlet turbidity and 30 min retention time. The average efficiency was 45.3% for the control pilot, 89.9% for the tube pilot using coagulants, 57.2% for the tube pilot without using any coagulants, and 99.4% for the tube pilot using coagulants and a slow sand filter. The results demonstrated the high efficiency of the tube pilot in removing turbidity compared to the control pilot.

Keywords: Emergency conditions; Water treatment; Turbidity; V-shaped nested tubes

1. Introduction

Generally, access to healthy water becomes limited in emergency conditions. The emergency water treatment technology refers to supplying water when the quality of raw water becomes temporarily unpleasant due to an accident [1,2]. In areas where people do not have access to healthy drinking water, water-borne diseases are the main cause of mortality. According to World Health Organization (WHO), 1.8 million people around the world died due to poverty and lack of sanitary annually [3]. Water treatment in such conditions always involves the in-site treatment, which is considered a bridge for increasing the quality of raw water to a desirable degree. Therefore, making decision about the necessary degree of water treatment depends on the physicochemical and bacterial quality of water [1,2]. Indeed, the aim of water treatment in emergency conditions is to improve water quality using cheap and simple processes and functions [4].

Turbidity is one of drinking water's physical indexes, which consists of colloids and particular matters that prevent the passage of light through water. One of the important

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points during turbidity removal is protecting microorganisms during disinfection [5,6]. In case of high turbidity of raw water, storage for removing suspended solids, and reducing turbidity are necessary, which can be done through several methods. In case supplying water for a large group of people is the goal, it is necessary to use sedimentation tanks for removing suspended solids [7,8].

Settling is an important unit in water treatment as about one-third of investment expenditures of usual water treatment is allocated to the settling unit [9]. Settling process is divided into a grit chamber and settling tank. The size and specific weight of the removed suspended solids are the main factors in selecting the settling process [10]. Settling removes suspended solids from the liquid phase using gravity power and is one of the conventional units used in water and wastewater treatment [11]. The most important parameters in the settling process include water nature, the velocity of particular settling, and physical nature of sediments [12,13]. According to Hazen Williams' rule, the efficiency of a settling pond depends on the horizontal surface and is independent from depth. The efficiency of the sedimentation tank enhances with an increase in the horizontal surface, which is similar to the decrease of surface over flow rate (superficial load). This goal can be achieved via adding parallel tubes to the sedimentation tank. These chambers are called tube chambers. Increasing these tubes causes Reynolds number to decrease and the Froude number to increase. Decrease in Reynolds number causes the flow regime to get closer to the laminar regime and increase in the Froude number ends in higher stability of the flow regime. These are the bases of the full settling ponds function [14–19].

1.1. Sedimentation tank basic functions

Camp [15] explained the discrete particles sedimentation pattern in an ideal rectangular-shaped sedimentation tank. According to this model, V_0 represents particle critical velocity and can be measured by Eq. (1):

$$V_0 = \text{SLR} = \frac{Q}{A} \tag{1}$$

where V_0 is the average flow velocity (m/s); SLR is the surface loading rate (m/s).

Eq. (1) shows that the efficiency of a sedimentation tank depends on the surface loading rate. Therefore, by increasing the horizontal surface of the settling chamber, the surface loading decreases, which improves the efficiency of the chamber [15].

In addition to the surface overflow rate, the efficiency of a sedimentation tank depends on the condition of the sedimentation tank and flow hydraulic condition. The more laminar and stable the state flow, the higher the efficiency of the sedimentation tank will be. Indexes for laminar and stable state flow are Reynolds number [Eq. (2)] and Fraud number [Eq. (3)], respectively.

$$\text{Re} = \frac{V_0 d}{\upsilon} \tag{2}$$

where Re is the Reynolds number; V_0 is the average flow velocity (m/s); d is the hydraulic radius of the channel (m); υ is the kinematic viscosity of water (m^2/s).

$$\text{Fr} = \left(\frac{2V_a^{\,2}}{gd}\right) \tag{3}$$

where Fr is the flow Fraud number; V_a is the average flow velocity (m/s); d is the hydraulic radius of the channel (m).

