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(Review Article)

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Spiral tube flocculation for drinking water treatment plants

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Abstract

Almost all water treatment plants for either surface raw water or water from reservoirs needs to have some kind of a system to eliminate time required for particles to settle down in the settling tanks (This occurs by increase turbidity particle size).

A coagulant to be added and a flocculation's system to inshore a good and homogenous distribution of chemicals to form up the correct size of particles to settled within the settling tanks.

In water treatment plants many types of clary- flocculates are used either the mechanicals paddle or hydraulic jumps of steam water or using the spiral tubes (As on this study).

In addition, a Jar Test should be used to assess the suitability of flocculation treatment for a given raw water. Unfortunately, even Jar Test suffers from a number of disadvantages.

a number of study for Spiral Flocculate, has been shown I claimed to be a better method for continuous assessment of flocculation. Within multimedia sands and a spiral flocculate's.

Constant flow (generated from a tank with spill way to ensure a constant head all through the test cycles, results are recorded, and a number of remarks and suggestions are produced.

This study will make use of a number of laboratory tests on a small model of treatment plants made for this purpose consist mainly of a gravity filter compares the performance of Spiral Flocculate

The experiments conducted reveal that the Spiral Flocculate has a better effective energy. Even that this method need more future study and theoretical equations for the developing of chain flocs are needed.

However, the size of flocs in Spiral Flocculate seems to be overestimated relative to the real flocculate and coagulations.

Purpose: A continuous need for improving water treatment techniques allows for new technologies for obtaining adequate water, both in terms of quality and quantity.

In order to obtain an efficient, rapid and low-cost clarification system, this study proposes the use of spired coiled tubes as a coagulation-flocculation reactor to evaluate the proposed clarification system, a number of experimental test where generated and a pumped kaolin with controlled quantities are pumped to city water and used in this study. Water with controlled head is used all the time and records are generated for the evaluation.

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Keywords: Spiral Tube; Flocculation; Drinking Water Treatment Plants; Coagulation; Flocs

1. Introduction

World Health Organization (WHO) guidelines are generally followed throughout the world for drinking water quality requirements. In addition to the WHO guidelines, each country or territory or water supply body can have their own guidelines in order for consumers to have access to safe drinking water [1].

Purification of water is the removal of contaminants from untreated water to produce drinking water that is pure enough for the most critical of its intended uses,

For human consumption. Substances that are removed during the process of drinking water treatment include suspended solids, bacteria, algae, viruses, fungi, minerals such as iron, manganese and sulfur, and other chemical pollutants such as fertilizers.

Measures are taken all the times to ensure the water quality not only relate to the treatment of the water, but to its conveyance and distribution after treatment as well. It is therefore common practice to have residual disinfectants in the treated water in order to kill any bacteriological contamination during distribution [2][3].

Mainly almost all microorganisms found in source waters do not pose health risk to humans, As Filters represent the key unit process for particles removal in all surface water treatment.

Optimization used prior to the filtration process will control loading rates while allowing the system to achieve maximum filtration rates. One of the important staged are the coagulation and flocculation of turbid particles [4].

A laboratory study is performed in Baghdad city with a proto type plant, inlet is operative to receive source water having particles (In this study we use the drinkable water from city main and the turbidity will be added in) A spiral mixer has a defined spiral pipe operative to mix the source water with a coagulant material (chemical coagulants are used in the tests with jar test to fix the correct dosage [2][3][5].

The spiral mixer is formed to perform in-line coagulation and flocculation processes. Within the defined spiral channel to form bigger flocs particles.in this study we attend to use the water direct generated to a filter media no buffer tank is operative to receive the aggregated flocs, this called direct filtration [6].

2. History of spiral tube flocculation studies

There are significant challenges associated with sludge treatment in water treatment plants (WTP).

Several authors have suggested the use of SPIRAL TUBE to promote flocculation without abrupt changes in the direction of flow, but rather with smooth changes of direction throughout the unit (Al-Hashimi and Ashjyan, 1989; Elmaleh and Jabbouri, 1991; Gregory, 1981; Grohmann et al., 1981; Hameed et al., 1995; Thiruvenkatachari et al., 2002; Tse et al., 2011; Vaezi et al., 2011; Vigneswaran and Setiadi, 1986) [1].

