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Field Approach on the Effectiveness of Hydraulic Flocculator Followed By Sedimentation and Rapid Sand Filter

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Abstract

This research investigates the effectiveness of a hydraulic flocculator at the Kalanki Groundwater Treatment Project-Sipradi in Kalanki-Kathmandu. Hydraulic flocculation is a cost-effective alternative to mechanical flocculation, particularly beneficial for developing nations. The study involved determining the optimal Poly Aluminium Chloride (PACl) dosage through Jar Testing and assessing the flocculator's efficiency in the field with this dose. The research also analyzed other treatment units under various PACl doses to evaluate the Water Treatment Plant's operational conditions and the required PACl dose for efficient turbidity removal. The system included components like a deep well source, V-Notch weir tank, hydraulic flocculator, sedimentation tank, rapid sand filter (RSF), chlorinator, and clear water reservoir, with a 16-minute flocculator detention time. Baffle walls were strategically positioned at various intervals on-site. The study revealed that while sedimentation with coagulation achieved peak efficiency at a PACl dose of 80mg/l, it was less efficient than a 16-minute jar detention, likely due to sedimentation tank short-circuiting. Increasing the PACl dose from 20 mg/l to 80 mg/l improved overall unit efficiency, indicating the need for more mixing energy in the existing flocculator length for optimal results. The filter unit's efficiency remained consistent, whether with or without coagulation, at 57.69% and 54.10%, respectively. These results emphasize the importance of further investigation to enhance water treatment processes and coagulant dosages for improved effectiveness in this critical field.

Keywords: Water treatment; Hydraulic flocculation; Hydraulic flocculator; Flocculation efficiency; Rapid sand filter; Turbidity removal efficiency

1. INTRODUCTION

In general, turbidity can be understood as the cloudiness or murkiness of a fluid. It is defined as the measure of resistance to the passage of light through it [1]. Due to the presence of suspended particles including clay, silt, finely split organic and inorganic materials, soluble colored organic compounds, and microbes, the water becomes murky or opaque. On a silica scale, it is measured in parts per million (ppm) or milligrams per liter (mg/l). The turbidity created by one milligram of Fuller's earth, which is silica that has been finely split, in one liter of distilled water is regarded as the standard unit of turbidity. The units are determined by the measuring procedure and tools. Turbidity is often measured using a nephelometer turbidity unit (NTU). The instrument used for measuring it is called a nephelometer or turbidimeter. It measures the intensity of light scattered at 90 degrees as a beam of light passes through a water sample [2]. Turbidity was the main determinant in assessing the effectiveness of the pilot plant processes [3]. The turbidity of 5 NTU is permissible value for drinking water, up to 10 NTU may be tolerated [1].

To keep the turbidity to a safer value, different treatment processes were utilized where flocculation, sedimentation, filters, and aerators are common units. In traditional water treatment facilities, stirring the water after adding coagulants to lessen the repulsive force between particles promotes floc development and particle collision. Mechanical stirring or the energy produced by hydraulic head loss can both be used to trigger the flocculation process. The flocculate was followed by sedimentation and for this purpose sedimentation tanks or tube settlers were employed. Mechanical flocculation pro- vides high flexibility in operation but its relatively high running and maintenance costs along with its dependence on the availability of skilled labour makes a hydraulic flocculation method a suitable alternative for developing countries [4].

The treatment of clean water frequently involves flocculation procedures. Impurities can be removed more quickly by filtering or sedimentation when particles are flocculated into bigger aggregates, or "flocs." To make the particles less stable and increase the flocculation process' effectiveness, chemical coagulants can be used. To improve mixing and encourage particle collision, mechanical or hydraulic flocculators may be utilized. Hydraulic flocculator employs a series of baffles to create mixing. The channel's size progressively rises over its length in order to restrict floc breakdown and minimize turbulence. The channel's initial size is modest to induce turbulence, which encourages flocculation.The primary objective of this research is to analyze the performance of hydraulic Flocculator in terms of turbidity removal efficiency theoretically, at sedimentation tank and rapid sand filter for various coagulant (PAC-poly aluminum chloride) doses, analyze the theoretical design parameters and field implementation and find out the improvements that can be done to increase the efficiency of the system. Filtration is the process in which the suspended particles removed from a flow by passing through a prose media and rapid sand filtration is a purely physical treatment process which can be explained by two physical principles: mechanical straining and physical adsorption [5, 6]. Firstly, Mechanical straining: larger suspended particles get stuck between the sand particles as they pass through the filter media. Secondly, Physical adsorption: smaller particles adhere to the sand particles due to the Van der Waals force of attraction. An additional chemical such as a coagulant or flocculant can be added to increase the adhesion process.

