



Determination of the Feasibility of a Renewed Approach to the Mechanical Cleaning Stage in Wastewater Treatment Plant: A Laboratory Study

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Growing population and industrial complexes require municipalities to initiate costly upgrades of their wastewater treatment facilities in order to protect the environment and nearby water bodies. This research project explores if a process combination of centrifugation, flocculation and filtration could increase the treatment capability of a wastewater treatment plant. For all wastewater samples the first process step of centrifugation decreased the total solids content by 23.5%, the chemical oxygen demand between 5.0% and 30.0%, and the total phosphorus content by 20.7% and 32.1% in the supernatant. Flocculation with Ca(OH)_2 , FeCl_3 and $\text{Al}_2(\text{SO}_4)_3$ followed by centrifugation increases the solids content of the supernatant, but decreased the chemical oxygen demand and total phosphorus

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content of up to 55.0% and 95% respectively. Filtration increased the total removal of chemical oxygen demand up to 70% and total removal of phosphorus to 96.4%. The best removal process for Total phosphorus was achieved using $\text{Ca}(\text{OH})_2$ as a flocculant due to a precipitation process that forms calcium phosphate $\text{Ca}(\text{PO}_4)_2$. Based on the results a maximum removal rate for chemical oxygen demand of and total phosphorus of 70% and 96.4% respectively could be achieved, which could make future wastewater treatment more effective.

Keywords: Aluminum sulfate; calcium hydroxide; centrifugation; contaminants; ferric chloride; filtration; flocculation; sewage; wastewater; wastewater treatment plant.

1. INTRODUCTION

This research project explores a concept that allows existing wastewater treatment plants (WWTP) to handle large volumes of Wastewater (WW) and or serve more users without extensive upgrades.

Domestic WW can contain pollutants such as human waste, soap, fats, chemicals, and residues from industrial and agricultural processes, as well as surface water, containing pollutants including chemicals from household such as laundry and dishwashing detergents, and pharmaceutical compounds due to medicine use of residents [1-6].

If WW is released into nearby waterbodies, nature alone does not have the ability to treat the billions of gallons of WW produced every day and can harm humans, wildlife, and the environment. Therefore, these water types need to be treated before they can be released into nearby streams, river and water bodies. Regulatory release limits for WWTP and determines in general the content of Phosphorous (P), Nitrogen (N), Ammonia ($\text{NH}_4\text{-N}$), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Suspended Solids (SS), Total Suspended Solids (TSS) and Total Kjeldahl Nitrogen (TKN) in the released water. [7]. To achieve the regulatory measurements WWTP removes the solid, liquid, and solubilized contaminants in WW using various mechanical and biological processes.

WWTP are designed to a certain contamination load which limits their influent volume as well as the contamination in the WW. The WWTP is therefore one of the limiting factors for municipalities to develop new housing areas and industrial complexes without costly expansion of the WWTP. In addition, municipalities are cash strapped and are limited to upgrade their facilities. Solutions such increasing the cost of

treating WW for residents is not favored as well as additional charges of industrial customers. Therefore, in many cases monetary help from governmental entities is needed to fund expensive upgrading of WWTP [8].

For example, Fig. 1, represents a simple process schematic of an existing WWTP in upstate New York at which municipal sewage is treated. Approximately 1.8 million l/d of municipal WW enter the WWTF through an influent structure where a mechanical prescreening process removes large impurities via a gravel trap and rake. This pre-cleaning removes leaves, stones, and hygiene items, for example. The screenings can be either pressed, dried, and disposed of at a landfill or converted into energy at an incineration plant.

From the influent structure half of the WW is pumped to a primary clarifier which is a large settling tank where organic substances are removed from the wastewater through sedimentation by reducing the flow velocity in the primary clarifier. This ensures that substances that could not be removed in the previous treatment steps are deposited. Feces or paper settle in the primary clarifier as "settleable substances" or float on the surface. Around 30 percent of the organic substances can thus be removed from the wastewater. The settled solids are also referred to as primary sludge.

