International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.12 No.04, pp 283-290, 2019

Electrocoagulation followed by Settling and Filtration Process in Treatment of Domestic Sewage

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Abstract : The Domestic Sewage (DS) was treated using Electrocoagulation (EC) process. Effect of current and number of plates were taken as variable. Current = 2A and no. of plates = 6 was found to optimum with COD reduction of 62 mg/dm^3 from initial COD 288 mg/dm^3. During the treatment sludge was obtained which was separated from solution using filtration and sedimentation. The filtration cake resistance was found to 16.06 × 10^{12}, 21.98 × 10^{12} and 11.28 × 10^{12} m/kg at pH 7, 8 and 9 respectively. During the settling studies more than 70% settling was obtained in 5 minutes which shows significant separation of solid from mixture of solid and liquid. Design of settler has also been presented.
Keywords : Domestic Sewage, Electrocoagulation, Filtration, Sedimentation, COD.

Introduction

Low cost and effective separation is need of every industry. By this, production cost decreased and goods are available to consumers at low price. In agro based industries lot of wastewater is generated and it is treated by suitable methods. The methods may be bioaerobic[1,2], coagulation[3], EC[4,5], thermolysis[6,7] etc. These processes were applied in lab studies and in all the processes sludge is generated, which is contained in treated wastewater. This sludge need to separate earlier to discharge of treated water. For this settling and filtration process could be applied. Settling is most economical process which is widely used in industries and also it has been tested for various lab scale experiments[4,6,7].

Filtration is also widely used process and it gives water quality better to settling, but more costly to settling process. It can be applied where settling performance is poor. In present article the settling and filtration study of EC treated DS is presented.

Acharya Neela *et al* /International Journal of ChemTech Research, 2019,12(4): 283-290.

DOI= http://dx.doi.org/10.20902/IJCTR.2019.120434

Materials and methods

To perform EC experiment, the electrodes were immersed in DS contained in electrocoagulation reactor. Electrodes were connected in series and connected to DC power supply. When current was applied the dissolution of electrode took place and coagulant species were formed, which results in reduction of pollutants contained in DS by various mechanisms like charge neutralization, enmeshment of pollutants in flocks and by sweeping. To study the separation process by settling, 1 dm^3 treated DS was taken in a cylinder of capacity 1 dm^3 and the liquid-solid inter face H/H_0 as a function of time was noted with time. For the study of filtration characteristics, gravity filtration was performed with filter paper on a buckner funnel at atmospheric pressure. The volume of filtrate at different time was noted.

Results and Discussion

Electrocoagulation of domestic sewage

To treat the DS by EC, the experiments were performed at optimum pH 8, current 1 to 3A for 2, 4 and 6 number of plates. The results of experiment are presented in Figure 1.

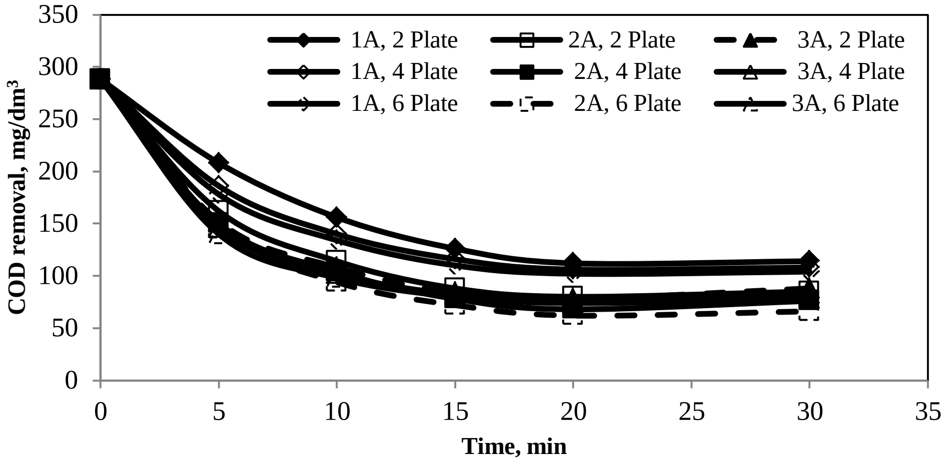

Figure 1: Effect of current and no. of plates at on COD removal of DS, COD_i = 288 mg/dm^3, optimum pH = 8

