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Modified wastewater treatment process for optimal utilization of effluents for irrigation to substantiate eco-friendly environment

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Abstract
This study aims to investigate the feasibility of using a flotation unit as the primary treatment process for municipal wastewater treatment and utilize the treated water for irrigation. A metal salt namely polymerized aluminum chloride (PAXXL 36) and two flocculation chemicals namely: a high molecular weight polymer (HM) (SNF Nordfloc C-192) and a low molecular weight polymer (LM) (Purfix 120) were used as the flocculating agents. Apart from the chemicals needed for flock formation, the DAF (Dissolved Air Flotation) unit was used, which supplies compressed air essential for the flock flotation. Laboratory experiments were carried out to analyze COD (chemical oxygen demand), ammonium, nitrate, total nitrogen and phosphorus using Dr. Lange cuvettes. The minor changes in the design unit gave better results and expected water quality, which can be utilized for irrigation purpose was achieved. A significant and consistent reduction in the amounts of phosphorus and COD were observed. High dosages of metal salt and polymer were observed to yield better results but this is an unsustainable, non-eco-friendly and also expensive practice.

Keywords: flotation unit, irrigation, flocculation, total nitrogen, COD, dissolved air flotation

Introduction
Water is one of the most vital components for sustenance of life. The survival of every living creature on the Earth depends on its access to water. The water on planet Earth is purified and re-circulated in a gigantic solar powered water cycle. Of all the water on Earth, 98% is salt water, 1.6% is ice, 0.4% is ground water and 0.004% is surface water (Larsson, 2006). The natural purification cycle is no longer sufficient to meet the present day water demands. The availability of water to mankind is unevenly shared across the continents. Rapid growth of population, industrialization, changing global trends and relentless usage and exploitation of water resources for various purposes has led to an increase in the toxicity and contamination of surface and ground waters. Therefore, it is not only sufficient to treat potable water but, treating wastewaters before being let out into water streams such as lakes and reservoirs is equally important (Gillberg *et al.* 2003) [4]. The quest for sustainable innovations and advancements in water treatment technologies is on the rise and has been identified as one of the prerequisites for healthy living now and for generations to come. The usage of water for various purposes is on the rise, whereas the sources are fast depleting due to various manmade and natural changes in the environment. Irrigation, which is a source for food production, energy which runs the world and sustainability are the motivating factors and form the aim of the present work.

In the beginning, wastewaters were only treated mechanically, as the years passed by; more and more sophisticated methods and treatment technologies were developed. Today wastewater can be purified to any degree required. Although advanced wastewater treatment technologies have been developed in recent decades, the principals of mechanical, chemical and biological treatments have been understood and were practiced in different processes and purposes for at least a hundred years (Hespanhol and Prost, 1994) [6]. At present, with the available state of knowledge about various treatment processes, best of various process technologies can be combined to achieve maximum efficiency in wastewater treatment.

The concentration of various contents in wastewater varies fairly from place to place. It is usually depended on social behavior, economic aspects, type and scale of industries located in the particular area, climatic conditions, water consumption, type and conditions of the sewer system. Domestic wastewater is usually the main component of sewage and it can be divided into two different streams based on their source. One is the concentrated – black water from toilets (faces, urine and flushing water) and the other being, diluted – grey water from bath, wash and kitchen. Considering the various demands and decline of resources on the other side, every drop of contaminated water needs to be treated for the sustainable growth and well being of life on Earth. The water source in the present study was from municipal wastewaters/sewage water which was a mix of both black and grey waters (Mohammedsaid, 2009) [10]. The present study aims at developing a sustainable and feasible solution for wastewater treatment using a flotation unit and utilizing these treated waters for irrigation which is one of the vital sectors of water demand.

Materials and Methods

Flotation unit

Flotation unit is a well-designed and pre-fabricated processing unit. In which, the suspended particulate matter in the wastewater are removed by coagulation, flocculation and flotation mechanisms. Coagulation and flocculation mechanism in a wastewater treatment process leads to the formation of flocks called as the sludge. Thus flocculants are formed and later made to float on the surface of water by using air dispersion. The mechanism of making the flocks float on water is called as flotation. This is achieved by dissolved air flotation technique (DAF). In this technique bubbles are formed in the DAF chamber by a reduction in pressure of water, pre-saturated with air at pressures higher than atmospheric. The supersaturated water is forced out trough needle-valves or special orifices and clouds of bubbles, 30-100 mm in diameter, are produced just down-stream of the constriction (Bratby, 2006) [1]. DAF is a fast and highly efficient method for removing turbidity, color, suspended solids and other contaminants from water using air bubbles. The treated waters leaving the flotation unit are carried to further treatment processes before being utilized for irrigation. A flotation unit as shown in Fig. 1 basically comprises of three tanks designated for specific purposes: pre-precipitation tank, flotation tank and equalization tank.