The other half of the WWTP inflow is pumped into a sequential batch reactor (SBR) where it is treated and discharged after chlorination. Half of the clarified water from the primary clarifier is directed into an influent box that feeds the trickling filters. The other half of the clarified water is directed to subsurface biofilters (S2BF). The S2BF consists of 3 cells. Cell 1 operates with a recirculation process. Cell 2 is dormant and can be put into service if needed. Cell 3 operates as a through flow cell receiving WW from Cell 1. All three cells of the S2BR are

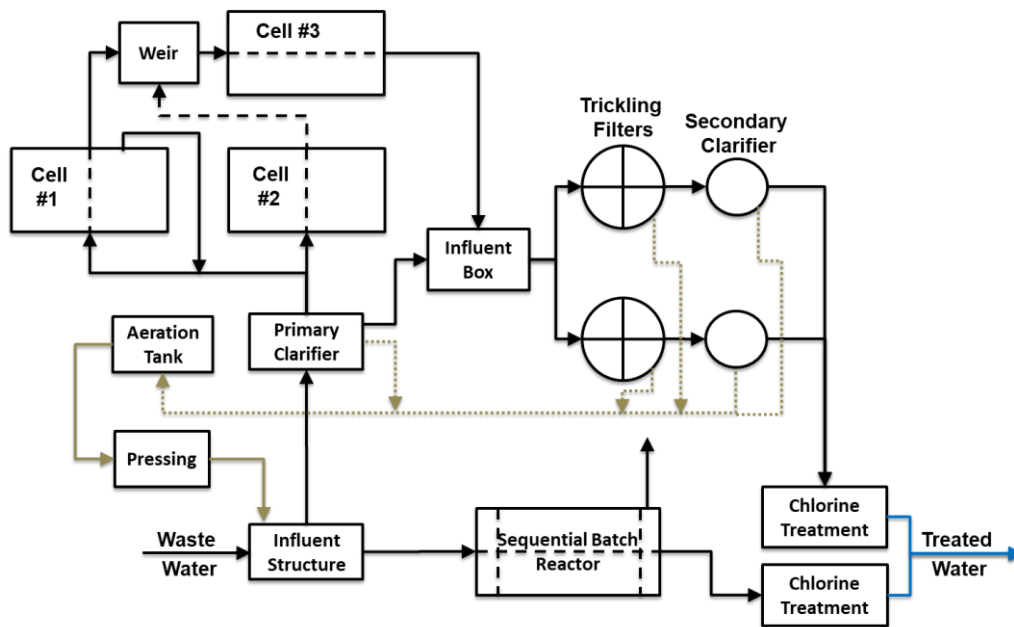


Fig. 1. Wastewater treatment plan schematic [9]

planted half with grass and the other half with Phragmites. The complex root system of Phragmites and grass in the cells as well as bacteria cultures present help take up nutrients and filter the water. The effluent from the S2BR is redirected into the influent box where it mixes with the primary clarified water and is then forwarded for secondary treatment into the trickling filters.

Trickling filter and SBR remove with the help of bacteria and other microorganism the organic WW constituents with the help of oxygen. Special bacteria break down nitrogen compounds.

After the trickling filters the treated WW is forwarded for final treatment into the secondary clarifiers (SC) for settling the remaining organic components.

Sludge generated by the PC, SC and SBR Is forwarded into an Aeration Tank (AT), which is basically an aerobic holding tank and biological reactor to which oxygen is supplied to enhance bacteria performance. During the holding time bacteria break down the pollutants further till the sludge in the WW of the AT tank is dewatered bi-weekly with a belt press. The resulting solids are dried in a drying field prior to disposal at a landfill. The removed press water is forwarded to the influent structure of the WWTP.

As described above a WW treatment process contains many single process steps that are interlinked with each other before the treated WW from the SBR and PC is chlorinated prior to its discharge into a stream.

The objective of the described research project is to evaluate if solids contained in the influent WW stream can be removed upstream in a WWTP prior to the treatment in the PC by centrifugation, precipitation, flocculation and filtration before the biological removal process take place, allowing that the following biological processes and clarification steps can be downscaled in size and or more WW can be treated.

2. MATERIALS AND METHODS

The material and methods section describes the materials, laboratory type equipment, procedures and analytical methods that were used for this research study on a Renewable Approach of Primary Influent Treatment (RAPIT) process applicable to WWTP's.

2.1 Influent Materials

For this study municipal WW and cow manure was used for the simulation of different influent types for the RAPIT process. WW was sampled from a primary clarifier at the Cleanwater Educational Research Facility (CERF) located at

the Village of Minoa Wastewater Treatment plant in Minoa, NY.

Cow manure was sampled from the State University of NEW York Dairy Farm operation in Morrisville, NY.

