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Analysis of Sludge Settling and Rising Behavior in Sewage Treatment Plant in Kuwait

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Abstract: All wastewater treatment plants in Kuwait utilize the activated sludge processes in the removal of organic matter and nutrients from domestic sewage. The efficiency of solid liquid separation in the activated sludge system is determined by the ability of sludge constituents to remain flocculated and to settle fast. In Kuwait's wastewater treatment plants, solids separation problems may occur in activated sludge system, such as bulking sludge, which affects the quality of the secondary effluent. The main aim of this paper is to study and analyze sludge settling and rising behavior in the activated sludge process of Jahra sewage treatment plant. The results indicated that clarifier effluent has significant suspended solids carry-over, which is eventually removed in the sand filtration process. In addition, test results showed poor settlement of clarifier sludge. The poor sludge settling is related to insufficient oxygen level in the aerators. Suggestions were made to raise oxygen level particularly in the aeration unit.

Key words: Sludge, sewage, treatment, carry-over.

1. Introduction

Discharge of untreated wastewater directly to the environment, will cause pollution of the receiving waters and spread of waterborne diseases. In the early years of the twentieth century the method of biological treatment was invented, and nowadays forms the basis of wastewater treatment worldwide [1]. In Kuwait and because of severe environmental impact of dumping wastewater into sea, several wastewater treatment plants have been constructed and operated since 1968 [2]. In recent years, treatment of wastewater in Kuwait has become essential not only for environmental protection of aquatic ecosystem but also for augmenting limited water resources by reusing of treated wastewater [3]. The collected sewage in Kuwait is treated in four main wastewater treatment systems located at Um-Alhaiman, Sulaibiya, Riqqa and Jahra. The sewage treatment plants in Kuwait generally employ the activated sludge treatment process. In this process, the microorganisms metabolize and transform organic and inorganic substances into environmentally acceptable forms, and they proliferate and grow as flocs [4]. These flocs are allowed to settle to the bottom of the tank, leaving a relatively clear water free of organic material and suspended solids. Many problems can develop in conventional sewage plants especially in the activated sludge operation that adversely affect the final effluent quality [5]. Sludge bulking and rising are common and serious problems in activated sludge operation, which affect most activated sludge plants at one time or another. Sludge rising or bulking usually occurred in an activated sludge plants when the sludge does not settle easily and has an excessive volume. Poor sludge settling is due to the excessive proliferation of filamentous bacteria, foaming due to growth of certain microorganisms and poor flocculation properties of the microorganisms [4]. This can lead to carry over from the final effluent clarifies. A bulking sludge is usually characterised by a sedimentation rate of less

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than 0.3 m/h, or an SVI (Sludge Volume Index) of above 150 mL/g [6]. The aim of this study is to investigate sludge settling behavior in the aerator tank and common observations such as floating sludge in clarifier and high average SVI in Jahra wastewater treatment plant.

2. Jahra Sewage Treatment Plant

The Jahra sewage plant is located at the northwest of Kuwait city and adjacent to Jahra satellite town. It started operation in 1983 with an average design capacity of 86,000 m^3/d. Present inflow is 65,000 m^3/d. The plant consists of EASP (Extended-Aeration Sludge Process) with clarifier, and tertiary treatment. As it has no primary clarifiers, raw wastewater flows directly from the preliminary treatment (coarse screening and grit removal) level to EASP units and then to the tertiary treatment units. The sludge is wasted from the aeration basins and thickened in a sludge gravity thickener. The thickened sludge is wasted and is applied on drying beds for drying and subsequent disposal. A schematic diagram of unit processes of Jahra sewage plant is shown in Fig. 1.

Table 1 presents the technical data of the sludge treatment processes of Jahra wastewater treatment plant.

3. Materials and Methods

In this study, samples were collected once in each week from designated locations for 12 months starting from May 2004 and ending in April 2005. Samples were collected from three critical points representing the performances of the unit processes. The sample points as shown in Fig. 1:

- Aeration tank effluent line (sample point 1);
- Return sludge line (sample point 2);
- Thickener wastage sludge line (sample point 3).

All parameter determinations in the laboratory were performed according to the Standard Methods. Both chemical and biological analyses were carried out at the laboratories of the DRP (Doha Research Plant) and at Sulaybiya Wastewater Research Plant. The methods