From the figure it can be seen that, when number of plates was fixed and current was increased the COD reduction was also increased upto 2A. At 1A, 2A and 3A current, respectively, for 2 plate configuration in 20 minutes COD value reached to 112, 80 and 78 mg/dm^3; for 4 plate configuration COD value reached to 106, 68 and 76 mg/dm^3; similarly for 6 plate configuration COD value reached to 102, 62 and 74 mg/dm^3 in same time of treatment. Upto 20 min, the COD of solution decreased, which is due to increase in metal and metal hydroxide monomers and polymers with dissolution of electrode material. When current is applied across the iron electrode Fe^{2+} is formed by scarification of iron electrode Fe^{2+} further changes in Fe^{3+} and metal hydroxide cations like $Fe(OH)^{2+}$, $Fe(OH)_2^{+}$, $Fe_2(OH)_2^{4+}$, $Fe(OH)_2$, $FeO(OH)$, $Fe(OH)_3$, $Fe(H_2O)_4(OH)_2^{+}$, $Fe(H_2O)_6(OH)_4^{+}$, $Fe(H_2O)_8(OH)_2^{4+}$, $Fe(H_2O)_5(OH)$ as per pH of solution[8,9]. These cations neutralize the colloids which have negative charge present in DS and settle down in bottom of EC reactor due to heavy mass. In most of cases COD value increased slightly with increase in time after 20 min, which is due to excess coagulant species to that of desired. The excess coagulants cause restablization of colloids.[10] The overall studies show 6 plate configuration with 2A current and 20 min of t_R was optimum as lowest COD value of treated DS reduced to 62 mg/dm^3.

Filterability of sludge

To evaluate the filtration characteristics of treated DS by EC, the gravity filtration was performed by using a filter paper on a buckner funnel at atmospheric pressure. The force balance for this can be written as[11]

$$\frac{\Delta t}{\Delta V} = \frac{\mu}{A\Delta P}\left(\frac{\alpha c V}{A} + R_m\right) \quad (1)$$

where, V is the volume of filtrate collected (dm^3), t is time of filtration, 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, R_m is filter media constant. From the plot of $\frac{\Delta t}{\Delta V}$ verses V (Figure 2) the values of filter media constant R_m and cake resistance were evaluated from intercept and slope, respectively. The various values of cake resistance and filter media resistance for pH 7, 8 and 9 were evaluated which is presented in Table 1. The values of R_m was evaluated to 4.3×10^{10}, 5.22×10^{10} and 4.62×10^{10} m^{-1} and α to 16.06×10^{12}, 21.98×10^{12} and 11.28×10^{12} ml/g at pH 7, 8 and 9, respectively. Values of R_m is important only in the initial stage of filtration. The value of specific cake resistance have been reported by Barnes et al., which were in the range of (4-12) × 10^{12} and (3-30) × 10^{13} for activated sludge and biodigester sludge, respectively. In our case values of α is less, which shows better filterability as compared to municipal sludge.