The Reynolds number is the index of laminar flow, which is calculated by Eq. (2). Accordingly, efficiency increases as the flow get laminar. In order to ensure the laminar flow in pipe shape settlers, the Reynolds number must be held less than 800 [16].

With the increase in the horizontal surface that is similar to decreased horizontal surface flow rate, the efficiency of the sedimentation tank gets better. This can be accomplished by adding parallel pipes to sedimentation tanks. These tanks are called tube sedimentation tanks. Generally, tube shape settlers are used in one step parallel arrangement [17]. In some functions and treatment processes like multi-stage filtering, biological complete-mixed reactors, and floatation process, stage making is used to improve efficiency [18,19]. In stage tube shape settlers, counter-current flow pipes are usually installed at 45°–60°. At these degrees, sediment particles do not stick to the pipes and slip down. Therefore, sludge collection is done automatically [14]. In pipe settlers, water, and sediments can flow through both current and counter-current flows. The advantage of current flow is that sludge collection is done automatically and pipes can be installed at less than 60° [20]. Sarkar et al. [21] determined the optimum counter-current flow to be at 45° [22].

According to Eq. (4), the effective factors in a settler's efficiency are the pipes joint degree, pipes diameter, flow velocity, and falling velocity [9–23]. Researchers such as Yao, Willis, Fadel, Baumann, and Ziolo reformed this basic equation in their works [9,22,24,25].

$$V_s\left(\sin\theta - \frac{l}{d}\cos\theta\right) = V_a \tag{4}$$

where V_s is the settling rate (m/s); θ is the tubes installing angle; V_a is the average flow rate (m/s).

In order to survey the multi-stage pipe shape settler theory, the possibility of the above equations was observed. In these calculations, the average flow velocity inside the pipes was taken from Eq. (5):

$$V_s = \frac{L}{t} \tag{5}$$

where V_s is the settling rate (m/s); L is the tube length (m); t is the resident time (s).

The falling velocity of the particles removed completely from the sedimentation tank was obtained from Eq. (4). Additionally, assuming that the particles were spherical and Reynolds number was 1, the diameter of the completely removed particles with V_s settling velocity from the Stox equation was calculated using Eq. (6) [26]:

$$V_s = \frac{g\left(S_p - S_w\right)d_p^{\,2}}{18v} \quad (6)$$

where S_p is the sedimentation particles density; S_w is the water density; d_p is the particle diameter (m); v is the kinematic viscosity of water (m^2/s).

The present study aims at surveying the function of tube settlers in water treatment, especially for removing turbidity, in emergency conditions.

In 2000 by front tracing method, Mortazavi and Tryggason [27] surveyed the motion of one alone drop in Poison flow for Reynolds numbers. They studied drop motion as a function of Reynolds number, Veber, and cohesion ratio.

Campbell and Brennen [28] stimulated granular flow on slope surfaces in a two-dimensional form. They compared particle density and speed distribution with theoretical analysis and laboratory results and found that flow behavior is severely related to ground temperature.

Charles and Pozrikidis [29] gained cohesion ratio effect on flow properties by studying with two-dimensional suspended drops in zero Reynolds number. They observed that by increasing drop cohesion, drops behave like solid particles. Also clusters? Formation and particle concentration in one flow region inside the canal is more important.

Lowenbeg and Hinch [30] studied a liquid with three-dimensional suspended drop in one shear flow in large volume ratios for zero Reynolds number and observed that a liquid with suspended particles shows a shear-thinning behavior.

2. Materials and methods

In this 6 month study, two polyvinyl chloride (PVC) tube pilots attached to each other according to Fig. 4 were used as a settler. In this survey, the efficiency of the tube sedimentation tanks in removing turbidity particles was determined in the three following stages:

- Without using coagulants
- By using coagulants
- By using coagulants and a slow sand filter.