Pre-precipitation tank

The incoming raw wastewaters from the sewage discharge were initially screened using wire mesh for removal of large solid matter and debris which could clog the treatment system. The water was then directed to individual treatment units of the entire treatment plant, which in this case is the flotation unit. The pre-precipitation tank is the first compartment through which the wastewater enters into the flotation unit. It is the largest wastewater holding component of the entire unit. Major physical and chemical reactions related to flock formation take place in this tank. It is sub-divided into 3 chambers, and this division is made based on the reactions that take place in the respective chambers due the type of dosage chemicals used and the physical conditions maintained. Each chamber is equipped with a motor driven stirrer, a doser for chemical dosage and an internal inlet and exit point.

The incoming wastewater after being screened mechanically enters into chamber 1. This chamber was fitted with an automatic dosing machine to dose metal salt into water at set intervals of time and specified quantity. During flash mixing, coagulant chemicals were added to the water and the water was mixed quickly and violently. After flash mixing, coagulation occurs. The metal salts react with water, forming a precipitate of hydroxides, called flocks, which absorb impurities and aid in chemical bonding. During coagulation, the coagulant chemicals neutralize the electrical charges of the fine particles in the water, allowing the particles to come closer together and form large clumps (Bratby, 2006) [1]. Thus, it aids in coagulation and flock formation which makes removal of impurities easier. The metal salt used in the present study was a polymerized aluminum chloride (PAXXL 36) with specific composition.

The incoming water mixed with a high molecular polymer enters chamber 2, leaving chamber 1. Here the charge carriers which are the suspended particles and the coagulants are attracted even closer to form large flocks. The attractions occur between the oppositely charged particles. The polymer used in the present study was Purifix 120 which is a biodegradable organic polymer. It aids in flock formation by attracting the suspended solids together. The water mixed with both polymers enters the chamber 3 as an overflow from chamber 2. The rate of mixing is slower compared to chamber 2. The outflow from this chamber leads to the flotation tank. At this outflow juncture a high molecular weight polymer was added to the waters. The polymer used here was Nordfloc C-192. It aids in further strengthening of the flocks.

Flotation tank

The water mixed with metals salt and polymers enter the flotation tank from the bottom of the chamber. At the point of entry into the chamber, compressed air coming from the needle valves of DAF chamber is mixed with incoming water of the flotation tank. Compressed air which is in the form of small bubbles mixes with the incoming water and the flocks are attracted even closer and lifted up onto the surface of the water in the flotation tank. Water which is free of major suspended particles escapes out through an outlet in the form of a ring with several tiny holes which passes around the flotation tank. The flocks which are floated and collected on the surface of the tank are continuously scrapped using a mechanical scrapper which rotates at continuous intervals. The flocks are now called as the sludge which is collected into the sludge pocket placed within the flotation tank and has an outlet at the bottom. The scrapper deposits the sludge at regular intervals into the sludge pocket which is in turn emptied at regular intervals into a sludge thickener.

Equalization tank

The treated waters from the flotation unit were collected into the equalization tank. The water collected here were continuously pumped to the membrane polishing unit and then to the sand filter for further treatment before utilizing for any un-potable purposes. The other important units utilized to achieve the expected results are: sludge thickener, digester, moving bed biological reactor and sand filter. The type of sludge thickener used in the present process was a gravity thickener. It is equipped with a pressure dispenser which provides gravitational pressure which makes the solid matter i.e., the sludge to settle down at the bottom of the tank.