2. METHODOLOGY

2.1 Experimental setup

The water source for the treatment unit was a boring (deep well) which was located near the project area. The major characteristics of the water of the well were observed as the electrical conductivity 835 µs/cm, pH of 7.4, total iron concentration 2.8 mg/l, total ammonia 16 mg/l, total arsenic 0.05mg/l and turbidity at the entry of flocculator 14.68 NTU. The schematic layout of the study is presented by fig.1.

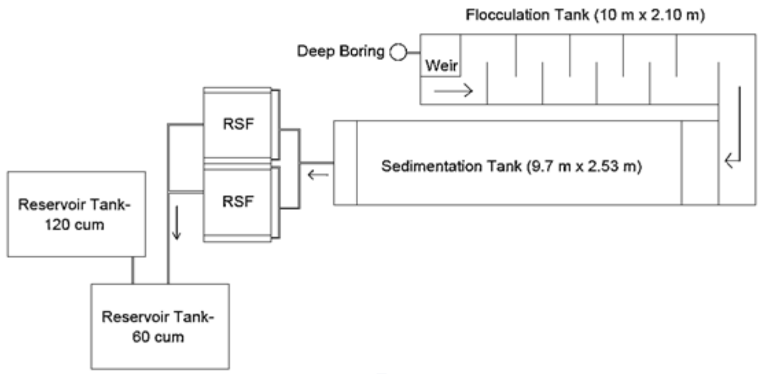

Figure 1: Schematic layout for the study

2.2 Flocculator

Baffled type hydraulic mixing flocculator was employed in this research in which rather than using mechanical energy, the water is agitated by being routed round a complex geometry. This process induces the turbulence that leads to the primary particles being brought into close enough proximity to facilitate coagulation [2]. A separate chamber was provided at the start of the flocculator for mixing the coagulant. The colloidal particles became unstable and began to agglomerate when the coagulant was introduced to the water. The baffles provided a mixing effect when the water hit them, increasing the likelihood of particle collisions and facilitating aggregation. Additionally, it kept the larger floc in suspension, allowing them to expand even further. The flocculator was designed and operated for a 16-minute detention time. The 90-degree V-notch weir was provided at the inlet of the flocculator, from where water was discharged to flocculator from boring and I measured the discharges with the help of the 90-degree V-notch weir equation.

2.3 Sedimentation Tank

The sedimentation process then uses the water from the flocculator. A single unit of a sedimentation tank has been provided for sedimentation. The size of the sedimentation tank is 9.7 m by 2.53 m. The depth of a tank is 2.4 m with operational water height of 2.28 m.

2.4 Rapid sand filter

Rapid sand filters (RSF) are found to perform well when it comes to turbidity removal. A well-operated RSF reduces turbidity to less than 1 NTU and often less than 0.1 NTU [7]. In the experiment setup the two units of the RSF are provided which receive water from the sedimentation tank separately through inlet pipe of diameter 0.16 m. The size of each RSF is 2.0m by 1.95m and depth of filter is 2.5 m (0.3 m underdrain, 0.6 m gravel depth, 0.6 m sand depth and 0.65 m water depth and 0.35 m inlet weir). To obtain purer water, the RSFs are operated concurrently. Four valves are offered, and they may be used to start one filter running while the other is being backwashed. Backwashing is done every day, and the time between backwashing cycles depends on how much floc hasn't settled down in the sedimentation tank. Pumps are used to draw water for backwashing from the clear water reservoir. The main fold and laterals of HDPE pipe make up the under drainage system.