Since the quality of drinking water is normally controlled in the water distribution system, not at the using place, operating treatment system in using place is one of the methods discussed for achieving new drinking water regulations [31]. The main structure of this unit was made of 20 cm diameter PVC pipes with 200 cm length. The components used in this pilot were joined together at 90° using the same material.

Inside the main bodies of the first, second, and third tubes were filled with PVC pipes with 200 cm length and lower diameters. The diameters of these pipes were 5, 1.5, and 1 cm, respectively (Fig. 1).

The fourth part was filled with rubble and sand according to the slow sand filter arrangement (Fig. 3). There are 10, 106, and 320 pipes in tubes A, B, and C, respectively.

The upper area of the first part of the main pipe was designed a little higher than outflow in order to provide hydraulic gradient, overcome the pressure drop, and prevent the water inlet over flow. The pilot was fixed on the wall with the aid of a clamp (Fig. 4).

It should be noted that two pilots were launched at the same time, one of which being the control reactor. The control reactor was exactly the same as the pipe pilot, with the only difference being its main inner structure that contained no other pipes or sand. Sampling procedure of both pilots and the results have been presented in the following sections.

2.1. Raw water production and coagulation unit

Raw water production, flocculation, and coagulation units have been depicted in Figs. 5 and 6. The influent to the settling units was produced artificially according to the following descriptions. Clay was used to produce turbidity. In order to reach similar conditions in different steps of sampling, clay was first sieved through sieve number 200 and was then mixed with spring water at a constant ratio. The average turbidity of this soil varied from 100 to 300 NTU. The flow was entered hydraulically from this reservoir to reservoir No. 2. In this reservoir, the produced slurry from spring water was diluted at a designated ratio in order to obtain the desired turbidity. In order to produce similar conditions, a mixer with a constant speed was used. The reason for using high turbidity in this study was simulating the condition when a high amount of turbidity enters the water treatment unit because of flood. Also, when the distribution system is damaged due to flood or earthquake, possibility of entrance of turbidity into the system is quite high. This system can be used for high turbidity river water treatment during military maneuvers and tours, as well.

In this study, the stage tube settlers' efficiency was surveyed at three steps.

2.2. Step one: comparing the tube settlers' efficiency to the control reactor without using coagulants (sedimentation tank)

At first, the obtained raw water at three different turbidity degrees (100, 200, and 300 NTU) and the designated

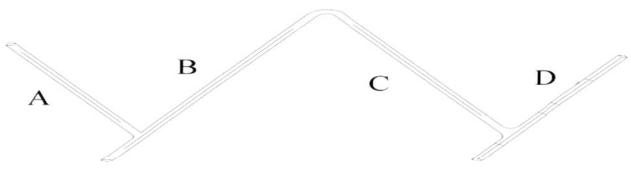

Fig. 1. Scheme of the used pilot.

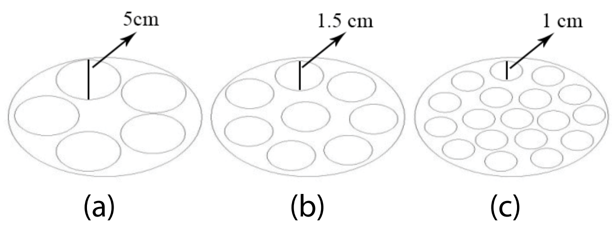

Fig. 2. Vertical sections of the first, second, and third tubes.

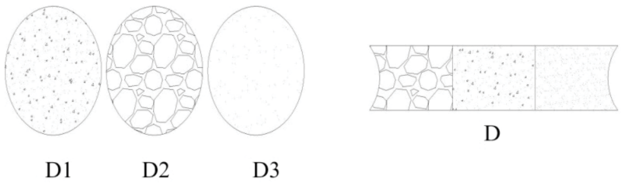

Fig. 3. The horizontal and vertical sections of the fourth part of the pilot.