Those studies have shown that this flocculator, called the 'helically coiled tube flocculator -HCTF' (figure 1), promotes efficient floc formation with high velocity gradient values (due to its helical characteristic -with high head loss values) and low process times. The experimental apparatus used is shown in Vigneswaran and Setiadi (1986) [7]. based on a complete cycle of the clarification system,

and composed of:

- a reservoir of synthetic water;
- a flow meter (flow controllers),
- dosing pumps of chemical reagents,
- pressure gauge connected at flocculate’s input and output sections,
- flocculator,
- decanter system (settling tank)
- drain to the final disposal of the fluid

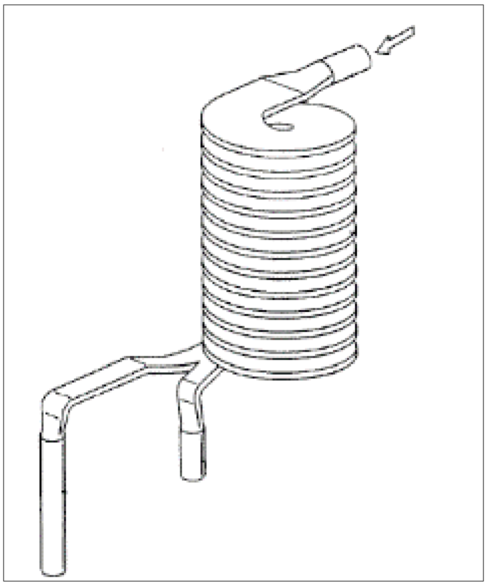

Figure 1 A spiral tube flocculation example

3. Typical processes for drinking water treatment

A combination selected from the following processes is used for municipal drinking water treatment worldwide (see figure 2):

- Pre-chlorination - for algae control and arresting any biological growth
- Aeration - along with pre-chlorination for removal of dissolved iron and manganese
- Coagulation - for flocculation
- Coagulant aids, also known as polyelectrolyte - to improve coagulation and for thicker floc formation
- Sedimentation - for solids separation, that is, removal of suspended solids trapped in the floc
- **Filtration** - removing particles from water
- Desalination - Process of removing salt from the water
- Disinfection - for killing bacteria.

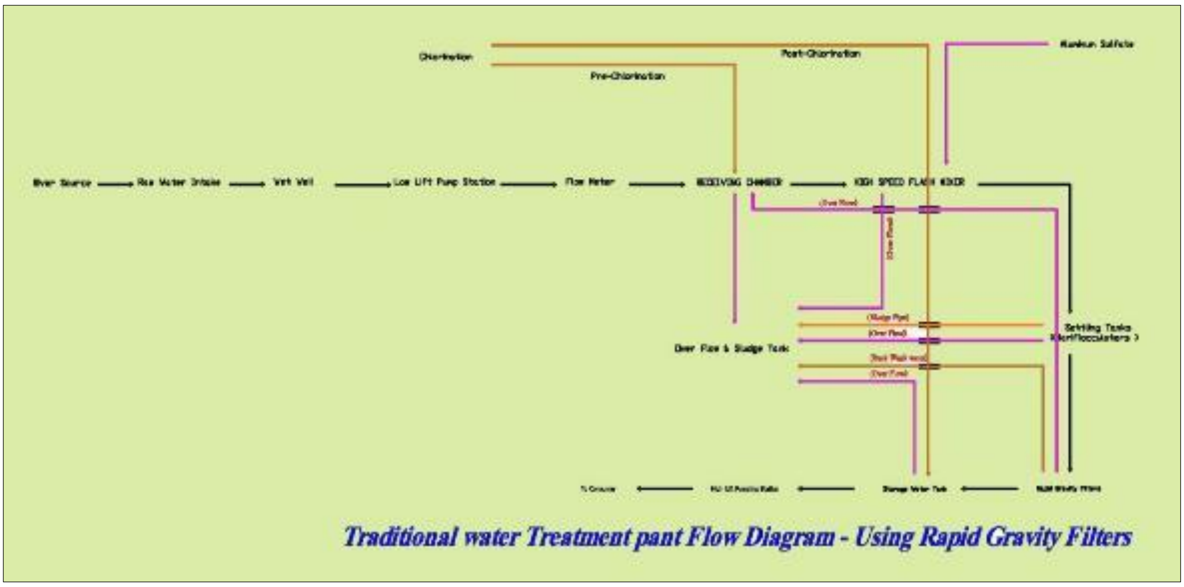

Figure 2 Traditional water treatment plant flow diagram

Technologies for potable water treatment are well developed, and generalized designs are available that are used by many water utilities (public or private). In addition, a number of private companies provide patented technological solutions.

Automation of water and waste-water treatment is common in the developed world.

