Coagulation Followed By Ion Exchange to Treat Domestic Sewage

Acharya Neela, Thakur Chandrakant, Chaudhari Parmesh Kumar

***Abstract:** The pollutants contained in domestic sewage (DS) was separated using coagulation in first stage followed by ion exchange (IE) in second stage. The coagulants $FeCl_3$, Alum and $Al_2(SO_4)_3.16H_2O$ were used for treatment. Among these, performance of $Al_2(SO_4)_3.16H_2O$ and $FeCl_3$ was equally good in term of chemical oxygen demand (COD) removal at their optimum pH and optimum dose. COD values were reduced to 78 and 80 mg/dm^3 with $Al_2(SO_4)_3.16H_2O$ and $FeCl_3$ from initial value 256 mg/dm^3. The $FeCl_3$ coagulant treated DS was further treated using IE process, which was able to reduce hardness upto 10 mg/dm^3 from initial value 580 mg/dm^3. Settling of $FeCl_3$ treated sludge was found to best and design of settler has been presented from experimental data.*

***Keywords:** Chemical oxygen demand, domestic sewage, ion exchange, coagulation, hardness.*

I. INTRODUCTION

The main source of DS is wastewater generated from kitchen, bathroom, and laundry usage. The pollution severity of DS is not much, but its volume is very high, due to this its disposal is a major problem. In developing and under develop countries, the scarcity of sanitary conditions causes contamination to water, resulting in many diseases. Wide varieties of dissolved and suspended pollutants are present in DS. Organic matters are mainly food and vegetable waste. DS also contains bacteria which causes many harmful diseases if it is spread in the environment. The substances used for cleaning houses, washing cloths and other activities contains harmful chemicals like phosphates, sulfate, nitrate, phenol, etc put very harmful effects on all life forms of water. In all over the world, septic tank is used as primary collection and treatment of DS. Here only upto 40% of biological oxygen demand (BOD) is removed, thus most of the organic pollutants and pathogenic bacteria remain in the effluent [1,2], therefore, further treatment is required.

In most of cities, DS is mixed with municipal wastewater (MWW) and treated by the municipal corporation using biological method. The biological treatments including activated sludge process (ASP) [3]-[5], sequential batch reactor (SBR) [6]-[8] and membrane bioreactor (MBR) [9]-[11] have been reported to treat MWW. The effectiveness are found in order ASP < SBR < MBR. The ASP is low cost process, but effluent quality is not so good even process applied for long time MBR gives very good treated effluent quality, but cost of the process is high. Sever operating conditions and fouling of membrane is a drawback of the process. Due to this, physiochemical processes like coagulation and electrocoagulation are being popular. Some chemical processes like fenton per-oxidation and coagulation [12], coagulation [13,14], Electrocoagualtion [15,16] have been reported to treat MWW. A comparative study have been reported to treat MWW by coagulation, electrocoagulation and biological techniques, respectively in which 93%, 84% and 78 % COD removal was obtained from initial COD value of 170 mg/dm^3 [17]. In a study DS was treated by electrocoagulation electro-fenton process [2], which gave 15.1% COD, 17.8% TSS and 90.4% turbidity removed.

In the present process coagulation has been taken for treatment of DS for which different coagulant, pH and coagulant doses have been taken as a parameter for COD reduction of DS. As per literature available no work related to coagulation process has been found for treatment of DS.

II. MATERIALS AND METHOD

The samples were collected from sewage line located in campus NIT Raipur, C.G, India. The main characteristics of DS are shown in Table 1. The samples collected were kept in refrigerator at about 4 °C for subsequent experiments. The coagulants selected for the treatment of DS were commercial alum, laboratory grade $Al_2(SO_4)_3$ and $FeCl_3$. They were selected because of their performance and availability in the local market.

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Table 1. The characteristics of raw and treated DS

Influent parameters (mg/dm^3, except pH)	Raw	Treatment by Coagulation			Treatment by coagulation followed by ion exchange	CPCB norms, 1986 [18]	Kharun River, Raipur (C.G)
		$Al_2(SO_4)_3$	Alum	$FeCl_3$			
pH	7.3	7	6	6	6.66	6.0 – 8.5	7.15
COD	256	78	100	80	76	200	63
BOD	126	24	29	26	22	30	18
Total Hardness	580	490	520	550	10	200	210
Phosphate	5.64	0.154	0.27	0.12	0.10	5	1.18
Chloride	310	950	490	6800	60	1	70

Coagulation was performed in jar test apparatus containing six beakers of 1 dm^3 capacity. The beakers were filled with 0.6 dm^3 of DS and coagulants were added in this, after that pH was maintained using alkali and acids solution. Rapid mixing at 200 rpm was done for 5 min, which was followed by slow mixing at 80 to 100 rpm for 25 min. After experiment, the treated DS was kept to quiescent, which allows settling of sludge. The supernatant was taken for COD estimation. The other parameters were also estimated at optimum pH and dose of coagulants. The results are presented in Table 1.

