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Novel helical or coiled flocculator for turbidity reduction in drinking water treatment: a performance study

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Abstract. Helical or spiral coiled flocculator have not been applied in drinking water treatment yet in Indonesia. Only a few articles discussed it with different themes like hydrodynamic, floc characteristics, and performance. This study was done to know the efficiency (performance) of helical flocculator with parameters velocity gradient, pipe, helical diameter, flowrate, detention time, and coagulant dose. The study was divided into two steps: Jar test to determine the optimum dosage of coagulant and flocculation experiments to evaluate the helical flocculator efficiency. Efficiencies were in the range of medium to high. On flowrate, 13 ml/second was obtained good results for two pipe sizes but different in helical diameters. In a 0.5 inch pipe with 0.8 m helical diameters, the turbidity reduction efficiencies were 72.4% and 73.9%, and sediment volume was 18.3 ml and 20.0 ml. In a 0.625 inch pipe with 0.4 m helical diameters, the turbidity reduction efficiencies were 76.7% and 78.5%, and sediment volume was 14.3 ml and 19.7 ml. The optimum velocity gradient about 64.9–69.6 per second, and detention time about 438–649 seconds. The results showed that helical flocculator was effective for floc formation. Flowrate, pipe diameter, helical diameter were three key parameters to perform helical flocculator.

1. Introduction

Since the 1970s, all *PDAM* has applied conventional technology in water treatment plant because science and technology have not found an innovative design yet [1]. All *PDAM* does not have a new design, and the Ministry of Public Works has tended to implement *IPA Kedasih (Instalasi Pengolahan Air Keluaran Direktorat Air Bersih)*. In contrast, the quality of raw water varies widely from one island to another. Water in Java island has much suspended solid and different from Sumatera, Kalimantan, Sulawesi, Papua, where their water is rich with natural organic matter. Natural organic matter (NOM) was more influential than turbidity in controlling the coagulant dose [2]. The best removal efficiency on NOM with spiral clari-flocculator [3].

Since that decade, *PDAM* has used baffled flocculator both in rectangular and hexagonal. Baffled flocculator is an alternative to mechanical flocculator. Unfortunately, the baffled flocculator has a lot of sediment at its compartment's corners, reducing its performance. However, baffled flocculator is still used today because the consultants who designed flocculator in water treatment projects have not had much knowledge about helical flocculator. Efforts have been made to reduce sediment with helical flocculator, an innovation in drinking water treatment technology. Since the 1980s, there has not been much more research yet published. Some literature used different terms: helical, helicoidal, helix, spiral,

coiled. All terms have the same meaning and interchangeable. Flowrate, turbidity, and dimension of flocculators were different from each other [4-7].

In the hydraulic study and fluid dynamics in the flocculation process, it was investigated by Sartori et al. (2014) [8]. Tambo and Hozumi (1979) [9], Tambo and Watanabe (1979) [10] examined floc characteristics and floc strength, but they did not use helical flocculators. In other methods, Carissimi and Rubio (2005) [11] have studied the influence of compressed air on the flocculation process. Oliveira and Teixeira (2017) [12] have researched the performance of helical flocculator for turbidity removal. In Indonesia, there has not been researched yet on this flocculator after Arfandy (1979) [4], Harjoko et al. (1980) [5], but perhaps in different types or different nomenclature like hydrocyclone [13]. There are some differences in shape, configuration, and process mechanism compared to helical flocculator.

Optimum performance in turbidity removal efficiency, sediment volume, velocity gradient, and detention time is the research objective. Experiments are carried out using two pipe sizes and two helix diameters. A helical flocculator produces less sediment than a baffled flocculator. The circular shape in layers is the advantage of helical flocculator, but it is also difficult to make a circular pipe in layers, especially at a big flowrate. It is more difficult than a rectangular shape or hexagonal baffled flocculator if using a large steel pipe diameter. But it eases to implement in the laboratory with small flowrate and no difficulty in setting the apparatus.

The helical flocculators studied by the authors mentioned above used different pipe sizes and different helix diameters. Sartori et al. (2014) [8] used a helical flocculator in horizontal, but in this study, the helical flocculator was installed vertically. All researchers used laboratory scale with variation in pipe sizes and helix diameters. Researchers used a hose or pipe for helical flocculators. Another objective of this study was on small flowrate compared to previous studies by researchers mentioned. It is hoped that a small flowrate is more applicable to the small community of the city. If a larger flowrate is needed, more than one helical unit can be built and installed parallel. It is an alternative solution for a larger community. This study also runs on medium turbidity concentration i.e. 150 NTU. If the small flowrate's performance is good enough, the results of this research can be widely known and become more popular among consultants and governments.

Therefore, it may enrich academic or scientific information on efficiency (performance), velocity gradient (G), and detention time. The essential thing in the design of a hydraulic flocculator is G value and can be maintained in one compartment. Therefore, it could not breakdown the floc. This is the reason why this hydraulic type is more suitable to be applied in small and relatively constant flowrate. Concerning detention time (t_d), the flocculator requires more time than the coagulator unit for its floc growth. The typical values written on textbooks are 20–60 minutes or 25–55 minutes [14,15,16].