Treated waters from the equalization tank of the flotation unit were pumped to the moving bed biological reactor. The process utilizes an attached bio-film technique. One of the goals of this technique is nitrification/denitrification. Nitrification is an aerobic process in which bacteria oxidize reduced forms of nitrogen. Denitrification is an anaerobic process by which oxidized forms of nitrogen are reduced to gaseous forms, which can then escape into the atmosphere. Processing through sand filter is the final step of wastewater treatment in the present process. As water flows through the porous sand bed along a tortuous route, the particulates come close to sand grains and get captured, allowing only the water to pass through. Usually small amounts (<10 parts per million or <10 g/m^3) of fine solids (<100 micro meters) are captured, thereby purifying the water. The outlet water is tested and can be reused. In the present work, this water has been utilized for irrigation.

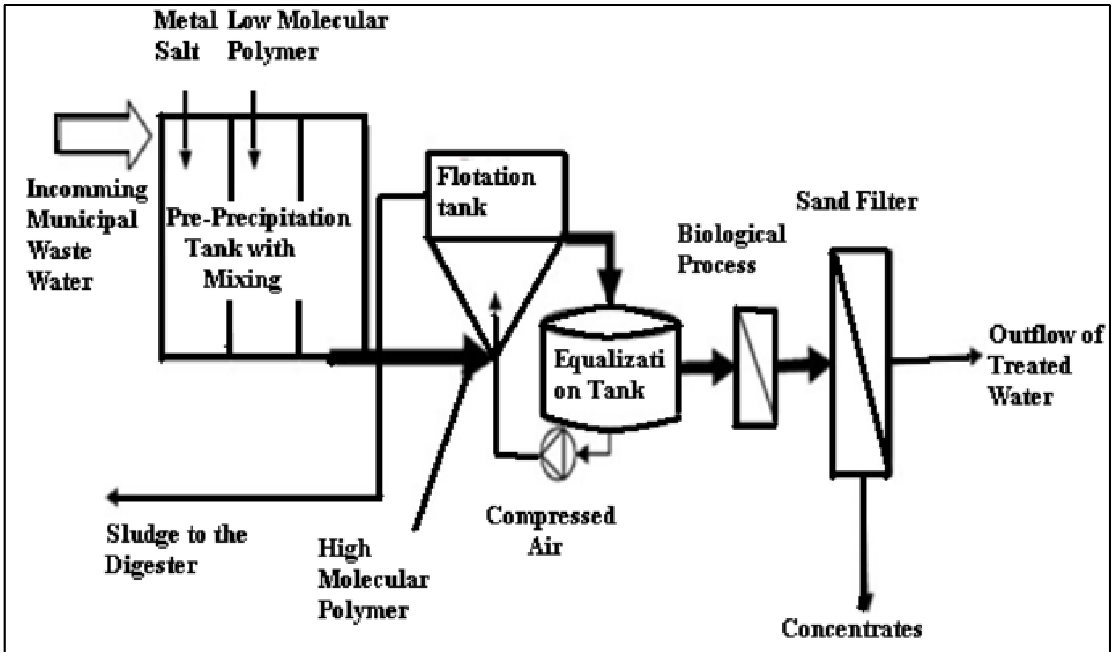

Fig 1: Process flow scheme of the flotation unit (Larsson, 2006)

Water quality analysis

Various analyses of water samples were carried out in the laboratory scale to determine the water quality and composition of various compounds in the water. These include: ammonium nitrate (N-NH_4^+), chemical oxygen demand (COD), Nitrogen-nitrate (N-$NO3^-$), Phosphate analysis and total nitrogen analysis (TN). All the experiments and analysis were carried out in the lab using Dr. Lange cuvettes which have pre-prepared solutions (A, B, C and D), spectrometer, incubator, electronic balance and mechanical pipette. The procedure followed is described below.

Table 1: Procedure for analyzing water quality parameter

Analysis	Procedure
Ammonium	0.2 ml of sample was added to the solution in the cuvettes and allowed to settle for 15 minutes and the readings were noted using a spectrophotometer.
COD	2 ml of probe sample was added into the cuvette and incubated for 24 hrs at 148 °C. Then allowed to cool down and the readings were taken.
Nitrate	0.5 ml of sample was added to the solution in the cuvettes and allowed to settle for 15 minutes and the readings were taken.
Phosphate	0.5 ml of probe sample was added to the cuvette and mixed well using dosi (dosage) cap and incubated for 1 hr at 100 °C. Then, 0.2 ml of solution B (from the kit) was added and a dosi cap 'C' was fixed to the cuvette and mixed well. The readings were taken after 10 minutes.
Total nitrogen	In an empty cuvette 0.2 ml of probe sample was added with 2.3 ml of A and a pill of 'B'; and incubated for 1 hr. A pill of 'C' is added and 0.5 ml of the solution was collected and slowly added into the cuvette solution. Then, 0.2 ml of 'D' was added and incubated for 15 minutes and the readings were taken.