Ion exchange setup consisted of two vertical cylindrical columns made up of polyacrylic material (5 cm dia), filled with cation resin (INDION 225 H) and anion resin (INDION NIP). The water treated by coagulation using $FeCl_3$ was fed to the IE unit for the softening of water. The treatment was done by passing the pretreated DS through the two columns with varying flow rate.

Water parameters were determined as per standard method given in American Public Health Association (APHA) 22nd edition, 2012 [19]. For COD estimation, the samples were digested for 2 h at 148 °C in a COD digester (WTW, CR-3200), Germany, then after digestion it was allowed to cool and further titrated with standard 0.1 N ferrous ammonium sulphate. Other parameters like hardness and chloride was determined by titrimetric method. Phosphate was determined by colorimetric method using Visible Spectrophotometer – Spectroquant (Prove 300, MERK, Germany). pH was measured by digital pH meter (EI-111, India).

III. RESULTS AND DISCUSSION

DS contains reducing carbohydrates, proteins, fatty acids and inorganics. Proteins denaturalize and produce negatively charged ionic components like amines. Carboxylic and hydroxyl functional groups are found in carbohydrates [20]. When coagulants like aluminium sulphate and ferric chloride ($FeCl_3$) are dissolved in water, it librates metal cations which hydrate and hydrolyze to form monomeric and polymeric species: $M(OH)^+$, $M(OH)^{2+}$, $M_2(OH)_2^{4+}$, $M(OH)_4^{5+}$, $M(OH)_2^0$ (s) and $M(OH)_4^-$ etc. At higher pH (>7) and high dose of coagulants $Fe(OH)_3$ or $Al(OH)_3$ are also formed [21]. The general form of hydrolysis reaction of trivalent metals is given by [22]

$$xM^{3+} + y\,H_2O = Mx(OH)y^{(3x-y)+} + yH^+$$

The metal hydroxide polymers formed in water has amorphous structure, which have very large surface area and also have positive charge [23]. Organic and inorganic species present in wastewater are adsorbed into these hydroxides and settle down due to the heavy mass [21,22]. The negative charges contained in effluent are also neutralized by the aluminium and iron cations and hydroxide cations. Due to this, colloidal destabilization and precipitation of metal (cations) – organics/ inorganics (anions) complexes takes place. Thus, charge neutralization, adsorption in monomers and polymer species and sweeping of pollutants during settling of heavy mass complexes is the mechanism for removal of pollutants contained in the effluent. At higher pH, MOH^- is also formed, which neutralize the cations contained in effluent and forms insoluble mass which settles down due to gravity. Due to this pollutants removal take place at wide pH range.

A. Effect of pH

Effect of pH on removal of COD was studied using the coagulants commercial alum, $Al_2(SO_4)_3$ and $FeCl_3$. Total hardness, calcium hardness and chloride was also estimated. The results are presented in Fig. 1. The Fig.1a shows removal of pollutants using $Al_2(SO_4)_3$ as coagulant at mass loading of Al^{3+} = 15 mM in aluminium sulphate. From the figure it can be seen that COD, chloride and hardness decreased with increase in pH from initial pH 3 to 7, further increase in pH shows increase in pollutants. At pH 7 COD of the DS reduced to 78 mg/dm^3 from initial COD value of 256 mg/dm^3, total hardness reached to 490 mg/dm^3 from 360 mg/dm^3, calcium hardness 260 mg/dm^3 from 250 mg/dm^3, chloride 950 mg/dm^3 from 310 mg/dm^3. These values are the lowest values obtained in the studied at pH range 3 to 9. The data show reduction in values of COD while increase in other parameters like chloride and hardness. The increase in hardness is due to presence of sulphate, chlorides and metals in coagulants which remain in dissolved state in wastewater. The COD values of 112, 86, 80, 92 and 224 mg/dm^3 was found at pH 3, 4.5, 6, 7.5 and 9, respectively. COD reduction is due to mechanism discussed above. At pH less than 5 and greater than 8 the coagulant species are at much dissolved state in the solution and all coagulant species formed are not active coagulants thus does not contribute more in reducing the pollutants.