- Capital costs,
- operating costs
- available quality monitoring technologies,
- locally available skills typically dictate the level of automation adopted

4. The Differences between Coagulation and Flocculation in Water Treatment

Almost all kind of water treatment plants are using Coagulation and flocculation those two methods are used to increase particle size to increases the treatment efficiency of removing particles from raw water. [1]

Regardless of the size of the system, coagulation and flocculation are typically the initial steps in water and wastewater treatment. [3].

Basically, through coagulation and flocculation process adding of positively charged chemicals to the water. [8].

These chemicals neutralize negatively charged dirt and other dissolved particles in the water, which causes them to bind with the chemicals to form larger particles that can easily settled, Called floc. Although both processes have the same end goal and are often used together, there are some differences between them: - Coagulation in water treatment uses specialized chemicals to encourage fine particles to clump together.

These chemicals, known as coagulants, create an electronic charge that causes the particles to cluster into larger groupings that make them easier to settle [4].

5. Types of Coagulants

Coagulants used in water treatment plants are either aluminum or iron-based.

Common aluminum coagulants include:

- Aluminum sulfate
- Aluminum chloride
- Sodium aluminate

Common iron-based coagulants include:

- Ferrous sulfate
- Ferric sulfate
- Ferric chloride
- Ferric chloride sulfate

In addition, some facilities may also use hydrated lime and magnesium carbonate.

6. Effect of Alum Dose Concentration on the Removal Efficiency

As the process steps in water treatment plants require corresponding physical structures such as coagulation basins and flocculation basins where the respective processes take place.

Typically, chemical coagulants are used (i.e., to neutralize charge) and promote aggregation of sub-micron particulates into chain floc.

Anyhow time needed to aggregate (i.e., aggregation time) is determined by

Several parameters including concentration and size of flocs to achieve less time of settling. Dose of chemicals should be well studied in each treatment plant, this is usually maintained by jar test to find the correct dose of chemises, the bigger the flocs will be broking easily before settling, the smaller the flocs will need more time for settling tanks and then bigger structures, the potential numbers for the chain flocs should be measured.

The Jar Test is a standard method used in the water treatment plants to determine chemical dosage for clarification of source waters.

Typical test volumes are 2L with determined dosage being scaled up for the operational flow rates. The protocol for a standard Jar Test includes:

- 2 minute rapid mix;
- 5.0 ml of Alum (as coagulant) added to source water with starting turbidity of 10 Nephelometric Turbidity Units (NTU);
- 28 minutes slow mix; - Mixing stopped at 30 min and floc allowed to settle out.

  An published paper EP 2 261 178 A1, EUROPEAN PATENT APPLICATION [9], Stated that A modified Jar Test Protocol to test the presently described embodiments includes passage of the fluid through a spiral mixer before collection in the jar running the protocol: (Figure NO.3 TURBIDITY REDUCTION COMPARISON OF SPIRAL DEVICE (JAR TEST)
- 2 minute rapid mix;
- 2.3 ml of 1 N NaOH (as base) and 110 mg/L of 1% Alum (as coagulant) added to source water with starting turbidity of 26 NTU; (figure 3)
- 28 minutes slow mix; and,
- Mixing stopped at 30 min and floc allowed to settle, Results are shown in this figure

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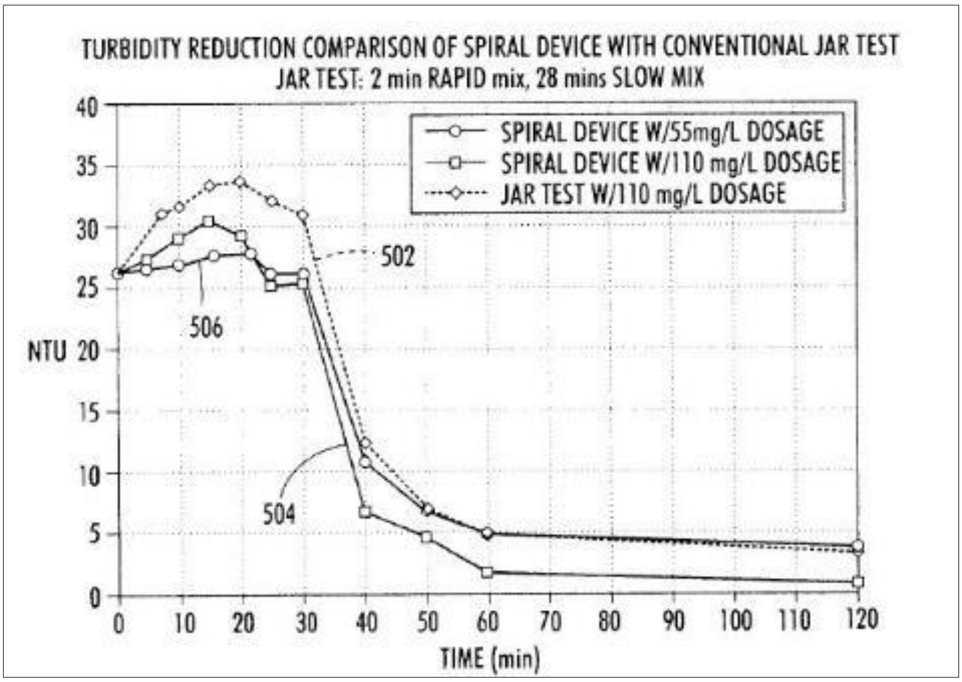