All these analysis were carried out on 3 types of probe samples. Sample-1 was collected from the incoming raw wastewater, sample-2 was collected from the equalization tank of the flotation unit and sample-3 was the outlet water from sand filter which is the final water treatment process in the present study. All the samples were collected using an automated sampling machine which collects 10 ml of sample every 6th minute continuously for 24 hours.

Initial phase of analysis

In the initial phase of startup of flotation unit, all the analysis were carried out to analyze and understand the working of the unit, study the water quality and the changes in the composition of various components in the water at various stages of the treatment process. Here, the dosage was always maintained constant, which was pre-set in the control system based on the inflow. The initial phase of studies was given an understanding regarding the operational and technical feasibility of the flotation unit. A set of 27 tests with varying dosage combinations of PAXXL 36, PURFIX and the high molecular polymer were postulated. The metal salt PAXXL 36 was varied between 1-3 g/m^3, low molecular starch based polymer PURFIX was varied between 5-7 g/m^3 and the high molecular polymer Nordfloc C-192 was varied between 0.125-0.5 g/m^3. The analyses are aimed at high COD removal, low phosphate removal and least possible metal salt and polymer usage. Low phosphate removal is desired as the treated water in the present study is utilized for irrigation. Plants require prescribed levels of phosphate for their growth. Hence, the parameters showing low phosphate removal coupled with high COD removal was the desired outcome. One hour time interval was maintained between each test. Prior to every experiment, content of COD and total phosphate in incoming water were measured and after every experiment, effluent water COD and total phosphate were measured. It takes about one hour for the unit to reach steady state after a change in any of the parameters such as coagulant dosage. The variation in water quality was observed after an hour, therefore the effluent samples were taken at a minimum time interval of one hour after the change in any parameter.

Results and Discussion

Results of the initial phase of analysis were conducted on 3 different probe samples with varying parameters are noted as shown in Table 2. A considerable decrease in COD composition was observed in the obtained results from sample 1 to 3, which imply the efficiency of the treatment process. Higher the COD removal greater was the treatment efficiency. The composition of COD and total phosphate were emphasized and taken as the benchmark in measuring the water quality of the treated water. Average COD and total phosphate of incoming water range as 100-400 mg/l and 2-10 mg/l, respectively (Fig. 2). Ammonium and total nitrogen levels of treated water from the flotation unit were observed as 11-33 mg/l and 23-60 mg/l, respectively (Fig. 2).

Table 2: Analysis results of various compounds in water

Sample No.	Ammonium (mg/l)	Phosphate (mg/l)	COD	Total nitrogen (mg/l)	Nitrate	Metal salt and polymer dosage (mg/l)
1	17.2	5.1	256			Inflow = 0.8 m^3/h
2	16.3	1.07	62	23.9		
3	14	0.499	33.9			
1	19.4	7.04	219			
2	19.3	0.46	61.4	33		
3	13.2	0.12	37.9			
1	28.8	12.6	259			
2	22.2	0.54	80	47.1		
3	14.8	0.208	34.4			
1	26	13.1	455		0.332	
2	24.9	0.392	94.2	32.8	0.049	
3	19.8	0.259	27.5		8.09	
1	33	15.1	603	39	0.801	
2	32	3.49	195		-0.139	
1	30.6	10.9	258		0.518	
2	32.3	2.44	134	42	-0.266	
3	23	0.427	49.5		7.53	
1	36.6	12.5	338		0.059	
2	40.7	7.46	226	49.2	0.029	
3	22.8	1.09	50.3		11.3	
1	36.2	12.3	335		0.014	Metal salt = 130 ml
2	35	0.925	139	54.5	-0.079	Polymer = 312 ml
3	13.8	0.51	59.7		19.2	
1	24	10.7	312		0.043	Metal salt = 90 ml
2	25.7	0.694	104	60.5	-0.121	Polymer = 680 ml
3	19.7	0.431	102		-0.2	
1	17.1	9.95	335		3.63	
2	16.6	0.44	73.6	30	1.41	
3	1.25	0.205	36.2		16.3	
1	19.5	9.33	290		0.587	
2	20	0.457	77.1	32.5	0.603	
3	0.104	0.216	61.8		20.5	