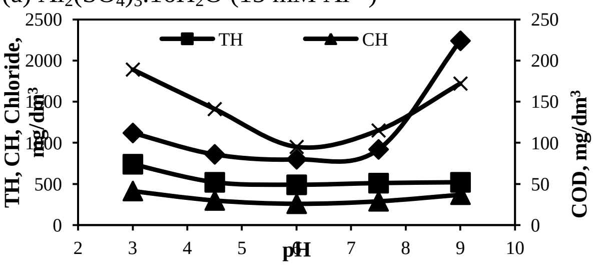
The variation in COD, total hardness and calcium hardness were also studied using commercial alum, (Al^{3+} = 15mM) in the pH range 3 to 9. Here COD reduction was found maximum at pH 6. The COD reduced to 100 mg/dm^3 from initial value of 256 mg/dm^3. Calcium hardness and total hardness reached to 360 mg/dm^3 and 520 mg/dm^3 from initial values of 215 and 360 mg/dm^3, respectively. Reason for increase in hardness is due to content of coagulant cation and anions in the solution. At pH greater than 6 and less than 6 COD and hardness of the solution were increased. The COD values of 130, 120, 100, 120 and 122 mg/dm^3 was found at pH 3, 4.5, 6, 7.5 and 9, respectively.

The functional group contained in wastewater coordinate with coagulants depends upon the pH. Therefore, the mechanism of pollutant removal was found to different at different pH. It has been reported that at pH less than 4, mainly metal cation (Al^{3+}) are formed and monomer and polymer species are formed at pH range 4 to 7. Further, increase in pH changes Al to $Al(OH)_3$ [24]. Monomer and polymer species are active coagulants as compared to metal cations.

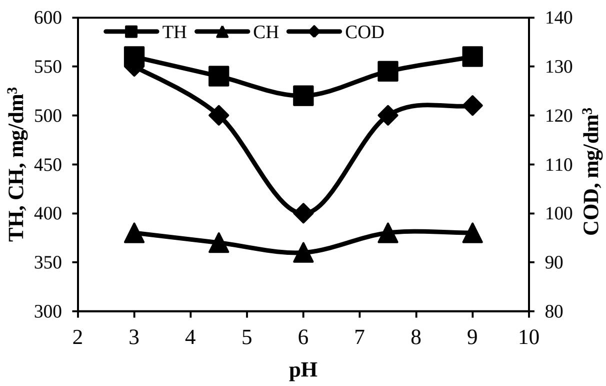
Effect of $FeCl_3$ as coagulant Fe^{3+} = 20 mM was also studied for the treatment of DS at different pH. Among pH range 3 to 9, pH 6 was found to optimum giving COD value 92 mg/dm^3 from initial values of 256 mg/dm^3. When pH was reduced from 6 to 3, COD value of DS was maximum (160 mg/dm^3). The COD value of DS = 256 mg/dm^3 reached to 160, 106, 92, 128 and 140 mg/dm^3, respectively, at pH 3, 4.5, 6, 7.5 and 9. This data shows acidic and basic condition is not favorable to treat DS using $FeCl_3$ and other coagulants as well. Calcium hardness and total hardness also had a lowest value of 360 and 550 mg/dm^3, respectively, at pH 6.

In all the coagulants, much COD reduction in the range of pH 5 to 8 is due to formation of active coagulant species ($Fe(OH)_3$ and $Al(OH)_3$ cations) which adsorbs pollutants and neutralized it and make heavy mass which settled down. At pH < 5, the coagulant species are at dissolved condition in the solution and not contribute more in reduction of pollutants, while at pH > 8 neutralized metal hydroxides and negative charged metal hydroxides form which are not effective coagulants.

(a) $Al_2(SO_4)_3.16H_2O$ (15 mM Al^{3+})



(b) Alum (15 mM Al^{3+})



(c) $FeCl_3$ (20 mM Fe^{2+})

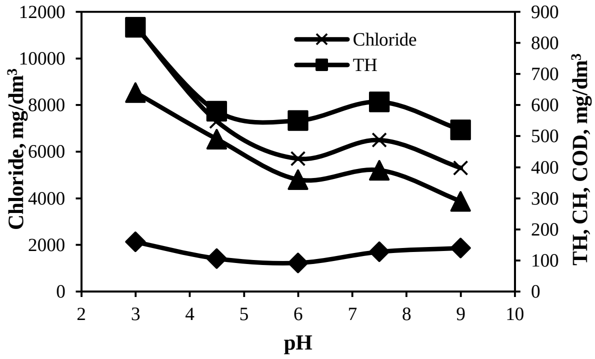


Fig. 1. Effect of pH on COD, total hardness (TH), calcium hardness (CH) and chloride values (a) $Al_2(SO_4)_3.16H_2O$, (b) Alum and (c) $FeCl_3$.