Fig. 4. Scheme of the used pipe pilot.

flow rate were entered into stage tube settlers and the control reactor. Then, in order to investigate the efficiency of the reactor at three retention times (10, 20, and 30 min), sampling was done from the effluent. Sampling of the tube pilot was also done from the third section of the effluent.

2.3. Step two: comparing the tube settlers' efficiency to the control reactor using coagulants

At the second step, raw water with 100, 200, and 300 NTU turbidity was entered into the tube pilot after flocculation and coagulation processes at 10, 20, and 30 min retention times. Then, in order to survey the pilot's efficiency, sampling was done from the third section effluent before entering the water into the sand filter.

In this step, $FeCl_3$ was used as the coagulant. The reason for using $FeCl_3$ was its low price compared to other coagulants in Iran. The appropriate amount of this coagulant for each turbidity degree (100, 200, and 300 NTU) was determined by Jar Test considering economic and technical factors. This amount was gained as 9, 11.5, and 13.5 mg/Lt in Fe_3 for each turbidity degree, respectively.

The fast mixing useful volume reservoir and coagulation useful volume reservoir were considered to be 15 and 400 L, respectively. Both reservoirs were equipped with variable rotation mixers.

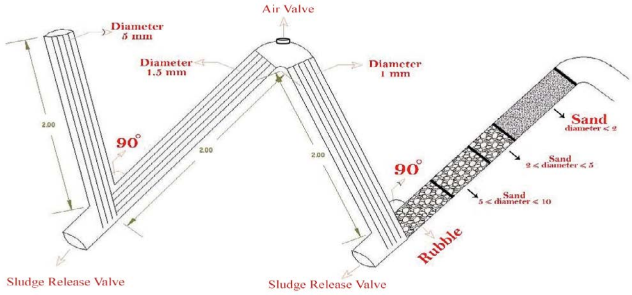

Fig. 5. Details of the scheme of the used pilot.

2.4. Step three: comparing the tube settlers' efficiency to the control reactor using coagulants and a sand filter

In this step, in order to survey the effect of the slow sand filter on removing turbidity, the fourth part was added to the reactor. As mentioned before, inside this part was filled with rubble and sand according to the slow sand filter arrangement.

The influent water was entered into the fourth section after flocculation and coagulation processes and running through the first three components. Sampling from the effluent was also done at three retention times (10, 20, and 30 min) in this step. The turbidity of the samples was determined on the basis of the standard method booklet using HATCH2001 turbidimeter appliance and nephelometric standard procedure [32]. In order to ensure proper results, sampling was repeated three times for each retention time and the average results for each retention time have been separately presented in Table 2.

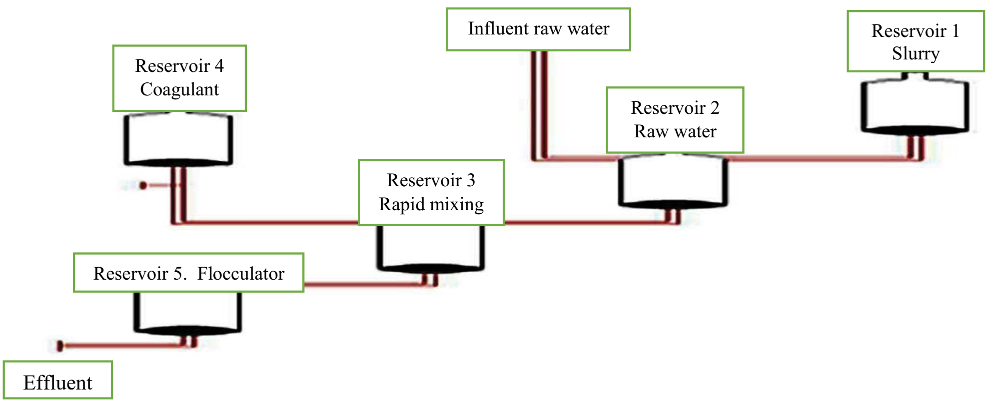

Fig. 6. Different influent raw water units.