Figure 3 Turbidity reduction comparison of spiral device (JAR test)

7. What is Spiral tube flocculation

Many studies and researches are performed to evaluate the use of spiral tube as flocculation in water plants [2]. such as

- Eustice … who made a serial of rests on spiral pipes and found that there is a significant resistant's with relation in reduction in its electrical charge.

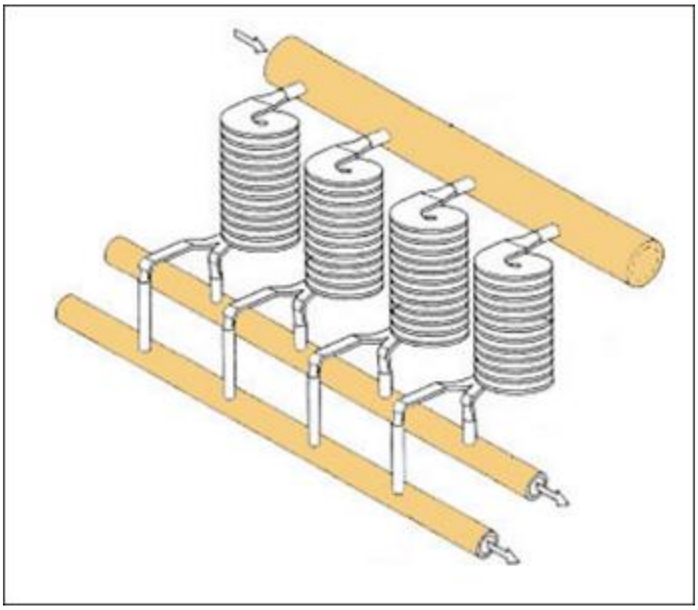

Figure 4 A collection of spiral tube pipes in water treatment

- Dean … gives the first theoretical relation of spiral pipes .as he solved the equations of Navier-Stokes on non-comprisable liquids steady flow [10].
- Eautice … in year 1910, Topa Koglu 1967, Lto 1971, Van Dyka 1975, 1978, & Nanshane & Nandakumar, Berger & Talbat 1983, they all study the effects of spiral pipes ih study flow on the characteristics of floc in study flow.
- As each raw water contains a collides with its electrical charged that gives a way to produce electrical double layers which gives the steady for AL collide liquid, as all particles have its negative charges, And the same charges will be away from each other's, adding any aluminum slats or ferries to the water will produce positive ion's (Posative Hykroxa) and poil nuclear spiral tubes. Which helps the flocculation of particles in the spiral flocculation. [5].
- Many restricts for spiral loops flocculation.
- Camp… fixe the value of hydraulic gradient (G) to be 500 – 1000 Sec^-1 for two minutes in ordinary flocculation & (G) should be for spiral 20 -70 Sec^-1 in other studies.
- Tyler …show that critical renold number increase depending on the ratio of (half radius of pipes loop / half pipe diameter) and the excepted value is 2100,
- To calculate renold number for spiral pipes

$$Re\ (cr) = 20000\ (d\ /dc)\ ^{\wedge}0.32$$

$$\text{In which } (dc\ /\ d) < 860$$

- To calculate the G value for spiral tubes

$$G = 703.6\ (fc/d)^{\wedge}0.5{*}v^{\wedge}1.5$$

figure no.4 shows proposed collection of spiral tubs in water treatment plant

Where

V =speed in m.sec
D = diameter in mr

8. Remarks should be considered in any design of Spiral tube used as flocculation's

A number of points should be considered in any future study of spiral tube such as: -

- The number of loops
- Time
- Diameter of loops and spiral
- Hydraulic gradient of flocs
- Constant flow all the time
- Jar test for correct dosage of chemicals
- Measure of chain flocs
- Make sure that the raw water doesn't have any chemicals that effect the forming of flocs
- Use smooth material for spiral tube
- Can use direct filtration (elimination of settling tanks)

9. Laboratory tests performed

An integrated 5, 50 m high direct filtration unit was constructed in the laboratory, it included four main units: an axial flocculating unit, a filtration unit, injection unit for pumping coagulants and clay materials, and a backwashing unit, a piezometric board is also included tot give reading at each 10cm of filter height. Water is supplied to the system through a constant head tank by gravity action. filtration is done through two mediums, a coarse media layer with 2 to 5mm sizes (30 to 40)cm deep figure no.5 below show the sieve analysis for sand filter used in this experimental tests, and a quartz sand layer 0-.60to 0.75mm (30to40)cm deep.[5][6].