Due to formation of poor coagulant species at higher pH, coagulation was not performed at pH > 9. Poor coagulant species does not participate effetivelly in coagulation and consequently poor COD removal takes place. In earlier studies reported by various investigators for treatment of pulp and paper mill wastewater [25], MWW [26], distillery wastewater [20] and textile industry effluent [27], the treatment efficiency was much in the range of pH 5 to 8.

B. Effect of coagulant mass loading

Optimum mass loading for coagulation process depends on types of coagulants, operational pH, type of wastewater, speed of mixing and temperature. Gentle mixing initiates the flock formation, complexion and adsorption. In our studies rapid mixing was done at 200 rpm for 5 min, which was followed by slow mixing of 80 to 100 rpm for 20 min. pH was kept to optimum as discussed above and temperature was 30 ± 5 °C.

Variation in pollutant parameters for different mass loading of $Al_2(SO_4)_3.16H_2O$ at optimum pH 6 is given in Fig. 2a. Initial COD value of DS (256 mg/dm^3) decreased to 98, 92,78, 82 and 82 mg/dm^3, respectively, for 10, 15, 30 and 50 mM doses of Al^{3+} in $Al_2(SO_4)_3.16H_2O$. The data shows 15 mM Al^{3+} to be optimum. The calcium hardness was lies in the range of 230 to 340 mg/dm^3 and total hardness in range of 420 to 550 mg/dm^3. Both were found to increase with increase in coagulant doses. Chloride content in the treated DS was increased with coagulant mass loading from 780 mg/dm^3 at 5 mM Al^{3+} dose to 950 mg/dm^3 at 50 mM Al^{3+} dose. The coagulant $Al_2(SO_4)_3.16H_2O$ adding did not contributed to increase in chloride, but since volume of supernatant was decreased, the concentration of chloride was increased from its initial value 310 mg/dm^3.

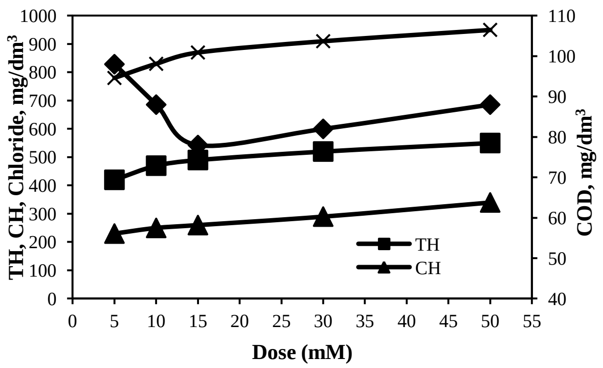
Values of pollutant parameters were also determined for alum coagulant at pH 6. Alum is also known as aluminium sulphate and it can be in liquid or dry form. In our study dry alum was used. The COD of DS reduced to 120, 110,100, 112 and 130 mg/dm^3 from its initial value of 256 mg/dm^3 at alum dose of 5, 10, 15, 20 and 30 mM, respectively. The total hardness, calcium hardness and chloride in the untreated DS were 360, 215, and 310 mg/dm^3, which were increased with addition of coagulants.

For alum dose of 5, 10, 15, 20 and 30 mM (Al^{3+}) respectively, total hardness was increased to 410, 460, 520, 540 and 570 mg/dm^3, and calcium hardness was increased to 260, 330, 360, 370 and 390 mg/dm^3. The COD reduction data show coagulant dose 15 mM (Al^{3+}) to be optimum dose of alum.

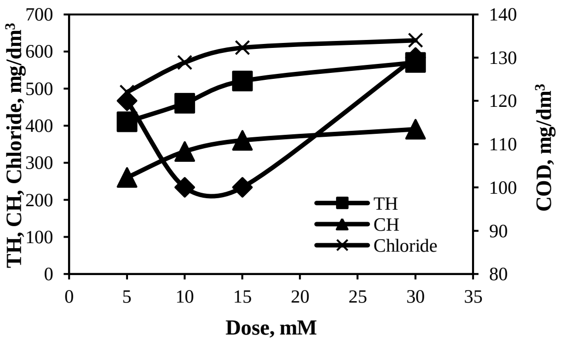
Mass variation of $FeCl_3$ coagulant for treatment of DS was also studied. The values of total hardness and calcium hardness and chloride was found to increase with adding of coagulant. Total hardness was lies in the range 370 to 650 mg/dm^3, calcium hardness in range 210 to 430 mg/dm^3, and chloride in range 2150 to 8400 mg/dm^3. Mass loading data for $FeCl_3$ coagulant shows 30 mM Fe^{3+} to be optimum as COD values reached to 80 mg/dm^3 from 256 mg/dm^3.