Table 1
Made pilot characteristics

Reactor's main body		Tube diameter (cm)	Tube length (cm)
		20	200
Characteristics of the components inside the main body	First section	5	200
	Second section	1.5	200
	Third section	1	200
	Fourth section	Slow sand filter	
Control reactor		20	200

Table 2
Influent and effluent turbidity of the tube and the control reactor under study conditions

Retention time (min)	Influent turbidity (NTU)	(Effluent turbidity) Tube settlers			Control reactor
		Without coagulants	Using coagulants	Using coagulants and a slow sand filter	Control reactor
10	100	63.1 ± 2.4	18.35 ± 1.7	7.2 ± 0.2	73.4 ± 2.7
10	200	129 ± 2.3	26.35 ± 1.9	5.7 ± 0.5	156.2 ± 2.2
10	300	189.6 ± 3	35.3 ± 1.25	6.4 ± 0.3	198 ± 1.4
20	100	52.2 ± 1.2	17.2 ± 1.2	6.4 ± 0.2	60.4 ± 2.3
20	200	98.7 ± 2.5	24.6 ± 2.4	5 ± 0.5	130.9 ± 1
20	300	152.3 ± 2.02	32.3 ± 1.7	4.8 ± 0.3	182.4 ± 2.12
30	100	41.8 ± 1.8	13.2 ± 0.7	0.6 ± 0.5	55.8 ± 2.4
30	200	83.8 ± 4.3	19.6 ± 2.3	0.64 ± 0.3	111.2 ± 1.9
30	300	132.2 ± 1.3	21.4 ± 1.5	0.2 ± 0.4	154 ± 1.3

3. Results and discussion

While using reactors, the tubes were inspected for clogging several times. No clogging was detected due to the accumulation of sediments. Yet, the reactor was inspected repeatedly. The possibility of tube clogging was expected to increase by the production of sludge and floc in the flocculation and coagulation processes. However, no clogging was noticed when the tubes were inspected again.

Using the reactor without coagulants produced less sludge compared to the stage using coagulants. Considering the proper diameter of the reactor pipes (especially in the first part) and regarding the fact that most turbidity removals was accomplished in this section, bigger flocs could easily pass without clogging.

The results of sampling showed that using sloppy multi-stage tube settlers caused better settling. In addition, decreasing the diameter of the tubes making the main body could improve the hydraulic conditions of settling.

The effluent turbidity from the tube reactor showed the noticeable preference of the tube settlers compared to the control reactor in both conditions (with and without coagulants).

In order to prevent tube clogging, the diameter of the tube at the first section of the pilot is recommended to be at least 5 cm. Since most turbidity was removed in the first section, tubes with lower diameters could be used in the second section.

Fig. 7. Schematic of different influent raw water units.

According to WHO's guidelines, the amount of turbidity should be less than 1 NTU to ensure effective disinfection [33]. On the other hand, the amount of turbidity is essential to determine the amount of coagulants [32].

In order to improve sedimentation in water treatment, if the flow regime can be approached to laminar, sedimentation will increase vastly. Reynolds number is one of the factors for determining the type of flow regime. On the other hand, increasing the Fraud number will lead to higher flow stability [9–14].

In this study, when pips with smaller diameters were added into the main body, the wet perimeter increased

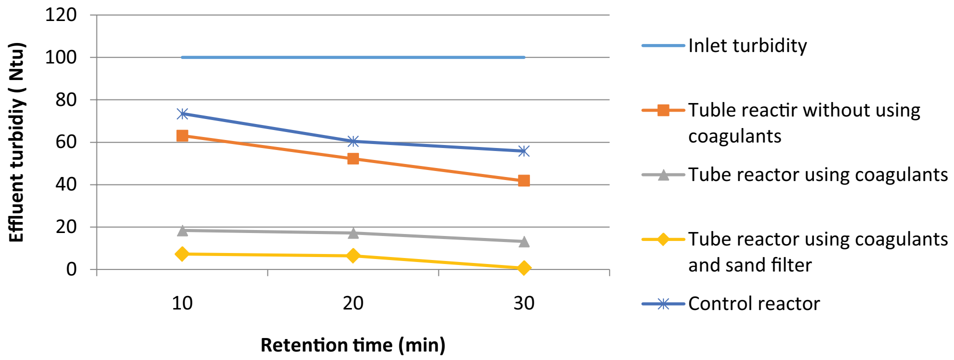

Fig. 8. Effluent turbidity in different conditions at 100 NTU influent turbidity.