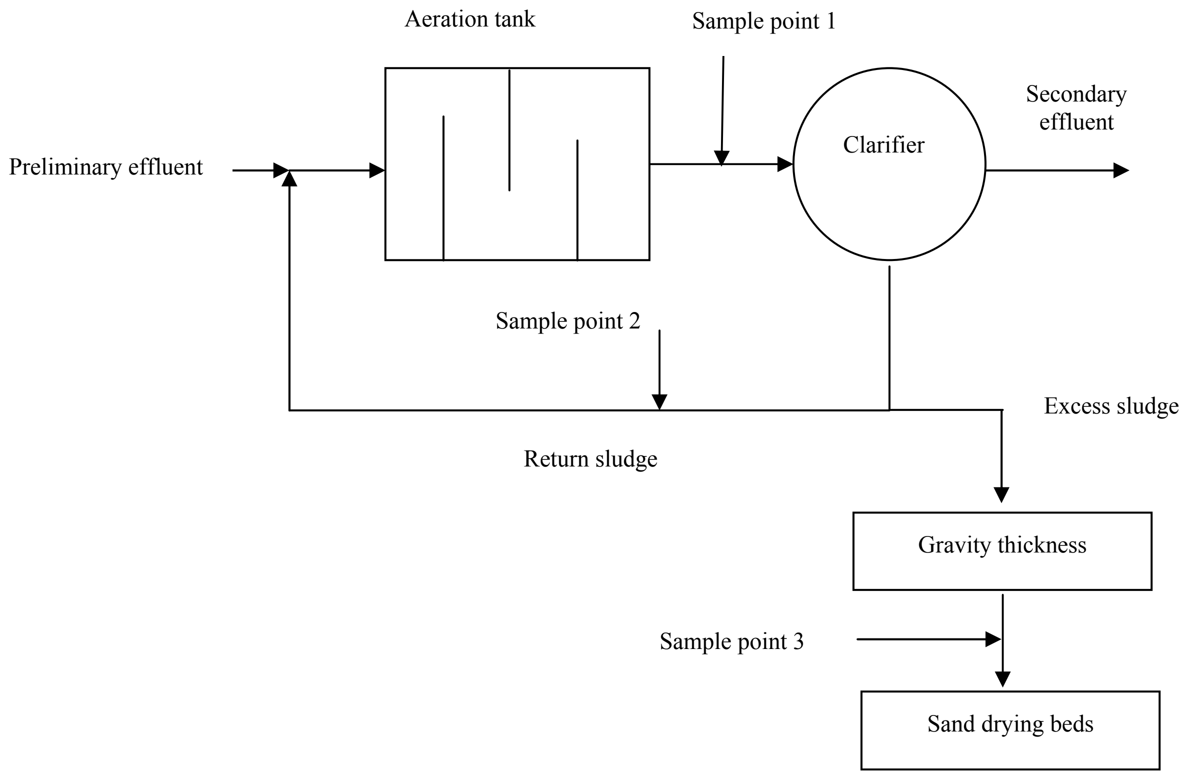

Fig. 1 Schematic diagram of extended aeration sludge process in Jahra sewage plant.

Table 1 Technical data of unit processes of Jahra sewage treatment plant.

Equipment	Unit	Description
Return sludge screw lift station		
Type		Open screw-Type
Number each	4	
Diameter	mm	1,600
Lift	m	5.6
Capacity	m^3/d	86,000
Motor	kW	50
Sludge thickeners		
Type		Circular, with full scraper and central
Number of units		2
Diameter	m	1.5
Sidewall depth	m	3.7
Surface area per unit	m^2	284
Volume per unit	m^3	727
Total surface area	m^2	567
Total volume	m^3	1,455
Sludge drying beds		
Type		Evaporation/percolation
Number of beds		3
Cells per bed		10
Cell Size:		
Length	m	25
Width	m	15
Surface area per cell	m^2	375
Total area, 4 beds	m^2	15,000

used in analyzing the chemical and biological parameters were according to the standard methods for the examination of water and wastewater [7]. In addition, sludge samples were collected for settling tests. In this test, one sludge sample from sludge recycle line was tested for determining the settling characteristics of sludge. The results are used to understand the sludge settling and rising behavior in activated sludge system, in addition, guide the operators to control the clarifier bottom-sludge recycle functions and compare the operating loadings with typical loading guidelines of similar clarifiers.

4. Results and Discussion

4.1 Activated-Sludge Settling in Clarifier

The clarifier performance with respect to solids separation through solids compaction is shown in Table 2. Important parameter is clarifier bottom TSS (Total Suspended Solids) which when compared with aerator effluent TSS, indicates sludge compaction factor in the clarifier. Average TSS in recycle sludge was recorded to be 6,114 mg/L when maximum and minimum values are 8,260 and 2,720 mg/L respectively. When the values are compared with those of clarifier-inflow (aerator-effluent) as presented in Table 3, the sludge compaction factor is about 1.5, which is very low when compared to expected value of 2-3 [8, 9].