Mass loading studies show, for all the coagulants, COD was reduced with increase in coagulant dose upto certain mass loading values, after that COD value of solution increased. As data reported above, optimum dose for $Al_2(SO_4)_3.16H_2O$, alum and $FeCl_3$ in terms of metal cations (Fe^{3+} and Al^{3+}) were 15 mM, 15 mM and 30 mM respectively. Upto optimum coagulant dose, removal of COD was increased this was due to availability of more coagulant species which was coordinated with pollutants available in effluent and pollutants were removed by various mechanisms like charge neutralization, adsorption and enmeshment of pollutants in amorphous surface of coagulant species and by sweeping. After this, addition of more coagulant gave high COD values. At high coagulant dose less COD removal is due to restabilization of colloids in the effluent [28].

(a) $Al_2(SO_4)_3.16H_2O$ (pH 7)



(b) Alum (pH 6)



(c) $FeCl_3$ (pH 6)

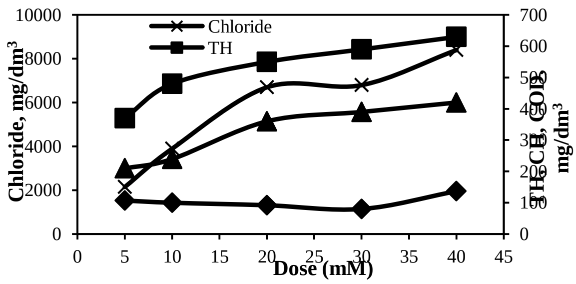
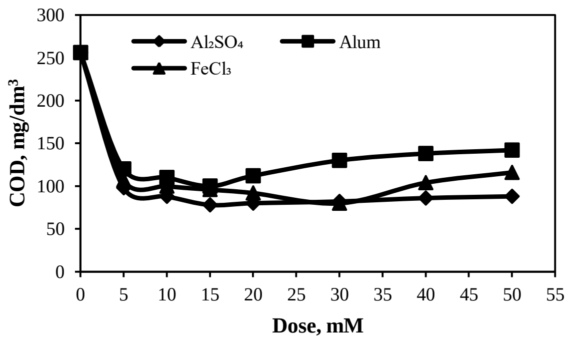


Fig. 2. Effect of coagulant dose (a) Al2(SO4)3.16H2O (pH 7), (b) Alum (pH 6) and (c) FeCl3 (pH 6) on COD, total hardness (TH), calcium hardness (CH) and chloride

The COD reduction at different coagulant dose are also presented in Fig. 3a, the better treatment i.e. COD reduction was found with $Al_2(SO_4)_3.16H_2O$ and $FeCl_3$ coagulant. In the studies, settling of sludge treated with $FeCl_3$ was found to best, while extremely poor with $Al_2(SO_4)_3.16H_2O$ and alum. Therefore, it is suggested to use $FeCl_3$ for treatment of DS. The values of hardness and chloride were increased in the treatment, which can be removed by further treatment like ion exchange process.

(a) COD reduction



(b)

Total hardness

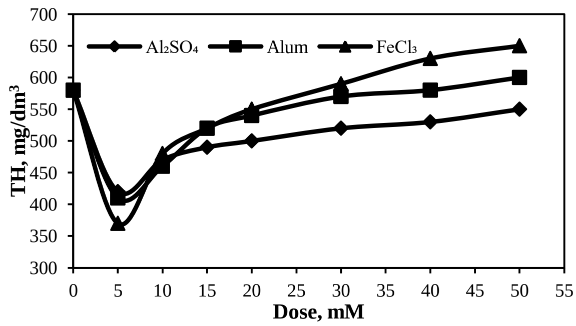


Fig. 3. Effect of coagulant dose on (a) COD reduction (b) total hardness (TH) contained.

C. Filtration study

In the coagulation process the dissolved organics and inorganics make complexation with coagulant species, which precipitated and settled down. The precipitated substance is known as sludge.

To separate the sludge from the treated effluent filtration and settling processes are mostly used. We have gone through both the processes. Filtration studies were performed using Whatman filter paper no. 42 supported by buchner funnel. The filtration resistance for the filter media and filter cake was determined for constant pressure (1 atm) filtration using the following equation [29]

$$\frac{dt}{dV} = k_p V + \beta \quad (1)$$

where,

$$k_p = \frac{c\,\alpha\,\mu}{A^2(-\Delta p)} \quad (2)$$

$$\beta = \frac{\mu R_m}{A(-\Delta p)} \quad (3)$$

Here V is the volume of filtrate collected (dm^3), t is time of filtration, k_p is slope of plot of equation 1 (s/m^3), c is the concentration of slurry (kg/m^3), A is filtration area (m^2), μ is the viscosity of filtrate (Pa. s), α is the cake resistance, Δp is pressure drop across the filtrate.