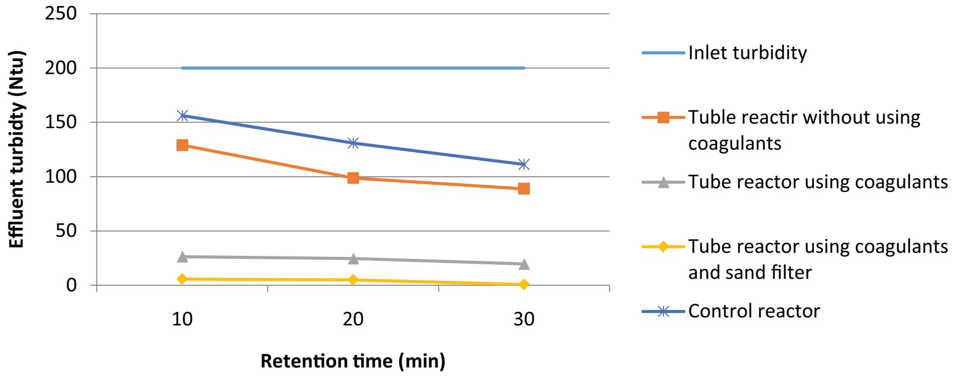

Fig. 9. Effluent turbidity in different conditions at 200 NTU influent turbidity.

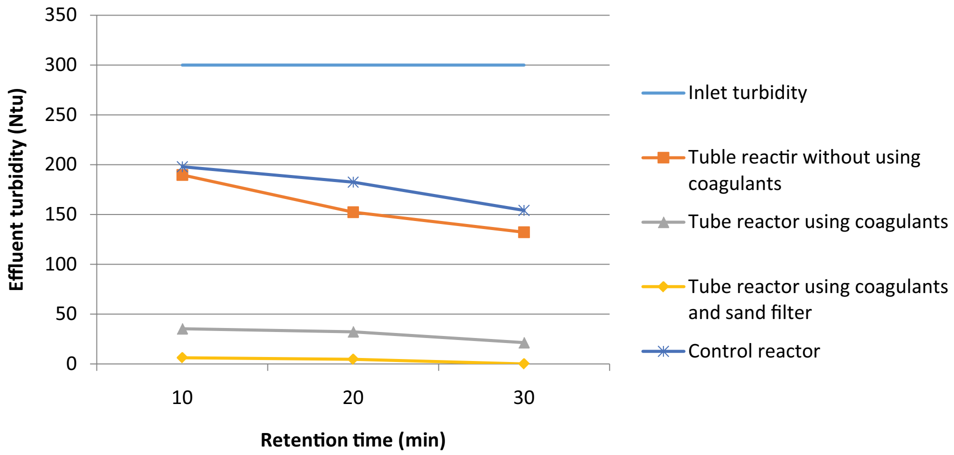

Fig. 10. Effluent turbidity in different conditions at 300 NTU influent turbidity.

vastly. This happened when the cross-section through which the flow passed remained constant. According to Eq. (2), decreasing the hydraulic radius led to a decrease in Reynolds number.

In this research, by making changes in the settlers' structures and increasing wet perimeter followed by decreased hydraulic radius, the Fraud number increased according to Eq. (3). These changes were along decreased Reynolds number and increased Fraud number to approach flow regime to laminar for increasing efficiency. This is the best condition for sedimentation.

One of the most important problems for horizontal settlers is sludge discharge. However, regarding the structure of V-shaped settlers, settling particles can be accumulated in the sludge discharge area, so that discharge will be done easily.