A 20% Calcium Hydroxide $\text{Ca}(\text{OH})_2$ solution is prepared with distilled water and is used to adjust the pH to 9.5 of the WW as well as the flocculation agent.

Iron Chloride (FeCl) in a 30% solution is used as a second flocculation agent.

Aluminum sulfate ($\text{Al}_2(\text{SO}_4)_3$) prepared in a 20% solution is used as a third flocculation agent.

Whartman No. 4 filter paper with a pore size of 20- 25 μm . for filtering the processed wastewater.

2.2 Laboratory Testing Procedures

The Chemical Oxygen Demand (COD) was measured according to HACH Method 8000 [10], Hach HACH COD TNTplus® Spectrophotometer Vial Test with a range of 3-150.0 mg/L. Total Phosphorous (TP) analyzation followed HACH Method 10127 using HACH-TNT Reagent Set (1-100.0mg/L) [11].

The TNTplus® test vials vials were heat treated with a HACH DRB200t according to the HACH 8000 Test Method, followed by analyses using a HACH DR900 Spectrophotometer.

The total Solids (TS) content was measured in triplicate. Each test sample was measured using a marked and weighted 300 ml aluminum sample container. For each test approximately 200 ml to 220 ml of the prepared substrate was added to each of the three corresponding aluminum sample containers, followed by weighting of the sample containers. The containers were then placed in a $\sim 105^\circ\text{C}$ oven to dry for 48 hours to evaporate the moisture. After drying, the sample containers were weight again to determine the dry weight measurement. The remaining solids in the sample containers represented the TS content of the substrate.

Temperature and pH measurements were conducted using a portable Milwaukee MW102 pH/temperature meter.

2.3 Preparation of Selected Influent Substrates

To determine the working capacity of the RAPIT process two different influent substrates were used. First, Wastewater (WW), which is known to be low degradable and with water highly diluted substances, and second, separated liquid cow manure with more easily degradable and less diluted substances.

The influent WW was collected from the primary clarifier was used as collected, however, the influent content and consistency of a WW is highly varying through the year, day and hour [7,12]. In addition, the WW also undergoes changes while in storage until it was used for the RAPIT process evaluation.

the WW was stored in a cold room at 5.0°C (41.0°F) until it was used in the simulation of the RAPIT process. Prior to usage the substrates were brought to room tempered 23.0°C (73.4°F) in the sampling container.

2.4 Centrifugation Procedure

For centrifugation an evaluation the material was centrifuged at 1500g for total of 6 minutes including the start-up time till the centrifuge reached 1500g and the break time till the centrifuge came to a complete stop.

2.5 Filtration Procedure

For the filtration a 300 ml laboratory syringe was used that had a drilled metal plate on the bottom as support for No. 4 Warthman filter paper with a pore size of 20-50 μm .

2.6 Testing Procedure

Testing followed the procedure shown in Fig. 2, which outlines the different process stages involved in evaluating the RAPID process.

The first stage evaluated TS, COD and TP of the municipal wastewater used for the following process stages. The second stage involves centrifugation of the wastewater and measuring TS, COD, and TP of the supernatant. The third stage involves a flocculation process. After Stage 3, the sample is centrifuged again and TS, COD, TP is measured of the supernatant. In the last stage 4, the supernatant is filtered with an 80 μ filter paper and the TS, COD, TP is in measured of the supernatant.

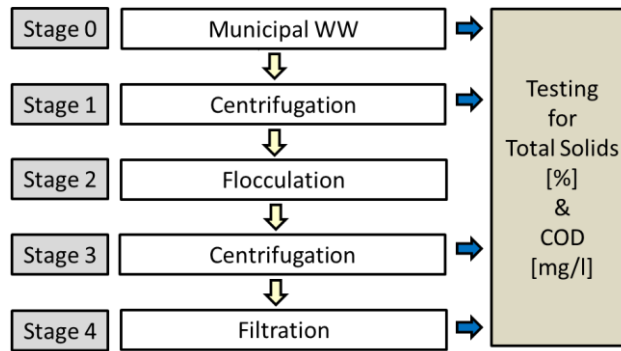


Fig. 2. Testing procedure

3. RESULTS AND DISCUSSION

The following chapter summarizes and compares the degradation processes and effluent qualities of the RAPID process.