2.5 Test Procedure

For both situations, the test procedure was used: with and without coagulation and each discharge was taken into consideration during the experiment. For the coagulated water, the turbidity is measured at the field after the determination of the optimum dose at the field at the same experiment is repeated for that dose. The samples were collected at four pints (at the inlet of the flocculator, inlet of the sedimentation tank, the inlet of the filter, and outlet of the filter for both cases).

2.6 Discharge Measurement

Weirs are frequently put in place in open channels, such as streams, to measure discharge (flow rate). The fundamental idea is that discharge is proportional to the water depth above the crotch (bottom) of the V; this measurement is known as the head (h). Small variations in discharge are translated into huge changes in depth by the V-notch design, enabling more precise head measurement than with a rectangular weir. The discharge at the inlet of flocculator is measured by using 90-degree V-notch weir equation (1) as:

$$Q = 4.28\, C \tan\left(\frac{\theta}{2}\right) (h+k)^{5/2} \tag{1}$$

Where, Q= Discharge in m^3/s,

C = Discharge Coefficient, θ = Notch Angle

H = head in meter, k = Head Correction Factor in meter

And $C = 0.607165052 - 0.000874466963\,\theta + 6.10393334 \times 10^{-6}\,\theta^2$

$k\,(ft.) = 0.0144902648 - 0.00033955535\,\theta + 3.29819003 * 10^{-6}\,\theta^2 - 1.06215442 * 10^{-8}\,\theta^3$

2.7 Jar Test

i. The JAR test was carried out for the determination of optimum dose of PACl in lab when
ii. 1000 ml of water sample was added to each jar for mixing, with different dosages of PACl introduced into each jar.
iii. Rapid mixing was performed at 100 revolution per minutes (rpm) for 3 minutes, followed by slow mixing at 30 rpm for 30 minutes. The jar with the most extensive floc formation was selected to determine the optimal coagulant dose.
iv. Turbidity levels in the initial and final water samples, collected 3 cm below the water surface using a pipette, were quantified using a Turbidimeter to assess residual turbidity [8].

2.8 Measurement of Turbidity

The Turbidity was measured in the scale of NTU with following procedure:

i. The instrument was turned on and let at least 30 minutes to stabilize.
ii. The instrument was calibrated up to 100 using a standard 100 NTU solution after being set to zero using pure water.

iii. After rinsing the cubette twice with distilled water and the sample, the sample's turbidity was assessed.

iv. Between measurements, the zero calibration and 100 calibrations were examined.

v. Throughout the filter operation, several measurements of turbidity were made for the influent and effluent.

vi. The sample's sampling time and the filter run time were both recorded.

2.9. Data Analysis

The data analysis includes:

Based on influent and effluent turbidity values at different unit is measured (as above mentioned four stages), efficiency of the flocculator was obtained. The dose of PACl was plotted against the outlet turbidity at flocculator, against the overall treatment efficiency of treatment system, against the efficiency of flocculator alone, against the efficiency of sedimentation tank alone, against the efficiency of RSF alone.
The data was then analyzed for the effectiveness of flocculator at the existing site.

3. RESULTS AND DISCUSSIONS

Test data were recorded systematically and further analysis was carried out.

3.1 Removal Efficiency and Dose of PACl

Influent and effluent turbidity at different units (at inlet of flocculator, inlet of sedimentation tank, inlet of filter and outlet of filter for both case with or without coagulation), and removal efficiency of different units and overall treatment plant was obtained. The dose of PACl is plotted against the outlet turbidity at flocculator, against the overall treatment efficiency of treatment system, against the efficiency of flocculator alone, against the efficiency of sedimentation tank alone, against the efficiency of RSF alone.