In addition to pipe diameter, another parameter which also plays an important role is the helical diameter. According to its function, the helical diameter can be adjusted to obtain a large G value at the inlet of the helical flocculator and then decrease gradually to the outlet. The helical position and shape of the flocculator can be arranged with any unit in the water treatment plant. If the water treatment plant (*IPAM: Instalasi Pengolahan Air Minum*) is equipped with a diffused aerator, the helical flocculator can be installed in circles outside the aerator body. The installation can be horizontal or incline depends on the desired hydraulic effect and artistic consideration [17].

2. Methodology

This study's idea development was based on the mechanical energy of water, colloidal, suspended solid, and coagulant to be mixed hydraulically. The flocculators were made of 0.5 inch and 0.625 inch plastic hose. The spiral (helix or helical) diameters were 0.4 m and 0.8 m. The flow were varied from 5 ml/second, 13 ml/second, 25 ml/second and 45 ml/second. Piezometers were installed to know the headloss due to major and minor losses in a pipe (hose). Parameters observed were detention time, velocity gradient (G), pressure loss (headloss), initial and final turbidity for removal efficiency.

2.1. Apparatus

- a. Pipe diameter 0.5 inch and 0.625 inch

- b. Raw water storage tank
- c. Constant headbox
- d. Coagulant tank
- e. Supporting rack
- f. Raw water flow measuring instrument
- g. Coagulant flow measuring instrument
- h. Pressure (piezometer)
- i. Imhoff cone
- j. Imhoff cone supporting static
- k. Turbidimeter
- l. pH meter
- m. Analytical balance
- n. Beaker glass 500 ml, 1000 ml
- o. Beaker glass 10 ml, 50 ml, 500 ml, 1000 ml
- p. Stopwatch and 20 ml syringe sput
- q. 125 watt water pump.

2.2. Materials

- a. Kaolin for raw water turbidity
- b. Aluminum sulfate coagulant
- c. Dyestuff, red

Figure 1. Configuration of helical or spiral coiled flocculator.

2.3. Helical flocculator

- a. Raw water reservoir
- b. Raw water flow measuring instrument
- c. Coagulant container
- d. The instrument for coagulant flow
- e. Pump
- f. Mixing raw water + coagulant
- g. Helix, helical or spiral coiled flocculator
- h. Pressure board
- i. Imhoff cone
- j. Supporting statif
- k. Constant headbox

A raw water sample was taken and prepared from a groundwater well in Kebangsaan University, Bandung, Indonesia. The turbidity was ± 150 NTU, made with kaolin suspension, and a stirrer was installed; therefore, the turbidity relatively constant during the experiments.

3. Results and discussion

The results were based on 0.5 inch and 0.625 inch pipe diameter with flow variation from 5 ml/second to 45 ml/second and 50 meters pipe length. Table 1 shows the results on variation of flow in two sizes of pipe diameter related to type or kind of unit, i.e., coagulation or flocculation process.

Table 1. Comparison of G (velocity gradient) on each pipe diameter.

Pipe Diameter (inch)	Helix Diameter (m)	Flow (ml/second)	G (velocity gradient) Theoretical (second ⁻¹)	G (velocity gradient) Experiment (second ⁻¹)	Type of Process
0.5	0.4	5	21.9	34.3	Flocculation
		13	67.2	79.3 – 80.0	Flocculation
		25	144.9	165.5	Coagulation
		45	288.8	272.3	Coagulation
	0.8	5	0.8	31.5 – 32.4	Flocculation
		13	63.2	68.7 – 69.6	Flocculation
		25	136.4	160.7	Coagulation
		45	271.9	268.1	Coagulation
0.625	0.4	5	11.0	28.5	Flocculation
		13	33.8	64.9 – 66.2	Flocculation
		25	72.8	132.5	Coagulation
		45	145.4	217.5	Coagulation
	0.8	5	10.4	24.7	Flocculation
		13	31.8	59.7	Flocculation
		25	68.5	130.9	Coagulation
		45	136.8	203.5	Coagulation

In the coagulation process, the G value was more than 80/second while flocculation was in the range of 20/second–80/second. Flowrate variation can produce a different performance on helical pipe, namely coagulator or flocculator. At helix diameter 0.4 m and 0.8 m, both 0.5 inch and 0.625 inch pipe diameter, at flow 25 ml/second and 45 ml/second, G values = 130.9/second up to 268.1/second. There was a coagulation process in this phenomenon and could be used as a coagulator. At flow 5 ml/second and 13 ml/second, it was obtained G values 24.7/second up to 80.0/second; therefore, the G value in the range of flocculation process and could take action as a flocculator.