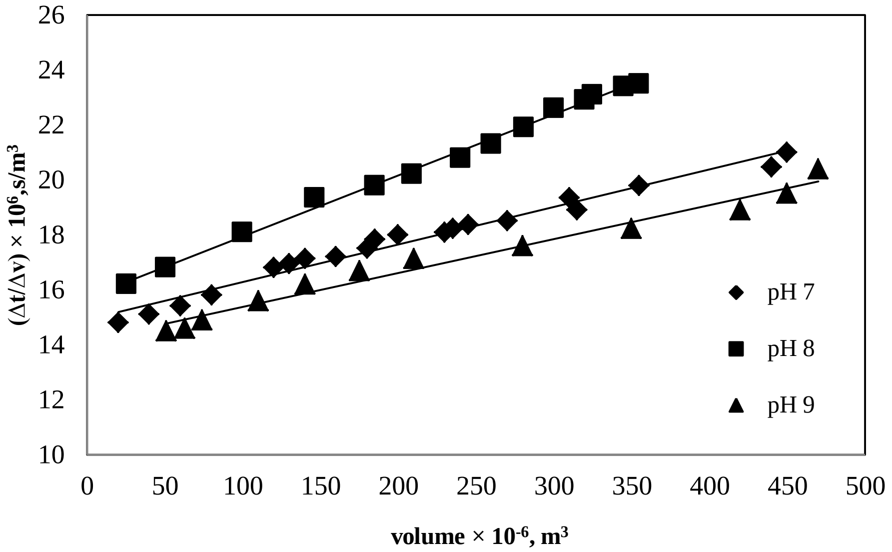

Figure 2: Filtration curve at pH 7, 8 and 9 of Domestic sewage (DS)

Table 1: **Filterability of treated wastewater**

pH	$k_P \times 10^9$ s/m^6	$\beta \times 10^6$ s/m^3	c kg/m^3	$\mu \times 10^3$ Pa S	$\alpha \times 10^{12}$ m/kg	$Rm \times 10^{10}$ m^{-1}
7	13	14.92	0.89	1	16.06	4.3
8	22	15.73	1.098	1	21.98	5.22
9	12	13.94	1.17	1	11.28	4.62

Separation of sludge by settling

Removal of solid from mixture of liquid and solid by settling is well established and acceptable process because the expenditure is very less as compared to other separation processes. The data of settling is presented in Figure 3. At the initial stage for a very short period of time slow settling of sludge was seen because of the Brownian motion of particles, after that fast settling was seen till 4 min which is known as zone settling, after the zone settling the transition regimes was seen in which settling takes place slowly, after that a study state compression settling occurs with a very smaller rate. From the figure it can also be seen that in the process about 70 % settling was noted in 5 min at all pH. Till 4 min of settling the settling rate of sludge at all the pH (7, 8 and 9) was constant, after that rate of settling was discriminated in the order pH 7 > pH 8 > pH 9. The difference in settling rate may be due to nature of sludge formed which is obtained during EC at various pH. At pH 7 about 81 % settling was noted in 10 min. In settling process, the rate of settling of sludge is excellent, thus separation could be easily done by sedimentation process. The graph shows that settling time of 15 min to be optimum.

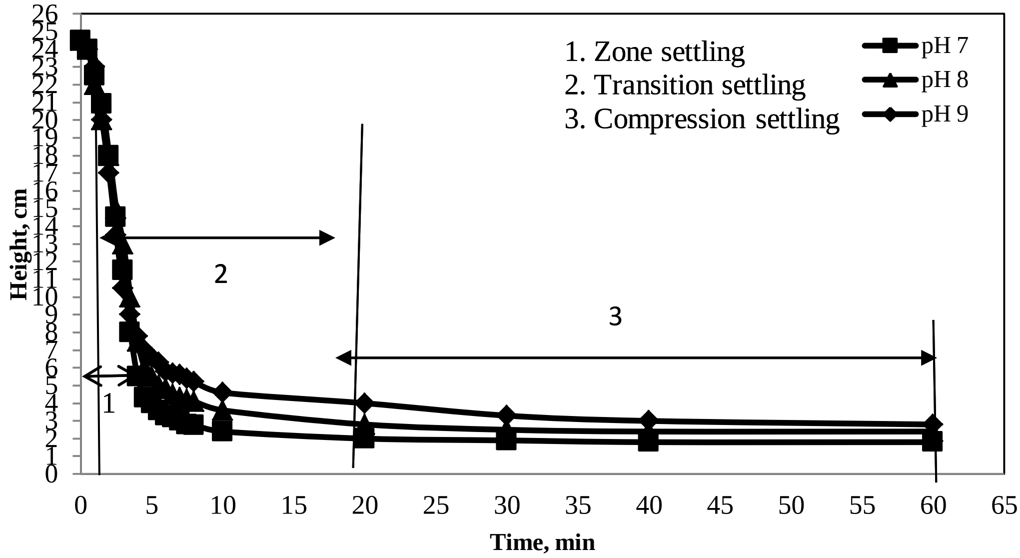

Figure 3: Settling study of slurry at pH 7, 8 and 9 of Domestic sewage (DS)