Experimental data of filtration study are plotted as Δt/ΔV verses V, which is shown in Fig. 4. The value of K_p and β was calculated by slope and intercept, respectively. The value of filter media resistance (α) was found to be 6.21, 5.68, and 29.4 m/kg and filter media resistance (R_m) was noted as 149, 78.78 and 124 × 10^{10} m^{-1} for alum, $FeCl_3$ and $Al_2(SO_4)_3.16H_2O$, respectively (Table 2). Value of α and R_m is lowest for $FeCl_3$ treated DS shows good filtration property which was also seen during the filtration study. As $FeCl_3$ treated DS was passed through filter media easily as compared to other coagulant treated DS. The value of R_m is important during the early stage of filtration. The first drop of filtrate was seen earlier for $FeCl_3$ treated DS as compared to $Al_2(SO_4)_3.16H_2O$ and alum treated DS. The porosity of cake affects the filtered media resistance. High porosity cake gives lower resistance for filtration cake, which was found to be maximum for $FeCl_3$ treated DS. The value of α was lies in the range of 5.68 to 29.40×10^{12} m/kg. Filtration characteristics of MWW sludge has been reported by Barnes et. al [30], they found value of α in the range of 4 to 12 ×10^{13} m/kg for the activated sludge, 3 to 30 ×10^{13} m/kg for the digester sludge. Our values are lower to these, showing better filterability.

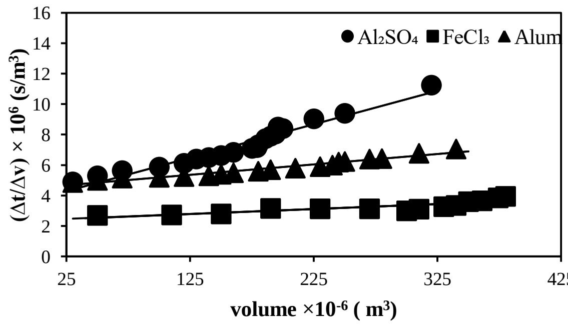


Fig. 4. Filterability of coagulants treated domestic sewage

Table 2. Filterability of treated wastewater

Coagulant	$k_P \times 10^9$, s/m^6	$\beta \times 10^6$, s/m^3	c, kg/m^3	$\mu \times 10^3$, PaS	$\alpha \times 10^{12}$, m/kg	$R_m \times 10^{10}$, m^{-1}
Al_2SO_4	22	3.741	0.82	1	29.4	124
$FeCl_3$	3	2.376	0.58	1	5.68	78.78
Alum	6	4.495	1.06	1	6.21	149

D. Settling study

Settling is a low cost separation process commonly used in the effluent treatment plant for separation of sludge and supernatant from its mixture. In the settling process three zones are formed in settling chamber (i) zone setting in which the height of the sludge and supernatant interface decreases fast and steady with nearby constant slope, (ii) transition settling in which the rate of decrease of intercept height is less and the slope changes continuously with time, (iii) compression settling in which smaller but steady rate of decrease in height of interface take place. These three settling zones are presented in Fig. 5. In the figure it can be seen that settling rate of alum and $Al_2(SO_4)_3.16H_2O$ treated sludge is low, while the $FeCl_3$ treated sludge is high exhibiting 80 % settling in 10 min. Since in the coagulation process, performance of $FeCl_3$ coagulant in terms of COD reduction is very good and good settling characteristics of sludge is obtained, therefore, treatment of DS with $FeCl_3$ is best among the three coagulants used.

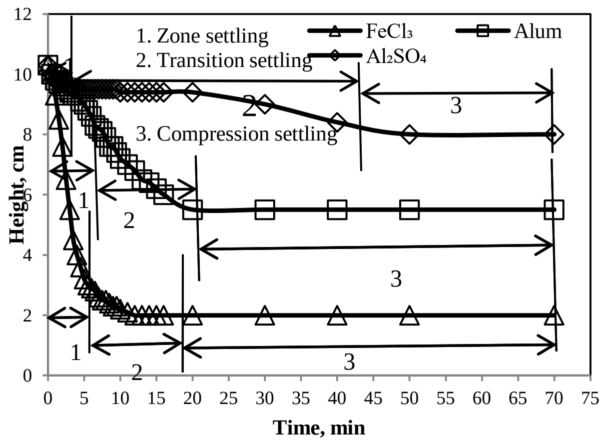


Fig. 5. Settling of slurry obtained after coagulation

E. Determination of area and height of sedimentation tank

The parameters such as sedimentation velocity (u_c), concentration of sludge (C) at time t(s), and the sedimentation flux ($kg/m^2.s$) were calculated which was further used to calculate area and height of sedimentation tank. The sedimentation velocity was found from the slope of the tangent at a given solids concentration, C. The parameters evaluated are presented in Table 3. The concentration of sludge (C) at time t was determined by the following expression

$$C = \frac{C_0 \times total\ weight}{weight\ of\ suspension\ after\ time, t} \quad (4)$$