3.1. Jar test

Determine the optimum dosage of coagulant needs Jar test was carried out on raw water with turbidity ± 150 NTU. It was done several times to have an optimum dose. From the series of experiments obtained, the optimum coagulant dose for turbidity ± 150 NTU was 220 mg/l alum ($\text{Al}_2(\text{SO}_4)_3$), and turbidity reduction efficiency was 98.63%, as presented in table 2. The results of the Jar test were used as an approach to experiments on helical flocculators.

Table 2. Turbidity, coagulant dose, and efficiency.

Turbidity NTU	Coagulant Dose, mg/l	Efficiency %
153	300	78.89
158	265	98.46
156	220	98.63*
152	220	95.52
152	190	93.95

3.2. Results on flocculation

Helical flocculation experiments with turbidity ± 150 NTU was applied for two pipe diameters: 0.5 inch and 0.625 inch, with helix diameters: 0.4 m and 0.8 m. There were two flowrates: 5 ml/second and 13 ml/second applied to 50 m pipe length of helical flocculators. The ability of flocculators was compared to Jar test results that were used as standard. Flocculator, which had turbidity reduction efficiency close to or greater than turbidity reduction efficiency in the Jar test, was called as good flocculator. While flocculator in which turbidity reduction efficiency was smaller than turbidity reduction efficiency in the Jar test was named worse flocculator.

The following data presented the efficiency of turbidity reduction on helical flocculators with helix diameters 0.4 m and 0.8 m in two pipe diameters: 0.5 inch and 0.625 inch, and flowrate 5 ml/second and 13 ml/second. The recapitulation of the data observed was presented in table 3.

Table 3. Recapitulation of serial experiments on the flocculation process.

Pipe diameter inch	Helix diameter m	Flowrate ml/s	Tur- bidity NTU	Td seconds	G 1/second	Efficiency %	Sediment Volume ml
0.5	0.4	5	151	1,110	34.3	56.7	15.7
0.5	0.4	5	152	1,110	34.3	55.0	14.0
0.5	0.4	13	158	450	79.3	72.2	0
0.5	0.4	13	153	450	80.0	71.8	0
0.5	0.8	5	154	985	31.5	91.4	0
0.5	0.8	5	159	985	32.4	91.3	0
0.5	0.8	13	154	438*	68.7*	73.9*	20.0
0.5	0.8	13	152	438*	69.6*	72.4*	18.3
0.625	0.4	5	156	1,410	28.5	91.1	0
0.625	0.4	5	152	1,410	28.5	91.5	0
0.625	0.4	13	153	645*	64.9*	78.5*	19.7
0.625	0.4	13	151	645*	64.9*	76.7*	14.3
0.625	0.8	5	151	1,335	24.7	94.0	0
0.625	0.8	5	155	1,335	24.7	93.6	0
0.625	0.8	13	154	565	59.7	77.4	2.0
0.625	0.8	13	157	565	59.7	77.0	2.2

Flowrate 5 ml/second on 0.5 inch and 0.625 inch pipe diameter flocculators as well as on 0.4 m and 0.8 m helix diameter gave bad results because all flocculators did not show any floc sediment in Imhoff cone. This happened because the detention time was too long, and its velocity was small enough so that the floc was settled inside the flocculator. At flowrate, 13 ml/second generally showed good results in both pipe diameters. The best result happened on the flocculator 0.5 inch pipe with 0.8 helix diameter. Turbidity reduction efficiencies in this helical flocculator were 72.4% and 73.9%, with sediment volume

was 18.3 ml and 20.0 ml. Turbidity reduction efficiencies on flocculator with pipe diameter 0.625 inch, 0.4 m helix diameters were 76.7% and 78.5%, and sediment volume was 14.3 ml and 19.7 ml.

Evaluated from helix diameters, the best results also occurred on flocculator 0.5 inch diameter with 0.8 m helix diameter and on flocculator 0.625 inch diameter with 0.4 m helix diameter. This happened because of the different flowrates at each helix diameter that can determine the quality of floc formed. The flocculator had turbidity reduction efficiency close to turbidity reduction efficiency in the Jar test and had sediment volume exceed the sediment volume in the Jar test, which means it could meet the requirement as a good flocculator. G value's optimum performance in the range of 64.9–69.6 per second and detention time between 438–645 seconds.

4. Conclusion

The flocculation process occurred effectively in helical (helix) spiral coiled pipe with velocity gradient (G) about 64.9–69.6 per second and detention time in the range of 438–649 seconds. The helical flocculator efficiencies were in the range of moderate to high. On flowrate 13 ml/second was obtained good results on two pipe diameter sizes: 0.5 inch pipe with helix diameter 0.8 m, turbidity reduction efficiencies were 72.4% and 73.9%, and sediment volume was 18.3 ml and 20.0 ml. On 0.625 inch pipe with 0.4 m helix diameter was obtained, turbidity reduction efficiencies were 76.7% and 78.5%, and sediment volume was 14.3 ml and 19.7 ml. On flowrate 5 ml/second, worse results were obtained because sediment occurred in flocculators. Also, it can be concluded that the performance of helical flocculator depends on three key parameters, i.e., flowrate, pipe diameter, and helical diameter.

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