For this research the pH of the WW was adjusted by titrating the WW to a pH of 9.5 in a 500 ml beaker for each of the flocculants by using a 20% $\text{Ca}(\text{OH})_2$ solution prior to the first process step of centrifugation. However, initial WW samples used can have different initial contamination values due to inconsistency of the sampled WW. After the first centrifugation step the flocculant $\text{Ca}(\text{OH})_2$ as a 20% solution, FeCl_3 as a 30% solution, and $\text{Al}_2(\text{SO}_4)_3$ as a 20% solution was added in the flocculation stage.

For all process stages pH, TS, COD, TP as PO_4 was measured.

3.1 Measurement of Total Solids Content

The initial TS content of the three 500 ml of WW samples prepared for each of the three flocculants was 0.089%. After the first centrifugation process step, as shown in Fig. 3, the TS content of the supernatant was measured at 0.068%. The pH of the supernatant from the first centrifugation process for each flocculant was then adjusted by titrating to a pH of 9.5 in a 500 ml beaker by using a 20% $\text{Ca}(\text{OH})_2$ solution prior to adding the flocculants $\text{Ca}(\text{OH})_2$, FeCl_3 and $\text{Al}_2(\text{SO}_4)_3$ in the flocculation stage.

Flocculant $\text{Ca}(\text{OH})_2$, FeCl_3 and $\text{Al}_2(\text{SO}_4)_3$ were added till flocs formed from the contamination remaining in the supernatant after centrifugation. A pH of 15.4, 4.6 and 5.6 resulted respectively for the flocculants $\text{Ca}(\text{OH})_2$, FeCl_3 and $\text{Al}_2(\text{SO}_4)_3$.

For the second centrifugation stage in the third process step the TS increased the $\text{Ca}(\text{OH})_2$ flocculant in the supernatant to 0.487% and to 0.653% for the fourth filtration process step filtering the supernatant from the third process step.

For the FeCl_3 and $\text{Al}_2(\text{SO}_4)_3$ flocculant the TS of the supernatant increased in the third process step to 0.493% and 0.221% respectively. The filtration of the supernatant from the third process step in process step 4 resulted in a decrease of the supernatant from the filtration process to 0.482% and 0.192% for the FeCl_3 and $\text{Al}_2(\text{SO}_4)_3$ flocculant respectively.

3.2 COD with Calcium Hydroxide as a Flocculant

Fig. 4 shows that when $\text{Ca}(\text{OH})_2$ is used as a flocculant the COD decreases over the different process stages from 60.0 mg/l of the original wastewater to 43.0 mg/l supernatant after the first centrifugal stage. Adding the $\text{Ca}(\text{OH})_2$ flocculant in the third stage followed by centrifugation decreased the COD to 21.0 mg/l in the supernatant. Filtering the supernatant in the fourth stage decreased the COD further to 18.0 mg/l.

The PO_4 content of the original wastewater was at 14 mg/l. after the first stage the supernatant after centrifugal had a PO_4 content of 11.1 mg/l. Adding the $\text{Ca}(\text{OH})_2$ flocculant in the third stage followed by centrifugation decreased the PO_4 content further to 0.7 mg/l. The PO_4 decreased further in the fourth stage to 0.5 mg/l by filtering the supernatant from the third stage.

3.3 Ferric Chloride as a Flocculant

When FeCl_3 is used as a flocculant as shown in Fig. 5, the COD decreases over the different process stages from 60.0 mg/l of the original wastewater to 42.0 mg/l supernatant after the first centrifugal stage. Adding the FeCl_3 flocculant in the third stage followed by centrifugation decreased the COD to 39.0 mg/l in the supernatant. Filtering the supernatant in the fourth stage decreased the COD to 33.0 mg/l.

The PO_4 content of the original wastewater was at 18.7 mg/l. after the first stage the supernatant after centrifugal had a PO_4 content of 14.4 mg/l. Adding the FeCl_3 flocculant in the third stage

followed by centrifugation increased the PO_4 content further to 21.7 mg/l. The PO_4 decreased in the fourth stage to 21.3 mg/l by filtering the supernatant from the third stage.

3.4 Aluminum Sulfate as a Flocculant

When $\text{Al}_2(\text{SO}_4)_3$ is used as a flocculant as shown in Fig. 6, the COD decreases over the different process stages from 60.0 mg/l of the original wastewater to 57.0 mg/l supernatant after the first centrifugal stage. Adding the FeCl_3 flocculant in the third stage followed by centrifugation decreased the COD to 27.0 mg/l in the supernatant. Filtering the supernatant in the fourth stage decreased the COD to 22.0 mg/l.