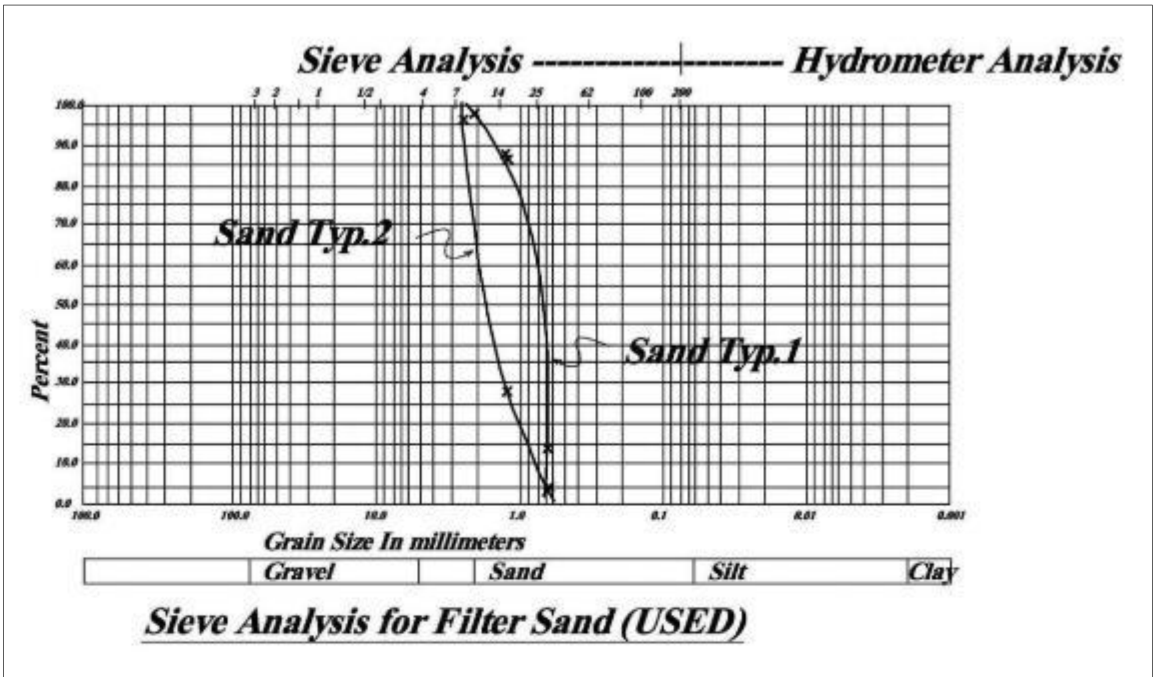

Figure 5 Ffilter sand sieve analysis

The laboratory procedure, prototype model was used with constructed filtration system,

For raw water used in the test, Baghdad drinkable water was used, controlled addition of kaolin (fine mud will be used as turbidity). [6].

to find the best combination of variables, loading, to highest water yield together with highest efficiency, experiments were run to find the effects of coagulating material and added catalyst in addition to the control of flocculation time and velocity gradient.