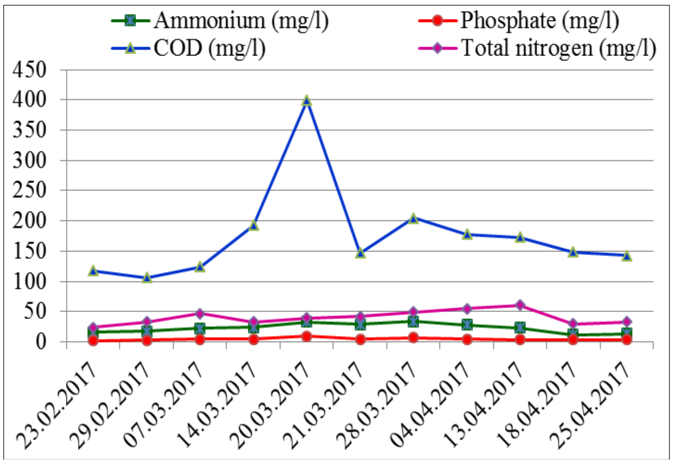

Fig. 2: sampling average of water quality parameters

The reduction levels of various components at various stages of the treatment process were observed in Figs. 3, 4 and 5. The concentrations of various components in the inflow water during a period of time were shown in Fig. 3. Samples were collected with a time interval of 1 week during a period of 2 months. The fluctuations in the compositions were attributed to be results of changes in weather, life style of the people in the locality and other local factors. All these factors resulted in the amount of water used and the dilution and concentration factors which are responsible for water quality.

Fig. 4 shows the composition of nitrate, phosphate and ammonium in the treated water leaving the flotation unit. The graph shows a considerable reduction in the compositions of these components. The results proved the flotation unit to be a technically feasible solution for wastewater treatment. The results as of the water quality of the water leaving the flotation unit are shown in Fig. 5.

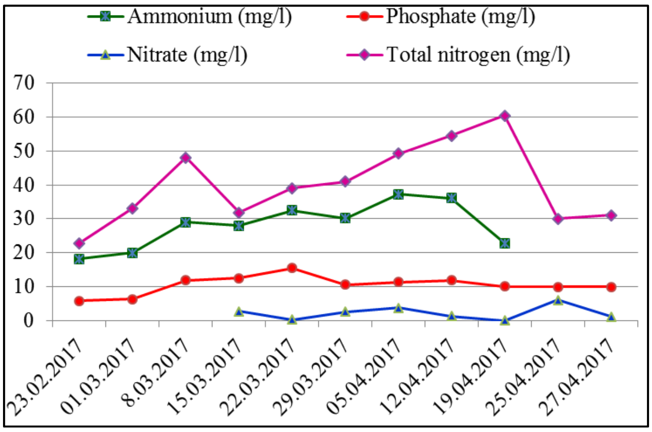

Fig 3: Analysis results of various compounds from the inflow sample

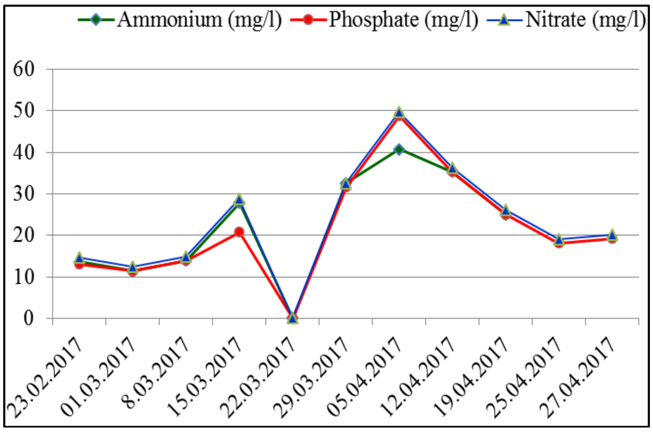

Fig 4: Analysis results of various compounds for the water samples from flotation tank