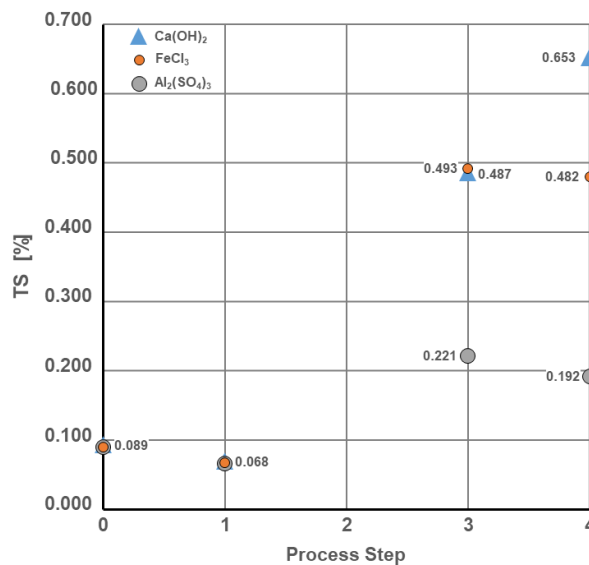


Fig. 3. Solid content of supernatant after the different process steps when $\text{Ca}(\text{OH})_2$ as precipitant used

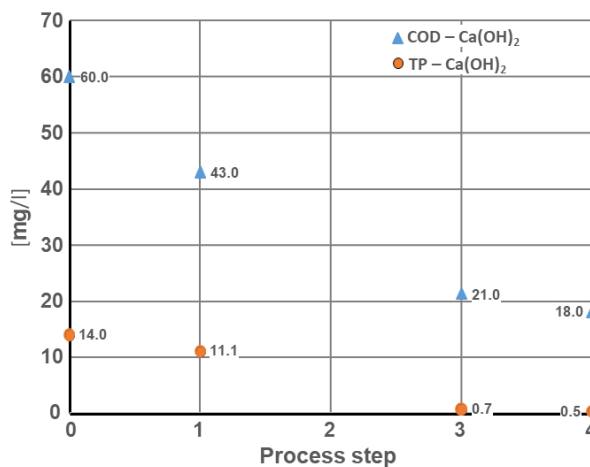


Fig. 4. Chemical oxygen demand and total phosphate after the different process steps with $\text{Ca}(\text{OH})_2$ as flocculant

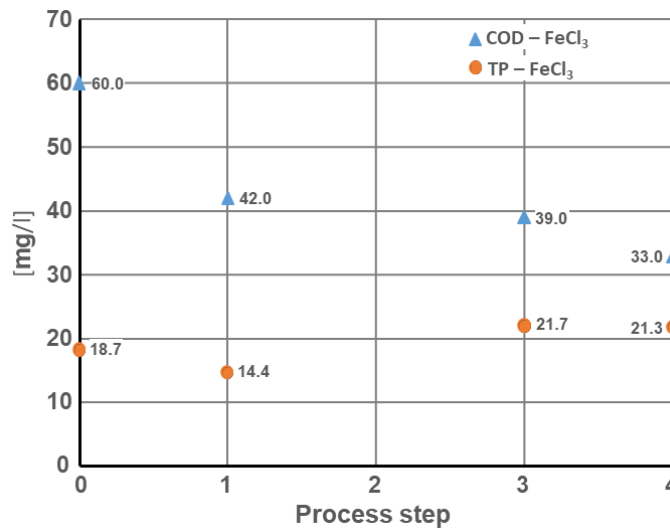


Fig. 5. Chemical oxygen demand and total phosphate after the different process steps with FeCl₃ as flocculant