Determination of area and height of sedimentation tank

At pH 7, 8 and 9, the parameters such as sedimentation velocity (u_c), concentration of sludge (C) at time t (s), and the sedimentation flux (kg/m^2.s) was evaluated 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 for pH 7, 8 and 9 are presented in Table 2-4. The concentration of sludge (C) at time t was determined by the following expression

$$C = \frac{C_0 \times \text{total height}}{\text{height of suspension after time, } t} \qquad (2)$$

At pH 7

The concentration of the solids required in the underflow C_u, for the treated effluent was evaluated to be 57.9444 kg/m^3 and the maximum value of $\left(\frac{\left(\frac{1}{C}-\frac{1}{C_u}\right)}{u_c}\right)_{max}$ was 1090 m^{2}s/kg.

Assuming a feed rate of Q_0 = 1 m^3/min for C_0 = 4.2571 kg/m^3, the area of the sedimentation tank was calculated as below[12,4]

$$A = Q_0\, C_0 \left(\frac{\left(\frac{1}{C}-\frac{1}{C_u}\right)}{u_c}\right)_{max} = 77.33 \text{ m}^2 \qquad (3)$$

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

$$Q_u = Q_0 \frac{C}{C_u} = 0.1 \times \frac{4.2571}{57.9444} \times \frac{1}{60} = 1.224 \times 10^{-3} \text{ m}^3/\text{s} \qquad (4)$$

In batch settling process, 1 dm^3 treated DS was taken in 1 dm^3 settling cylinder. Its diameter was 7.5 cm and height was 24.5 cm, thus, height to diameter ratio is 3.26. Based on this study diameter and height of continuous thickener was evaluated as below

$$A = \frac{\pi D^2}{4} = 77.33 \text{ m}^2$$

D = 9.93 m

H = D × (H/D ratio)

H = 9.93 × 3.26 = 32.35 m

At pH 8

The concentration of the solids required in the underflow C_u, for the treated effluent was evaluated to be 45.7917 kg/m^3 and the maximum value of $\left(\frac{\left(\frac{1}{C}-\frac{1}{C_u}\right)}{u_c}\right)_{max}$ was 90 m^{2}s/kg. Assuming a feed rate of Q_0 = 1 m^3/min for C_0 = 4.485 kg/m^3, the area of the sedimentation tank was calculated as described in equation 5[12,4]

Table 2: **Settling Characterization of slurry obtained by electrocoagulation of DS at pH 7**

S. No.	Time, min	Height, mm	u_c, mm/min	$u_c \times 10^{-5}$, m/s	C, kg/m^3	Sedimentation flux, ($u_c \times C$) $\times 10^{-5}$, kg/m^{2}s	$\left(\frac{1}{C}-\frac{1}{C_u}\right)$ = X, m^3/kg	$\frac{u_c}{\left(\frac{1}{C}-\frac{1}{C_u}\right)} \times 10^{-5}$, kg/m^{2}s	$\frac{\left(\frac{1}{C}-\frac{1}{C_u}\right)}{u_c} \times 10^5$, m^{2}s/kg
1	0	245	-	-	4.2571	-	0.2176	-	-
2	1	225	22.2200	37.0407	4.6356	171.7044	0.1985	186.6352	0.0054
3	2	180	52.0000	86.6840	5.7944	502.2856	0.1553	558.0951	0.0018
4	3	115	47.3700	78.9658	9.0696	716.1854	0.0930	849.0858	0.0012
5	4	55	19.2000	32.0064	18.9636	606.9577	0.0355	902.2345	0.0011
6	5	40	10.0000	16.6700	26.0750	434.6703	0.0211	790.3096	0.0013
7	6	33	3.8100	6.3513	31.6061	200.7386	0.0144	441.6250	0.0023
8	7	30	3.8100	6.3513	34.7667	220.8125	0.0115	552.0313	0.0018
9	8	27	2.0530	3.4224	38.6296	132.2042	0.0086	396.6125	0.0025
10	9	26	1.3850	2.3088	40.1154	92.6182	0.0077	301.0092	0.0033
11	10	24	1.3850	2.3088	43.4583	100.3364	0.0058	401.3456	0.0025
12	20	20	0.2666	0.4444	52.1500	23.1766	0.0019	231.7663	0.0043
13	30	19	0.0526	0.0877	54.8947	4.8134	0.0010	91.4547	0.0109
14	40	18	0.0526	0.0877	57.9444	5.0808	0.0000	-	-
15	50	18	0.0526	0.0877	57.9444	5.0808	0.0000	-	-