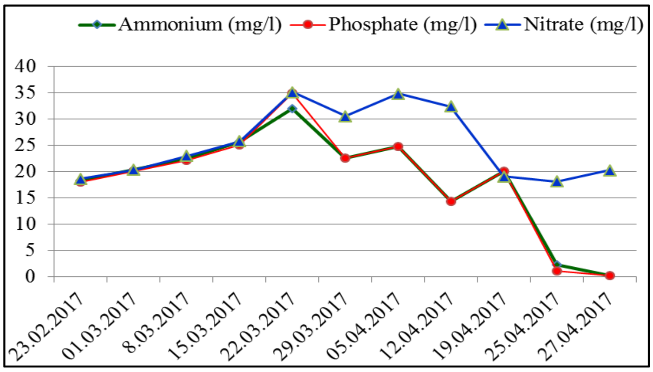

Fig 5: Analysis results of various compounds for the water samples from the sand filter

Tests to identify the optimal output parameters were conducted and the results are noted as shown in Table 3. The obtained values were analyzed to identify the most effective parameters. The efficiency of the experiment was analyzed by maximum reduction of COD and minimal reduction of phosphates. This can be understood by the percentage reduction of the respective components.

Table 3: Analysis results to estimate optimal combination of various parameters

Exp. No.	PAXXL-36 (Me/PO_4)	PURFIX (g/m^3)	High molecular polymer (g/m^3)	COD (mg/l)	$PTOT_{in}$ (mg/l)	COD (mg/l)	$PTOT_{out}$ (mg/l)
1	1	5	0.125	890	22.4	75.3	1.8
2	2	5	0.125	322	22.9	78.1	2.93
3	3	5	0.125	259	15.8	74.4	1.12
4	1	6	0.125	233	12.7	67.2	2.12
5	2	6	0.125	626	15.5	63.4	2.6
6	3	6	0.125	277	15.5	75.2	2.35
7	1	7	0.125	352	14.8	68.3	3.26
8	2	7	0.125	215	12.8	89.7	2.36
9	3	7	0.125	295	15	93.1	2.71
10	1	5	0.3125	327	16.6	95.4	4.48
11	2	5	0.3125	292	14.2	107	4.4
12	3	5	0.3125	215	13.1	94.1	1.25
13	1	6	0.3125	497	20.7	98.7	3.67
14	2	6	0.3125	315	14.8	77.1	3.36
15	3	6	0.3125	171	12	72.9	2.28
16	1	7	0.3125	195	13.7	63.9	3.55
17	2	7	0.3125	234	13.4	66.9	3.7
18	3	7	0.3125	265	15.3	83	2.34
19	1	5	0.5	353	17.7	71.4	2.72
20	2	5	0.5	298	14.8	76.6	3.08
21	3	5	0.5	231	15.1	155	2.09
22	1	6	0.5	365	17.8	120	4.22
23	2	6	0.5	315	15.4	129	3.89
24	3	6	0.5	326	16	105	3.32
25	1	7	0.5	285	13.2	95.3	2.97
26	2	7	0.5	305	14.8	98.2	3.41
27	3	7	0.5	255	14.2	101	3.12

Table 4 shows the percentage reduction of COD and phosphates in each of the respective experiments. As shown in Table 4, out of 27 experiments conducted, 5 experiments (1, 5, 7, 13 and 19) were observed to yield optimal results. Experiment 1 has shown a reduction of around 91% of both COD and phosphate. The dosage of metal salt and polymers was also minimal compared to other experiments in the group. Experiment 5 has shown 90% reduction of COD and 83% reduction in phosphate content. Metal salt and low molecular polymer dosage was higher compared to experiment 1. Experiment 7 has shown 80% reduction of COD and 78% reduction in phosphate content. In this experiment, the metal salt dosage was minimal whereas, the dosage of low molecular polymer was 7 g/m^3 which were considerably high. Experiment 13 has shown 80% reduction of COD and 82% reduction in phosphate content. In this experiment, the dosage of metal salt was minimal at 1 g/m^3 and low molecular polymer was slightly increased to 6 g/m^3 whereas the dosage of high molecular polymer was considerably increased from 0.125-0.313 g/m^3. Experiment 19 has shown 79% reduction of COD and 84% reduction in phosphate content. In this experiment, the dosage of metal salt and low molecular polymer were maintained minimal. However, the dosage of high molecular polymer was significantly increased to 0.5 g/m^3. Overall results suggested that, the experiments 1, 5, 7, 13 and 19 have yielded optimal results and hence the parameters with respective values can be considered for future experiments by making certain analytical manipulations if necessary