One of the most important advantages of these systems is their structural simplicity. Therefore, they can be launched

Table 3
Comparison of the pilots' efficiencies

		Percentage of turbidity removal (%)			
Retention time	Raw turbidity	Without coagulants	Using coagulants	Using coagulants and a slow sand filter	Control reactor
10	100	36.9	81	92.8	26
10	200	35	86	97	21
10	300	36.8	88	97.8	34
20	100	47.8	50.6	49	39
20	200	50.6	87	97.5	34
20	300	49	89	98.4	39
30	100	58	86.8	99	44
30	200	58	90.2	99.3	44
30	300	55.6	92.8	99.9	48

for operation with minimum time and expenses. In critical and emergency conditions, the components of these settlers can be transferred to the desired area by a truck and be launched easily.

- These kinds of settlers can be made in different sizes according to the amount of demand for water.
- Maintenance expenditures are very low.
- If pipe clogging happens due to settling suspended solids, a simple downwash can clean the pipe completely.

4. Conclusion

- Turbidity and suspended solids removal ratio was enhanced by increasing the retention time. Indeed, by increasing the retention time, the chance of settling increased, as well, resulting in the prevention of removal of particles with lower settling velocity. However, after 30 min, no change was found in efficiency. Thus, the sediments might enter the flow again and cause more turbidity.
- According to Table 3, the highest efficiency in removal of suspended solids from tube settlers was obtained at 30 min retention time under all working conditions.
- According to Eq. (4), decreasing the diameter of the tubes inside the main body and along the pilot reduced the Reynolds number, which increased the settling unit function.
- Based on Eq. (5), as the pipe diameters inside the main body decrease, the medium velocity of flow in the pipes increases, causing the Fraud number in the tube settlers to increase. This change in Fraud number of the flow will make the tube settlers more stable than the settling chamber, resulting in improvement of the settling function. The results have been presented in Table 2.
- Comparing the amount of effluent sludge from sludge drain cock in the first section to the second and third sections revealed that while using coagulants, high turbidity occurred due to making flocs. Settling of these flocs along the first section caused the particles that were settling separately to be trapped in these flocs and be settled in the first section.
- Transferring this pilot under different conditions is easy because of the light weight of its components.
- The cost of preparing this pilot is low because the components are cheap enough.
- This pilot can be easily assembled and launched and no expert operators are required.
- All the above-mentioned advantages help using this pilot under different conditions, especially in emergency cases when preparing drinking water is difficult.
- Using one stage as a slow sand filter can decrease the microorganisms existing in water and significantly reduce turbidity. Yet, this has to be investigated in future studies.

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References

[1] WHO, Emergency Simple Treatment of Drinking Water at Point-of-Use (POU), Technical Note for Emergencies, Water, Engineering and Development Centre, Loughborough University, 2011.
[2] P. Literathy, Emergencies in Drinking Water Sources, Institute for Water Pollution Control, Water Resources, 2013.
[3] M. Ahammed, K. Davra, Performance evaluation of biosand filter modified with iron oxide-coated sand for household treatment of drinking water, Desalination, 276 (2011) 287–293.
[4] WHO/WEDC, Technical Note for Emergencies, Emergency Treatment of Drinking Water at the Point of Use, 2009.
[5] M.W. LeChevallier, T. Evans, R.J. Seidler, Effect of turbidity on chlorination efficiency and bacterial persistence in drinking water, Appl. Environ. Microbiol., 42 (1981) 159–167.
[6] S.-W. Nam, B.-I. Jo, M.-K. Kim, W.-K. Kim, K.-D. Zoh, Streaming current titration for coagulation of high turbidity water, Colloids Surf., A, 419 (2013) 133–139.
[7] EPA, Emergency Disinfection of Drinking Water, Office of Water 4606-M EPA 816-F-06–027, 2006. Available at: www.epa.gov/safe water
[8] The International Federation's Global Agenda, Household Water Treatment and Safe Storage, A Field Manual for Red Cross/Red Crescent Personnel and Volunteers, 2010, pp. 1–44.