The concentration of the solids required in the underflow C_u, for the treated effluent was found to be 15.04 × 10^{-3} kg/m^3 (Table 3). The maximum value of $\left(\frac{\left(\frac{1}{C}-\frac{1}{C_u}\right)}{u_c}\right)_{max}$ was found to 1.645 × 10^3 m^2s/kg.

Assuming a feed rate of Q_0 = 0.5 m^3/min for C_0 = 2.92 kg/m^3, the area of the sedimentation tank can be determined as below [31, 32]

$$A = Q_0\ C_0 \left(\frac{\left(\frac{1}{C}-\frac{1}{C_u}\right)}{u_c}\right)_{max} = 40.0285\ m^2 \quad (5)$$

The volumetric flow rate of underflow (Q_u) was evaluated as

$$Q_u = Q_0 \frac{C}{C_u} = 0.5 \times \frac{2.92}{15.0366} \times \frac{1}{60} = 0.00162\ m^3/s \qquad (6)$$

F. Design of continuous thickener

In batch settling process 0.5 dm^3 treated DS was taken in 1 dm^3 settling cylinder. Its diameter was 7.5 cm and height was 10.3 cm, thus, height to diameter ratio is 1.378. Based on this study diameter and height of continuous thickener was evaluated as below

$$A = \frac{\pi D^2}{4} = 40.0285\ m^2$$

D = 7.12 m

H = D × (H/D ratio)

H = 7.12 × 1.378 = 9.82 m

Table 3. Settling Characterization of slurry obtained by coagulation of DS

S. No.	Time, min	Height, mm	u_c, mm/min	$u_c \times 10^{-5}$, m/s	C, kg/m^3	Sedimentation flux, (u_c × C) $\times 10^{-5}$, kg/m^2s	$\left(\frac{1}{C} - \frac{1}{C_u}\right)$ = X, m^3/kg	$\frac{u_c}{\left(\frac{1}{C}-\frac{1}{C_u}\right)} \times 10^{-5}$, kg/m^2s	$\frac{\left(\frac{1}{C}-\frac{1}{C_u}\right)}{u_c} \times 10^5$, m^2s/kg
1	0	103	1.3	2.17	2.92	6.33	0.28	7.85	0.13
2	1	93	1.47	2.45	3.23	7.91	0.24	10.08	0.10
3	2	76	1.77	2.95	3.96	11.67	0.19	15.84	0.06
4	3	55	1.72	2.86	5.47	15.64	0.12	24.58	0.04
5	4	40	0.88	1.47	7.52	11.03	0.07	22.06	0.05
6	5	32	0.64	1.07	9.40	10.03	0.04	26.74	0.04
7	6	29	0.25	0.42	10.37	4.31	0.03	13.90	0.07
8	7	26	0.16	0.27	11.57	3.09	0.02	13.38	0.07
9	8	25	0.13	0.22	12.03	2.68	0.02	13.41	0.07
10	9	23	0.12	0.19	13.08	2.52	0.01	19.34	0.05
11	10	22	0.1	0.17	13.67	2.28	0.01	25.10	0.04
12	11	21	0.12	0.20	14.32	2.89	0.003	60.79	0.02
13	12	20	0.06	0.10	15.04	1.43	0.00	-	-
14	13	20	0.06	0.10	15.04	1.43	0.00	-	-

Thus, for 0.5 m^3/min flow rate, for coagulation with $FeCl_3$ (30 mM Fe^{3+}), height of thickener will be 9.82 m and diameter will be 7.12 m.

G. Cost analysis of coagulants used

(a)Using Aluminium sulphate

COD of DS reduced to 78 mg/dm^3 from 256 mg/dm^3, which is 70 % COD reduction at optimum dose of 15 mM (Al^{3+}) in $Al_2(SO_4)_3.16H_2O$. For this 9.46 gm/m^3 $Al_2(SO_4)_3.16H_2O$ is required.

Cost of 15 mM $Al_2(SO_4)_3$ = US \$220/ton or US \$0.22/kg [33]

9.46 gm $Al_2(SO_4)_3$ is required to treat 1m^3 of DS

Price of 9.46 gm $Al_2(SO_4)_3$ = 9.46×0.22×73 = INR 151.93.

(b) Using Alum

61 % COD reduction was obtained at optimum dose of 15 mM Al^{3+} in Alum, which is equal to 8.91 gm alum/dm^3.