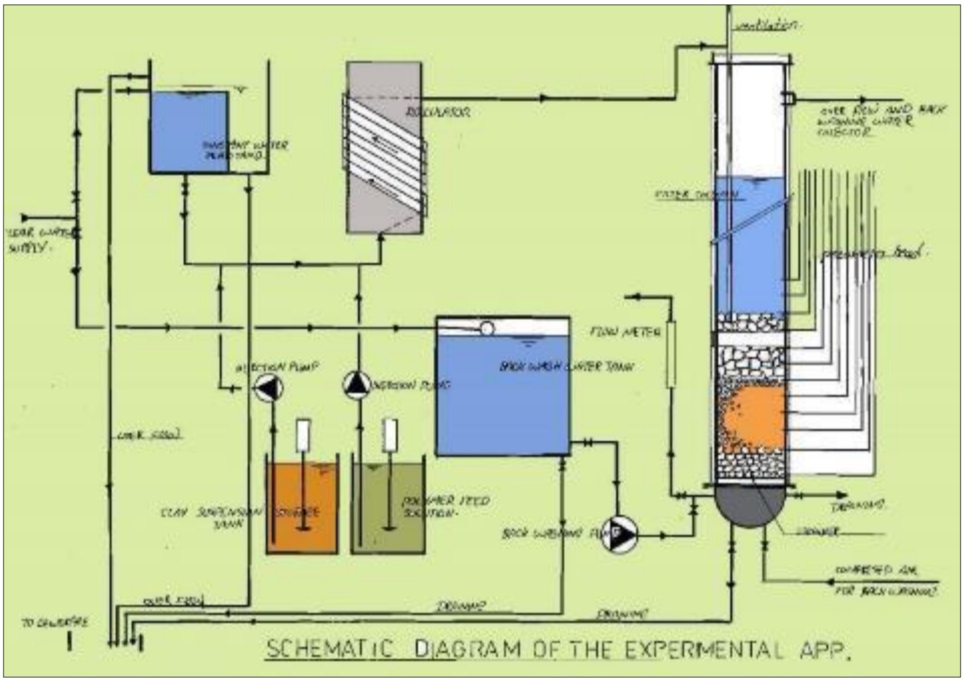

Figure 6 Schematic diagram of the experimental treatment plant used

Jar test was done to define the best quantities of coagulant to be injected each time all water test done at the past years indicates that the maximum turbidity not exceed 320.0 milligram per letters (p.p.m) equal to FTU=21.5 (FORMAZIN TUBIDITY UNIT).

Alum was injected at the rates 5, 10, 15, 20, 25 milligram/litters, attached diagram shows the flocculation, and clearly indicates that 15 milligram / litters is the optimum.

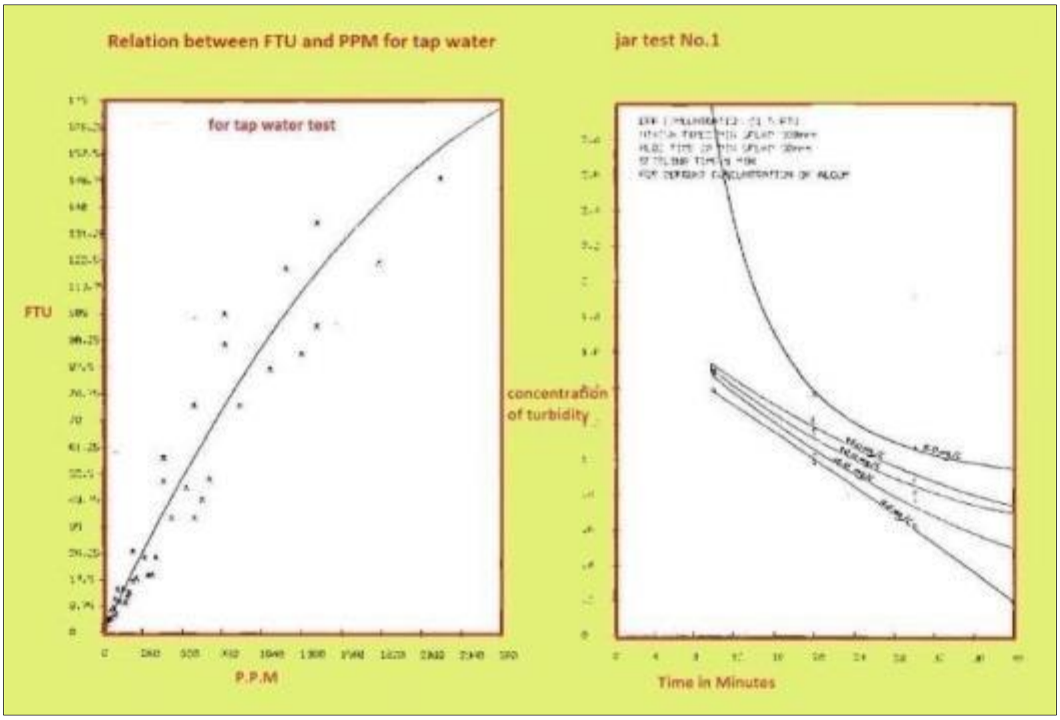

Figure 7 Experimental relation between FTU unit & ppm, in this study case

Second group of test was performed fixing alum dose as 15.0 milligram / letters, and variable speed from 20 to 500 rpm for 20 minutes.