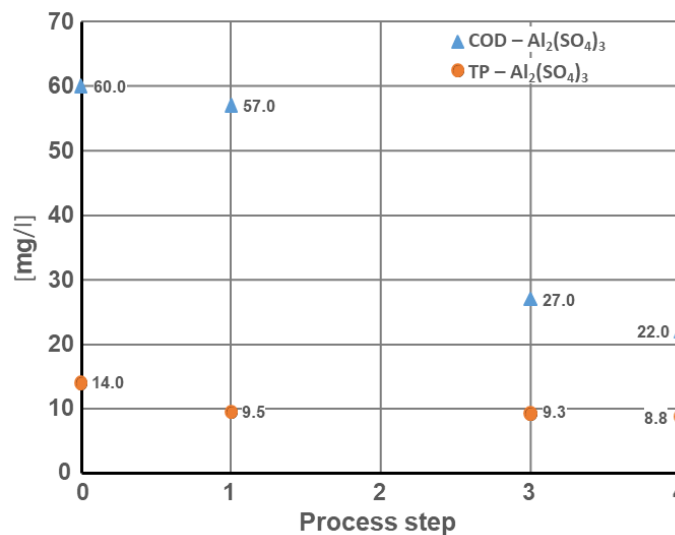


Fig. 6. Chemical oxygen demand and total phosphate after the different process steps with Al₂(SO₄)₃ as flocculant

The PO₄ content of the original wastewater was at 18.7 mg/l. after the first stage the supernatant after centrifugal had a PO₄ content of 9.5 mg/l. Adding the Al₂(SO₄)₃ flocculant in the third stage followed by centrifugation increased the PO₄ content further to 9.3 mg/l. The PO₄ decreased in the fourth stage to 8.8 mg/l by filtering the supernatant from the third stage.

4. CONCLUSION

For all WW samples centrifugation decreased the TS from 0.089% to 0.069% which represents a total reduction of 23.5%. Adding Ca(OH)₂, FeCl₃

and Al₂(SO₄)₃ as flocculants increases the solids content of the supernatant due excessive flocculant left in the supernatant that did not react with the contamination material. More accurate titration will result in a decrease of flocculant and solids content as well as save flocculant from a monetary standpoint.

The first process stage of centrifugation decreased the COD content in the supernatant from 60 mg/l to 57 mg/l, 47 mg/l and 42 mg/l, which represents a minimum decrease of 5.0% and a maximum decrease of 30.0%. TP content in the supernatant was reduced from 14.0 mg/l to

11.1 mg/l 9.5 mg/l and from 18.7 mg/l to 14.4 mg/l which represents a minimum reduction of 20.7% and a maximum reduction of 32.1% for the initial TP content of 14.0 mg/l TP, and a reduction of 22.9% for the 18.7 mg/l initial TP content.

Adding the Ca(OH)_2 , FeCl_3 and $\text{Al}_2(\text{SO}_4)_3$ flocculants in the second process stage reduced the COD content in the supernatant further to 21.0mg/l 39.0 mg/l and 27.0 mg/l respectively, which represents a COD reduction for the Ca(OH)_2 , FeCl_3 and $\text{Al}_2(\text{SO}_4)_3$ flocculant of based on the initial COD content of 60.0 mg/l of 65.0%, 35.0%, and 55.0% respectively. The TP was reduced in the supernatant to 0.7 for the Ca(OH)_2 flocculant after centrifugation in the third process step which represents a total reduction of 95.0%. Filtration in the fourth process step decreased the COD content of 60.0 mg/l 70.0%, 45.0%, and 63.3% respectively. TP removal rate in the supernatant slightly to 96.4%.

For the FeCl_3 flocculant a increase of TP content in the supernatant was noted for the third and fourth process stage to 21.7 mg/l and 21.2 mg/l respectively. This might have been due to inconsistent flocculation of the process sequence.

The TP was reduced in the supernatant to 9.3 mg/l for the $\text{Al}_2(\text{SO}_4)_3$ flocculant after centrifugation in the third process step which represents a total reduction of 33.6%. Filtration in the fourth process step decreased the TP removal rate in the supernatant slightly to 37.1%.

For the Ca(OH)_2 , FeCl_3 and $\text{Al}_2(\text{SO}_4)_3$ flocculants used the COD and TP content decreased for all process stages except for process stage 3 and 4 using the FeCl_3 flocculant. The best removal process for TP with over 96.4% was achieved using the Ca(OH)_2 flocculant due to a precipitation process that forms calcium phosphate $\text{Ca(PO}_4)_2$ precipitant. However, a high solids content and pH of over 14.0 in the supernatant was noticed due to overdosing the Ca(OH)_2 flocculant.

Based on the results a maximum removal rate for COD of and TP of 70% and 96.4% respectively could be achieved, which could make future WW treatment more effective if the RAPID process would be implemented prior to the primary treatment, allowing WWTP to significantly increase its WW treatment capability.

Future research should focus on combining the individual flocculants to achieve maximum COD and TP removal as well as cost associated with a future RAPID process.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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