For the various dosages of coagulant (PACl), the plot of outlet Turbidity at flocculator on Jar after detention is shown in the Figure 2, removal efficiency against PACl dose for sedimentation tank is shown in Figure 3, and removal efficiency against PACl dose for RSFs is shown in Figure 4, also, removal efficiency of overall water treatment plant (WTP) against PACl dose is shown in Figure 5. For dose of PACl at optimum dose of Jar Test, the turbidity removal efficiency is very low, whereas with increment of alum dose the efficiency of floc formation is increased, this is due to insufficient mixing energy available in flocculator. For the PACl dose of 25mg/l, the efficiency of sedimentation tank is 18.29 %, whereas efficiency in Jar detention of 16 minutes was 78.68 %. This shows that the flocculator was not functioning well in flocculation process, as well as, there was short-circuiting in sedimentation tank. With the increment of alum dose efficiency of all the units were increased and optimum dose required for the existing fill condition was obtained as 70 mg/l of PACl. Detail results are presented here in graphs.

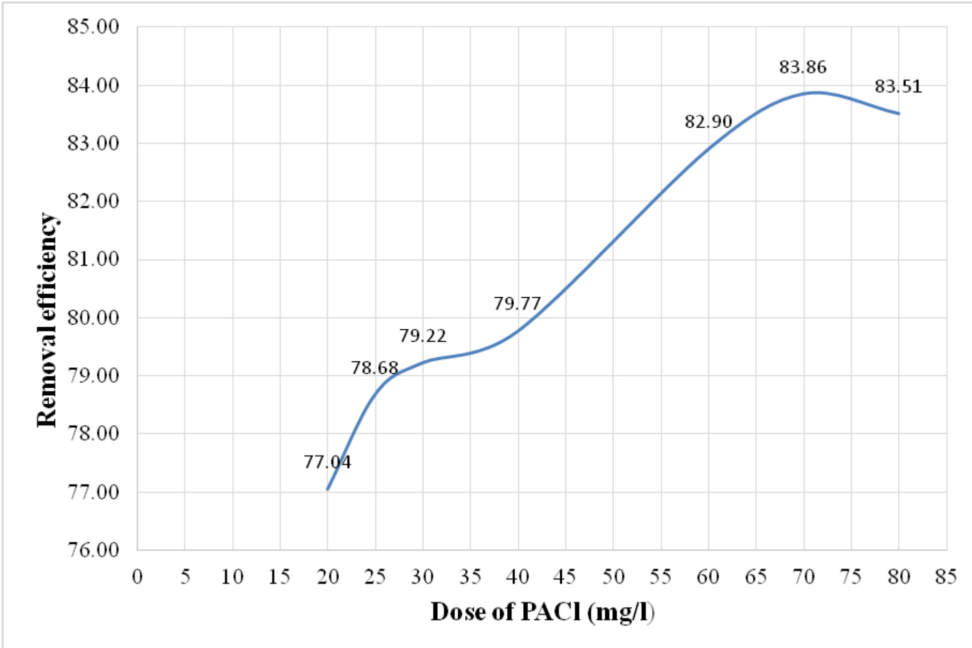

Figure 2 : Removal efficiency in y-axis at flocculator on Jar after 16 minutes of detention