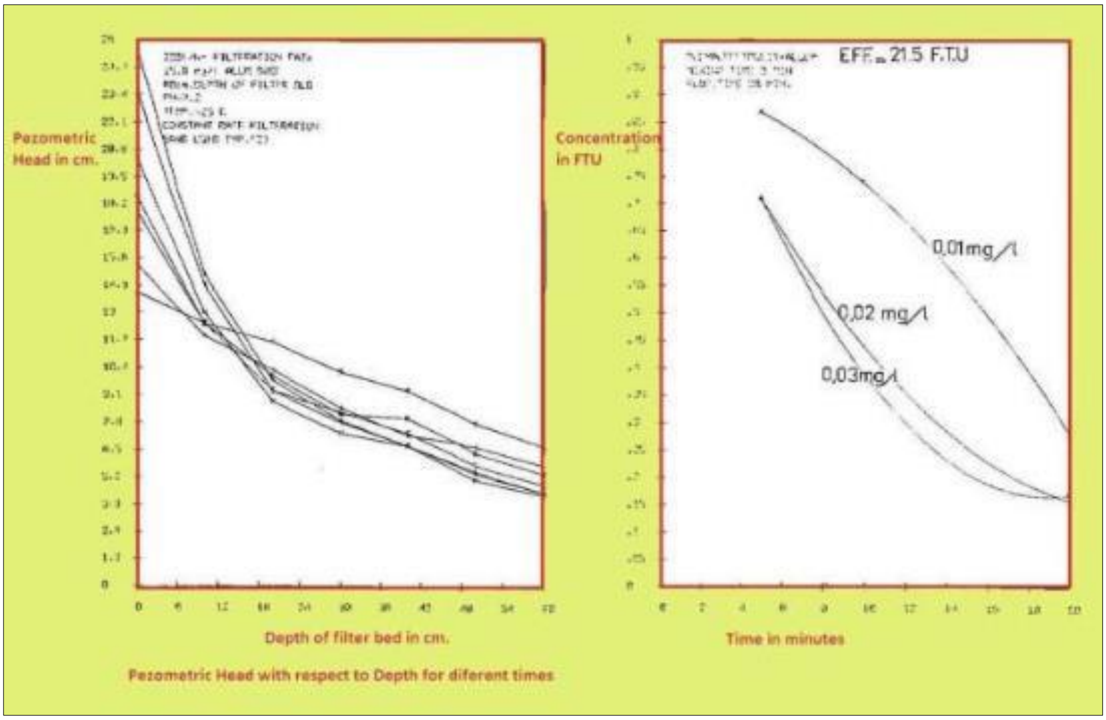

Figure 8 Pezometric head with respect to filter media depth

Figures above gives the relation between filter efficiency

10. Effect of Alum Dose Concentration on the Removal Efficiency

While coagulation helps to encourage particles to combine into larger, more easily filtered clumps, the resultant micro flocs are still far too small for standard filtration systems to clear. Flocculation takes the coagulation process a step further by gently agitating the micro floc-containing water at varying speeds to encourage more particle adhesion.[22][24][25].

Flocculation Process

The flocculation process takes treated water from the coagulation stage and mixes it slowly to increase the collision rate between suspended micro floc particles. As they collide, the micro flocs bond further to create larger flocs, which are visible to the naked eye

Many factors may affect the optimum dose of alum such as,

- size of Turbidity particles,
- turbidity level,
- the G potential of Coagulation,
- Surface loading, etc.

Studies shows the effect of coagulant dosage on the performance of settling & filtration, some stated that, there exist an optimum dose at which the filter produces high effluent efficiency [12][13][18]..

Table 1 Spiral tube summary and cycle loops with its discharge

Summary of spiral tube dia. And cycle loops ,Discharge					
No.	**PIPES Dia(mm)**	**b in cm**	**Dia.of loop Dia (cm)**	**Total length of loops pipe (cm)**	**Q (m3.hr)**
1	2.4384	1.1176	11.36	263	60.12
2	2.4384	1.1176	11.36	2631	60.12
3	2.4384	1.1176	11.36	526	119.88
4	2.4384	1.1176	11.36	3158	119.88
5	3.2512	1.3716	11.68	1184	60.12
6	3.2512	1.3716	11.68	592	119.88