Table 4: Reduction percentages of COD and phosphate (P) in each of the respective tests

Exp. No.	PAXXL 36 (Me/PO_4)	PURFIX (g/m^3)	High molecular polymer (g/m^3)	COD_{red} (%)	P_{red} (%)
1	1	5	0.125	91.54	91.96
2	2	5	0.125	75.74	87.2
3	3	5	0.125	71.27	92.91
4	1	6	0.125	71.15	83.3
5	2	6	0.125	89.87	83.22
6	3	6	0.125	72.85	84.83
7	1	7	0.125	80.59	77.97
8	2	7	0.125	58.27	81.56
9	3	7	0.125	68.44	81.93
10	1	5	0.3125	70.82	73.01
11	2	5	0.3125	63.35	69.01
12	3	5	0.3125	56.23	90.45
13	1	6	0.3125	80.14	82.27
14	2	6	0.3125	75.52	77.29
15	3	6	0.3125	57.36	81
16	1	7	0.3125	67.23	74.08
17	2	7	0.3125	71.41	72.38
18	3	7	0.3125	68.67	84.7
19	1	5	0.5	79.77	84.63
20	2	5	0.5	74.29	79.18
21	3	5	0.5	32.9	86.15
22	1	6	0.5	67.12	76.29
23	2	6	0.5	59.04	74.74
24	3	6	0.5	67.79	79.25
25	1	7	0.5	66.56	77.5
26	2	7	0.5	67.8	76.95
27	3	7	0.5	60.39	78.03

Conclusions

In this study, the flotation unit was found to be a feasible option for municipal wastewater treatment. The overall results were encouraging with a removal of COD up to 92%, but the removal of phosphate (P) was up to 93%, which has to be reduced. Therefore, it was possible to reach maximum COD reduction with a lower usage of precipitators, but this also gave a high P reduction which was of concern and has to be overcome. Both the low molecular polymer PAXXL 36 and the high molecular polymer can be maintained on low dosage levels. PURFIX seemed to have a slightly larger impact on the water quality but can be kept on a dosage of 5 g/m^3 (medium dosage), considering the sustainable use of chemicals. The water quality of the treated water leaving the system can be utilized for irrigation. Hence, the basic purpose and goal of the flotation unit has been achieved. Hence, from the obtained results, this treatment process can be considered as a highly efficient, effective and a promising solution for wastewater treatment.

References

1. Bratby J. Coagulation and flocculation in water and wastewater treatment. John Bratby Publication 2006; 12:34-52.
2. Eugene R, Weiner S. Applications of environmental chemistry: A practical guide of environmental professionals. McGraw-Hill Publication 2000; 12:267-288.
3. Foladori P, Andreottola G, Ziglio G. Sludge reduction technologies in wastewater treatment plants. IWA Publishing 2010; 2:28-37.
4. Gillberg L, Hansen B, Karlsson I. About water treatment: An internal research journal of Kemira Kemwater 2003; 3:34-165.
5. Hellstedt C, Starberg K, Olsson LE, Hellström D, Jonsson L, Mossakowska A. Increased biogas production at Henriksdal wastewater treatment plant. Biogas Integrated Project No 019795 2003.

6. Hespanhol I, Prost AME. WHO guidelines and national standards for reuse and water quality. Water Research 1994; 28(1):119-134.
7. Krishna Reddy YV, Adamala S, Levlin EK, Reddy KS. Enhancing nitrogen removal efficiency of domestic wastewater through increased total efficiency in sewage treatment (ITEST) pilot plant in cold climatic regions of Baltic Sea. International Journal of Sustainable Built Environment 2017; 6:351-358.
8. Larsson E. Kemisk fällning och flockning av avloppsvatten med flotation som förbehandling till omvänd osmos at Hammarby Sjöstadsverk. Project publication No 37 2006.
9. Metcalf X, Eddy X. Advanced wastewater treatment: in wastewater engineering, treatment, disposal and re-use. McGraw-Hill Publication 1999; 3:126-159.
10. Mohammedsaid S. Application of reuse of wastewater for irrigation in middle-east countries, particularly in Jordan. Trita-LWR Master’s Thesis 2009; LWR-EX-09-30.
11. Pescod MB. Wastewater treatment and use in agriculture. World Health Organization Technical Report Series 47 1992.