Cost of Alum = US \$210/ton or US \$0.21/kg [33]

8.91 gm Alum is required to treat 1m^3 of DS

Price of 8.91 gm Alum = 8.91×0.21×73 = INR 136.59.

(c) Using Ferric chloride

68.75 % COD reduction was obtained at optimum dose of 30 mM Fe^{+++} in $FeCl_3$, thus $FeCl_3$ required is 8.109 gm/m^3.

Cost of $FeCl_3$= US \$250/ton or US \$0.25/kg [33]

8.109 gm $FeCl_3$ is required to treat 1m^3 DS

Price of 8.109 gm $FeCl_3$ = 8.109×0.25×73 = INR 148 (=2.02 US\$).

Cost calculation shows, cost of coagulants for treatment for 1 m^3 DS using ferric chloride is INR 148, alum is INR 136.59 and aluminium sulphate is INR 151.93. Settling studies show treatment of DS with ferric chloride coagulant gave excellent settling property, while with alum and aluminium sulphate gave very poor settling. Due to this $FeCl_3$ is best coagulant among these.

H. Coagulation followed by ion exchange

The DS treated by coagulation using $FeCl_3$ coagulant was further treated by ion exchange (IE) process. The average

properties of coagulant treated DS had values COD = 96 mg/dm^3, BOD= 29 mg/dm^3, hardness = 580 mg/dm^3. The pretreated DS was chosen in IE resin column at a feed rate in the range of 1-10 dm^3/h. For all the range of feed rate, similar hardness (10 mg/dm^3) of treated DS was found. The COD was in the range 70 to 84 mg/dm^3 (Fig. 6).

The results of coagulation followed by IE show good values in terms of pollutant parameters (Table 1). The two stage treated DS can be recycled or discharged into water receiving bodies like pond and river after chlorination, and can also be used for various purpose. Chlorination kills the bacteria as done in DS/ MWW treatment plant. The coagulation and electrocoagulation removes the bacteria from the effluent upto much extent.

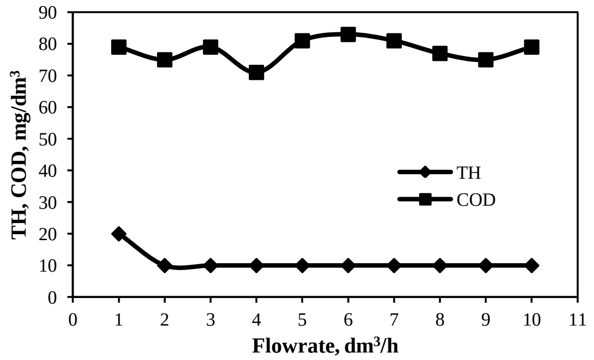


Fig. 6. COD and total hardness (TH) values (mg/dm^3) of IE treated DS

The anion exchange resin is available at price of US\$ 2000/ton and cations exchange resin at price of \$1000/ton[32]. In nearby power plant, 4.2 tons resin is used for softening of 1,63,000 m^3 river water. It is further regenerated time to time and used up to about five years. Thus, ion exchange process price is not much.

IV. CONCLUSIONS

Following conclusions are made from the study

(i) Among the coagulants $FeCl_3$, $Al_2(SO_4)_3.16H_2O$ and alum, the $FeCl_3$ was found to best in terms of COD reduction, filtration of sludge and settling of sludge. The COD value 256 mg/dm^3 of untreated DS was reduced to 100 mg/dm^3 at optimum pH 6 and optimum dose 15 mM Al^{3+} contain in alum. With 15 mM Al^{3+} in $Al_2(SO_4)_3.16H_2O$, at optimum pH 7 the COD reduced to 78 mg/dm^3 and with 30 mM Fe^{3+} in $FeCl_3$, at pH 6 COD reduced to 80 mg/dm^3.

(ii) Filtration studies show $FeCl_3$ treated DS gave good filtration characteristics of slurry in terms of cake resistance and filter media resistance. The value of $\alpha = 5.68 \times 10^{12}$ m/kg and $R_m = 78.78 \times 10^{10}$ m^{-1} was found.

(iii) Settling characteristics of $FeCl_3$ treated DS was found to best with 80 % settling in 10 min.

(iv) Further treatment of $FeCl_3$ coagulant treated DS by IE abled to reduce hardness upto 10 mg/dm^3 from initial value 580 mg/dm^3. The quality of two stage treated DS is found equally good to that of Kharun river located near to Raipur city. Water of this river is used by Municipal Corporation for treatment and further supply in houses for drinking and other purposes. Overall, these two processes could be used for treatment of DS.

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