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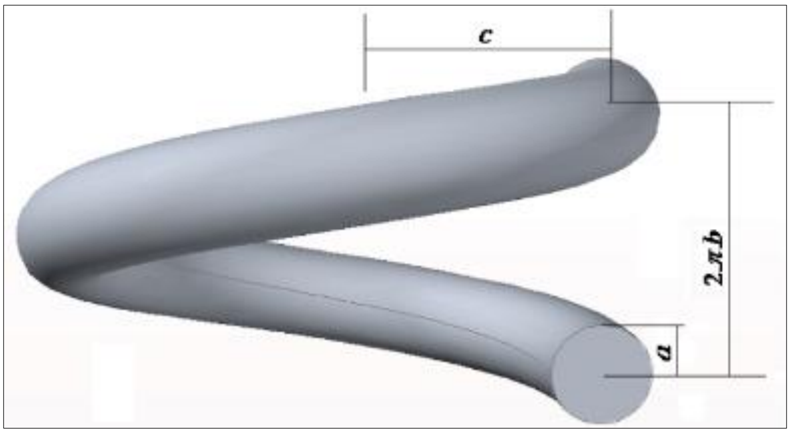

Figure 9 Reference for spiral pipes

Table 2 Main flocculation parameters

parameters	desciption	Equations
Turbidity removal efficiency	obtained to calculate the % of decanted flocculated particles ,with relation to total solid particle.	$Ef.(\%) = \left[1 - \left(\left(\frac{\text{remaining turbidity}}{\text{initial turbidity}}\right)\right)\right] \times 100$
Retention time	The theoritical detention time (Reacter total volume / flow rate)	$t = \frac{\text{Vol}}{Q}$
Mean velocity Gradient	head losses calculated from manometer ,retention time used to obtain the velocity gradient (G)	$G = \sqrt{\frac{\rho \cdot g \cdot hf}{\mu \cdot t}}$
Renolda Number	obtained from fluid characterstics & mean velocity	$Re = \frac{\rho \cdot v \cdot 2a}{\mu}$

11. Conclusion

This studies and all others study such as D. S. Oliveira, E. C. Teixeira, which Published 2 August 2017 Shows that the spiral tubes used as flocculation still need a further research studies and fields and/or laboratory tests to find the correct relations between the diameters of pipes and the loop cycle all together with the number of cycles and the time required to perform the correct size and ideal percentage of coagulant type and concentration.

The important point is that each case will have its own ideal data, it depends mainly on the type of collides, percentage of turbidity, temperature, time required and also PH factor…etc.

We can continue with the results found from D S Oliveira using it as base data, bellow are points to be considered:

There many other study for Spiral Flocculate, has been shown I claimed to be a better method for continuous assessment of flocculation. Within multimedia sands and a spiral flocculate's.

Constant flow (generated from a tank with spill way to ensure a constant head all through the test cycles, results are recorded, and a number of remarks and suggestions are produced.

This experiments also conducted reveal that the Spiral Flocculate has a better effective energy.

However, the size of flocs in Spiral Flocculate seems to be overestimated relative to the real flocculate and coagulations

Also further future studies should be carried out to find the best and optimum number and size of spiral tube needs for each situation.

Also it is important to know that each raw water will need a different number of loops and different size of Dia.

In addition, the effect of Torsion on a helical pipe flow.

12. Similar studies and results performed by:

1- G. H. Cahyana , Novel helical or coiled flocculate for turbidity reduction in drinking water treatment: a performance study, IOP Conference Series: Earth and Environmental Science, 2021 [11]

His results (Helical or spiral coiled flocculate have not been applied in drinking water treatment yet in Indonesia. Only a few articles discussed it with different themes like hydrodynamic, floc)

2- João Paulo Nascimento Armeloni, D. S. Oliveira, C. Donadel, Natural agents as auxiliaries in water clarification: literature review and experimental evaluation, 2020 [12]
Results (The increasing demand for water resources (primarily for human consumption and industrial and agricultural activity) is driven by socio-economic development, and population growth. Recent research… Expand)

3- Danieli Soares De Oliveira, C. Donadel, Mathematical modelling and analysis of the flocculation process in low retention time hydraulic flocculates .2019 [13]
Results (This article aims to advance the understanding of particle interactions in low retention time flocculates and proposes a new flocculation model that appropriately considers the influence)

4- D. S. Oliveira, E. C. Teixeira, C. Donadel , Novel approaches for predicting efficiency in helically coiled tube flocculates using regression models and artificial neural networks, 2019 [14]
Results (prediction models for turbidity removal efficiency (TRE) in helically coiled tube flocculates (HCTFs) are presented. The TRE was determined by physically modelling)

5- Zheqian Lin, Chengxuan Li, Jiaheng Liu, Zhili Yang, Hai-Ying Zhang , An effective process of harvesting Chlorella sp. biomass for bio resource by rapid flocculation in a helical tube, 2021 [15]
Results (Flocculation in a helical tube was proved to be a rapid and an effective approach for harvesting microalgae and the helix diameter may have an impact on the flocculation due to the secondary flow intensity, and the 30-cm diameter was found to be A suitable choice)

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest among the authors for publication of this article.

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