$$A = Q_0 C_0 \left(\frac{\left(\frac{1}{C}-\frac{1}{C_u}\right)}{u_c}\right)_{max} = 6.73 \text{ m}^2 \qquad (5)$$

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

$$Q_u = Q_0 \frac{C}{C_u} = 0.1 \times \frac{4.485}{45.7917} \times \frac{1}{60} = 1.633 \times 10^{-3} \text{ m}^3/\text{s} \qquad (6)$$

$A = \frac{\pi D^2}{4}$ = 6.73 m^2

D = 2.93 m

H = D × (H/D ratio)

H = 2.93 × 3.26 = 9.55 m

Table 3: Settling Characterization of slurry obtained by electrocoagulation of DS at pH 8

S. No.	Time, min	Height, mm	u_c, mm/min	$u_c \times 10^{-5}$, m/s	C, kg/m^3	Sedimentation flux, ($u_c \times C$) $\times 10^{-5}$, kg/m^{2}s	$\left(\frac{1}{C}-\frac{1}{C_u}\right)$ = X, m^3/kg	$\frac{u_c}{\left(\frac{1}{C}-\frac{1}{C_u}\right)} \times 10^{-5}$, kg/m^{2}s	$\frac{\left(\frac{1}{C}-\frac{1}{C_u}\right)}{u_c} \times 10^5$, m^{2}s/kg
1	0	245	-	-	4.4857	-	0.2011	-	-
2	1	220	36.6600	61.1122	4.9955	305.2833	0.1783	342.6649	0.0029
3	2	180	36.6600	61.1122	6.1056	373.1241	0.1419	430.5277	0.0023
4	3	130	39.0000	65.0130	8.4538	549.6099	0.0965	674.0498	0.0015
5	4	75	47.0000	78.3490	14.6533	1148.0740	0.0464	1688.3436	0.0006
6	5	55	33.1370	55.2394	19.9818	1103.7832	0.0282	1958.3240	0.0005
7	6	48	11.7140	19.5272	22.8958	447.0924	0.0218	894.1841	0.0011
8	7	43	4.2000	7.0014	25.5581	178.9428	0.0173	404.9753	0.0025
9	8	41	4.2000	7.0014	26.8049	187.6717	0.0155	452.6195	0.0022
10	9	38	2.5000	4.1675	28.9211	120.5285	0.0127	327.1483	0.0031
11	10	36	2.5000	4.1675	30.5278	127.2245	0.0109	381.6730	0.0026
12	20	28	2.5000	4.1675	39.2500	163.5744	0.0036	1145.0156	0.0009
13	30	25	0.5880	0.9802	43.9600	43.0894	0.0009	1077.2166	0.0009
14	40	24	0.2500	0.4168	45.7917	19.0837	0.0000	-	-
15	50	24	0.2500	0.4168	45.7917	19.0837	0.0000	-	-