[9] A.A. Fadel, E.R. Baumann, Tube settler modeling, J. Environ. Eng., 116 (1990) 107–123.
[10] S. Kawamura, Integrated Design and Operation of water treatment facilities, 2nd ed., John Willey and Sons, New York, NY, 2006.
[11] G. Tchobanoglous, E. Schtooder, Water Quality, Addition Wesley Publisher, London, 1985.
[12] Anon., Water Treatment Plant Design, American Society of Civil Engineering/American Water Work Assosiation, USA, 1990.
[13] Anon., Technologies for Upgrading Existing Water Treatment Facilities, USEPA, USA, 1990.
[14] G.L. Culp, S. Hansen, G. Richardson, High-rate sedimentation in water treatment works, J. AWWA, 60 (1968) 681–698.
[15] R.T. Camp, Sedimentation and the design of settling tanks, Trans. Am. Soc. Civ. Eng., 111 (1946) 895–936.
[16] American Water Works Association, Water Quality and Treatment, R.D. Letterman, Ed., A Handbook of Community Water Supplies, 5th ed., McGraw-Hill, New York, NY, 1999.
[17] MWH, Water Treatment Principle and Design, 2nd ed., John Wiley and Sons Inc., New York, NY, 2005.
[18] R. Nabizadeh, K. Nadafi, F. Vaezi, M. Khazaei, M. Safdari, Efficiency of horizontal roughing filter (HRF) in coliform removal from aerated lagoon effluent, J. Water Wastewater, 66 (2008) 2–9 (in Persian).
[19] W.W. Eckenfelder, D.L. Ford, A.J. Englande, Industrial Water Quality, 4th ed., WEF Press, the US, 2008.
[20] L. Huisman, Sedimentation and Flotation, IHE, Delft, the Netherland, 1986.
[21] S. Sarkar, D. Kamilya, B.C. Mal, Effect of geometric and process variables on the performance of inclined plate settlers in treating aqua cultural waste, Water Res., 41 (2007) 993–1000.
[22] R.M. Willis, Tubular settlers - a technical review, J. AWWA, 70 (1978) 331–335.
[23] K. Fujisaki, M. Terashi, Tube settlers for the enhancement of settling tank capacity, Filtration, 7 (2007) 168–172.
[24] K.M. Yao, Design of high-rate settlers, J. Environ. Eng. Div., 99 (1973) 621–637.
[25] J. Ziolo, Influence of the system geometry on the sedimentation effectiveness of lamella settlers, Chem. Eng. Sci., 51 (1996) 149–153.
[26] AWWA, Water Quality and Treatment: A Handbook of Community Water Supplies, 4th ed., McGraw-Hill Inc., US, 1990.
[27] S.S. Mortazavi, G. Tryggason, A numerical study of the motion of drops in poiseuille flow. Part 1: lateral migration of one drop, J. Fluid Mech., 411 (2000) 325–350.
[28] C.S. Campbell, C.E. Brennen, Chute flows of granular material; some computer simulation, J. Appl. Mech., 52 (1985) 172–178.
[29] R. Charles, C. Pozrikidis, Significance of the dispersed-phase viscosity on the simple shear flow of suspensions of two-dimensional liquid drops, J. Fluid Mech., 365 (1998) 205–234.
[30] M. Lowenbeg, E.J. Hinch, Numerical simulation of a concentrated emulsion in shear flow, J. Fluid Mech., 321 (1996) 395–419.
[31] K. Lautenschlager, N. Boon, Y. Wang, T. Egli, F. Hammes, Overnight stagnation of drinking water in household taps induces microbial growth and changes in community composition, Water Res., 44 (2010) 4868–4877.
[32] APHA-AWWA-WPCF, Standard Methods for the Examination of Water and Wastewater, 21st ed., American Public Health Association, Washington, DC, 2005.
[33] WHO, Guidelines for Drinking-water Quality, Geneva, 2011, pp. 423–434.