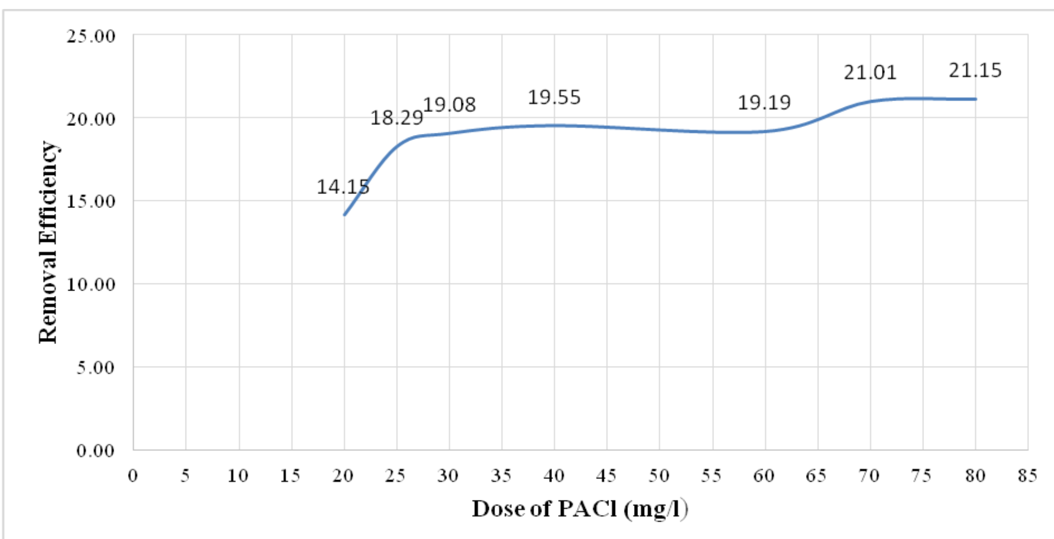

Figure 3: Removal efficiency against PACl dose for sedimentation tank

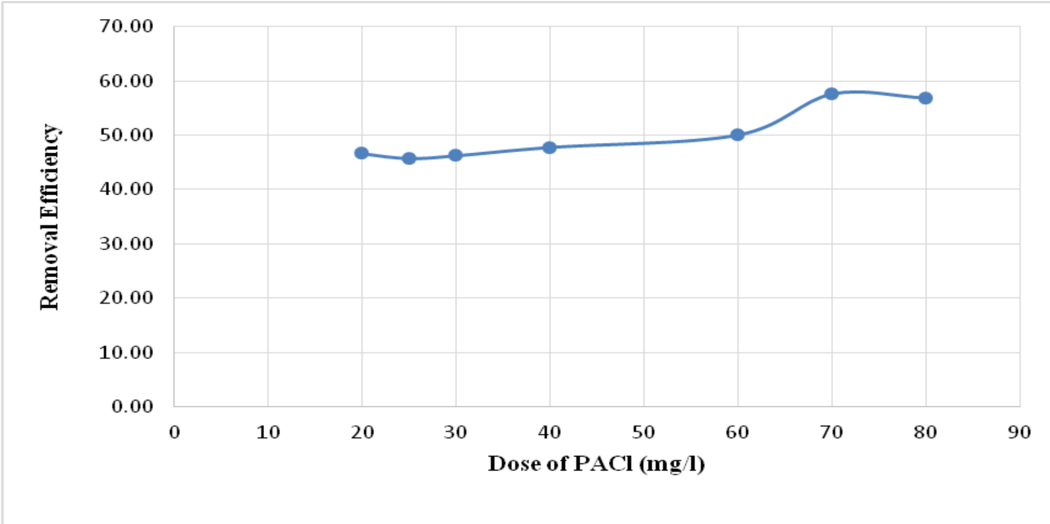

Figure 4 : Removal efficiency against PACl dose for RSFs

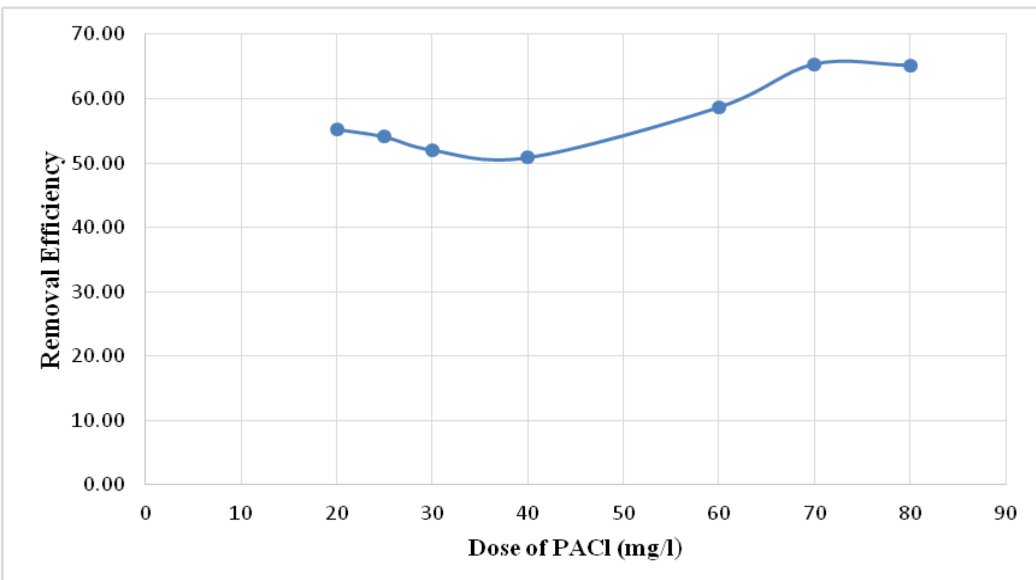

Figure 5 : Removal efficiency of WTP against dose of PACl

The efficiency of each unit of WTP and Jar detention of 16 mins for dose of PACl 25 mg/l (optimum dose at Jar Test) and for PACl dose 70mg/l is plotted and shown in Figure 6, where series1 represents efficiency graph for dose 25mg/l and series2 represents efficiency graph for 70mg/l and 1,2,3,4 represents Jar Detention of 16 mins, Sedimentation Tank Filter, and overall WTP respectively.

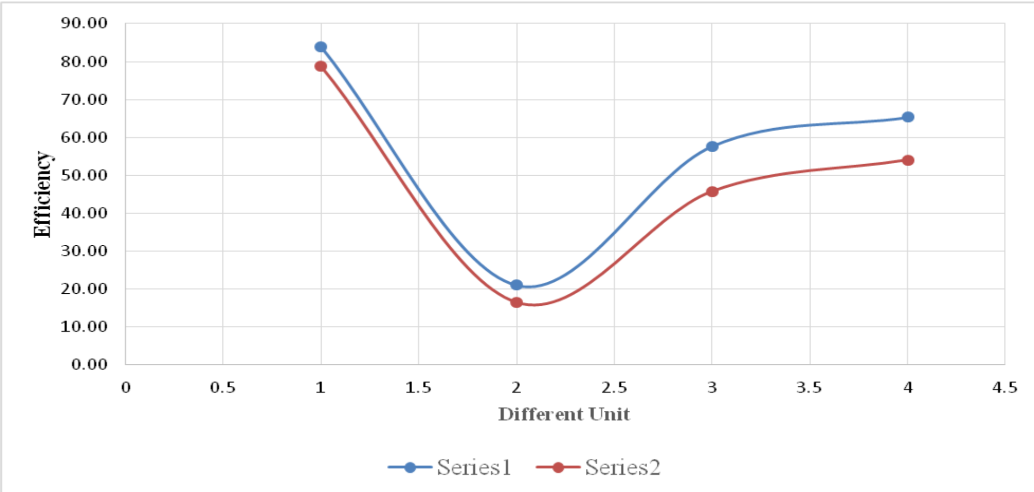

Figure 6 : Removal efficiency against different treatment unit

4. CONCLUSIONS

Several conclusions can be drawn from the results derived from the study conducted for the Kalanki Groundwater Treatment Project, Sipradi:

i. The research findings have established the optimal coagulant dosage for Poly Aluminium Chloride (PACl) in the water treatment process to be 80mg/l.

ii. Notably, the study has revealed that the sedimentation process with coagulation at this specified PACl dosage yielded a lower efficiency in turbidity removal when compared to the performance achieved through jar detention of 16 minutes. This discrepancy in efficiency could be attributed to various factors, including the potential occurrence of short-circuiting within the sedimentation tank.

iii. Furthermore, the research has demonstrated that the efficiency of all units within the Water Treatment Plant (WTP) at the optimal PACl dosage determined in laboratory Jar Test is relatively low. However, an increase in PACl dosage led to an improvement in the efficiency of all units, resulting in an overall efficiency increase from 54.09% to 65.33%. This suggests that the available mixing energy in the existing flocculator is insufficient for achieving the optimal dosage determined in the Jar Test.

iv. In light of these results, it is evident that further in-depth analysis and investigation are warranted to elucidate the precise underlying causes of reduced sedimentation efficiency in the presence of coagulation. These findings underscore the imperative of optimizing coagulant dosages and refining the flocculation and sedimentation processes to enhance the overall effectiveness of water treatment systems. These findings contribute to our understanding of the complex dynamics involved in water treatment and provide a basis for potential improvements in this critical field.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interests for this study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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