At pH 9

The concentration of the solids required in the underflow C_u, for the treated effluent was evaluated to be 53.2857 kg/m^3 and the maximum value of $\left(\frac{\left(\frac{1}{C}-\frac{1}{C_u}\right)}{u_c}\right)_{max}$ was 700 m^{2}s/kg. Assuming a feed rate of Q_0 = 1 m^3/min for C_0 = 6.0898 kg/m^3, the area of the sedimentation tank was calculated as below[12,4]

$$A = Q_0\, C_0 \left(\frac{\left(\frac{1}{C}-\frac{1}{C_u}\right)}{u_c}\right)_{max} = 71.05 \text{ m}^2 \quad (7)$$

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

$$Q_u = Q_0 \frac{C}{C_u} = 0.1 \times \frac{6.0898}{53.2857} \times \frac{1}{60} = 1.905 \times 10^{-3} \text{ m}^3/\text{s} \quad (8)$$

$A = \frac{\pi D^2}{4}$ = 71.05 m^2

D = 9.51 m

H = D × (H/D ratio)

H = 9.51 × 3.26 = 31.01 m

Table 4: **Settling Characterization of slurry obtained by electrocoagulation of DS at pH 9**

S. No.	Time, min	Height, mm	u_c, mm/min	$u_c \times 10^{-5}$, m/s	C, kg/m^3	Sedimentation flux, ($u_c \times C$) $\times 10^{-5}$, kg/m^{2}s	$\left(\frac{1}{C} - \frac{1}{C_u}\right)$ = X, m^3/kg	$\frac{u_c}{\left(\frac{1}{C}-\frac{1}{C_u}\right)} \times 10^{-5}$, kg/m^{2}s	$\frac{\left(\frac{1}{C}-\frac{1}{C_u}\right)}{u_c} \times 10^5$, m^{2}s/kg
1	0	245	-	-	6.0898	-	0.1454	-	-
2	1	230	55.2600	92.1184	6.4870	597.5682	0.1354	680.3994	0.0015
3	2	170	55.2600	92.1184	8.7765	808.4746	0.0952	967.8922	0.0010
4	3	105	35.0000	58.3450	14.2095	829.0547	0.0516	1130.5292	0.0009
5	4	78	10.5900	17.6535	19.1282	337.6803	0.0335	526.7814	0.0019
6	5	66	10.5900	17.6535	22.6061	399.0768	0.0255	693.1335	0.0014
7	6	58	4.6600	7.7682	25.7241	199.8308	0.0201	386.3396	0.0026
8	7	56	3.4200	5.7011	26.6429	151.8947	0.0188	303.7894	0.0033
9	8	52	3.4200	5.7011	28.6923	163.5789	0.0161	354.4210	0.0028
10	9	49	3.4200	5.7011	30.4490	173.5939	0.0141	405.0526	0.0025
11	10	46	3.4200	5.7011	32.4348	184.9152	0.0121	472.5614	0.0021
12	20	40	0.7250	1.2086	37.3000	45.0798	0.0080	150.2663	0.0067
13	30	33	0.7250	1.2086	45.2121	54.6422	0.0034	360.6393	0.0028
14	40	30	0.1142	0.1904	49.7333	9.4678	0.0013	142.0176	0.0070
15	50	28	0.0161	0.0268	53.2857	1.4301	0.0000	-	-
16	60	28	0.0161	0.0268	53.2857	1.4301	0.0000	-	-

Conclusions

From the studies following conclusions can be drawn. The filtration and settling process could be applied to separate sludge and supernatant from the slurry obtained after electrocoagulation of DS. The cake resistance was found to less to that of filtration of biologically treated MWW. In present study filtration cake resistance was found to 16.06×10^{12}, 21.98×10^{12} and 11.28×10^{12} m/kg at pH 7, 8 and 9 respectively. The settling was also found to good gave 70% settling in 5 min. Settling rate was in order of pH 7 > pH 8 > pH 9. The EC at 2A and 6 plate configuration was found to best, gave COD value of DS 62 mg/dm^3 from initial value 288 mg/dm^3. The EC followed by settling can be applied successfully to treat DS.

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