Four main observations such as occasional high carry over of TSS with clarifier effluent, low average sludge TSS concentration of 6,114 mg/L in clarifier underflow (Table 2), floating sludge in clarifier (as shown in Figs. 2 and 3) and high average SVI (≥ 150 mL/g) indicated that the settling of sludge in the aerator has some problem. It is not performing at normal solid-liquid separation at desired levels of sludge-compaction. The loading rates in Jahra clarifier in sludge mass and hydraulic flow are about 1.9 $kg \cdot m^{-3}$ and 9.85 $m^3 \cdot m^{-2} \cdot d^{-1}$ at flow rate of 67,000 m^3/d and 4,660 g/m^3 (mg/L). Jahra plant is an extended aeration system. The expected ranges of mass and hydraulic loadings are 1-5 $kg/m^3/d$ and 8-16 $m^3/m^2/d$ respectively. Therefore, the loadings are normal and there should not be any reason for poor sludge settling.

Table 2 Statistical summary of Jahra recycled sludge quality (Data point 5).

Parameter	Average	Std. dev.	Max	Min
Temperature (°C)	28.4	4.4	34	21
BOD (Biochemical Oxygen Demand)				
TSS	6,114	1,147	8,260	2,720
VSS (Volatile Suspended Solids)	2,637	668	3,960	800
TDS (Total Dissolved Solids)	1,352	165	1,650	1,030
Total N	30.1	3.1	32.3	27.9
PO_4	13.3	8.6	28	1.9
pH (unit)	7.4	0.14	7.6	7.1
Chloride	268	65	380	130
Oil & grease	14	5	28	6
Alkalinity as $CaCO_3$	514	229	800	150
SO_4	400	118	650	190
Sulfide	0.3	0.39	1.2	0.03

All concentrations in mg/L or as indicated.

Table 3 Statistical summary of Jahra aerator effluent quality.

Parameter	Average	Std. dev.	Max	Min
TSS	3,917	779	5,560	1,960
VSS	1,616	371	2,415	590
TDS	1,392	235	2,500	1,020
Total N	23.9	5.7	30.4	16.5
Org. N	5.4	1.2	6.9	3.9
NH_3	13	2.4	15	9.6
Nitrite N	0.8	0.7	2.4	0.4
Nitrate N	5.1	3.3	12	2.1
PO_4	21	5.7	32	12.5
Alkalinity as $CaCO_3$	437	186	660	140
Temp. °C	30.1	2.78	35	22
pH (unit)	7.4	0.2	7.8	7
SO_4	421	120	630	200
Sulfide	0.6	0.5	2.4	0
Chloride	267	52	320	150
O_2	0.8	0.7	4	0.3
Oil & grease	18.4	9.3	56	7

All concentrations in mg/L or as indicated.

Other possible causes may be bulking sludge, rising sludge and trapped gas bubbles in sludge. These factors along with possible remediation should be studied further to device corrective measures. With a poor settling or bulking sludge, solids carryover in the effluent will contribute to higher effluent. Poor sludge compaction will result in a low concentration of return sludge solids, which in turn will limit the concentration of MLSS (Mixed Liquor Suspended Solids) that can be maintained in the aeration basin.

4.2 Settling of Inflow Suspended Solids

Aerator effluent data as shown in Table 3 indicated average TSS and VSS concentrations of 3,917 and 1,616 mg/L respectively. Volatile suspended solids are about 41% of total suspended solids. The fraction in typical activated sludge is between 60-75%. It indicates somehow in the system inorganic fraction is building up. One of the causes may be the absence primary sedimentation tank in the system. Removal of inflow settleable solids in primary sedimentation prior to aerator would assist to raise the TSS/VSS ratio.

4.3 Sludge Thickener

Table 4 contains the statistical summary of long-term weekly measurements of wastes sludge from sludge thickener unit. Average TSS concentration in thickener bottom-sludge is 17,576 mg/L when maximum and minimum values are 31,100 mg/L and 4,960 mg/L respectively. When compared with inflow TSS of 3,917 mg/L (average), the compaction factor is about 4.5. Average compaction is normal. Average, maximum and minimum values of total-N are 22.1, 23.5 and 20.6 mg/L respectively. The content of total N in sludge does not fluctuate significantly. Nitrogen and PO_4 levels indicate significant fertilizer value of the wasted sludge.

Table 4 Statistical summary of wastage sludge quality (Data point 6).

Constituent	Average	Std. dev.	Max	Min
Flow (m^3/d)	709	337	1,240	20
TSS	17,576	7,037	31,100	4,960
VSS	8,059	3,255	14,310	1,820
TDS	1,272	139	1,550	1,060
Total N	22.1	2.1	23.5	20.6
NH_3	9	4.2	12	6
PO_4	14.1	9.3	31	2.1
pH	7.3	0.1	7.7	7
Coliform, colony/100 mL	10×10^7	6×10^7	18×10^7	4×10^7
F. coliform, colony/100 mL	3.7×10^6	3.3×10^6	9×10^6	0.6×10^6

All concentrations in mg/L or as indicated.

4.4 Sludge Settling Test

SVI is usually measured of aerator effluent to test the settleability of sludge. It indicates the sludge settlement behavior in the clarifier. The test is performed for a 30-minute sludge settlement in a cylinder or cone and the result is expressed as gram-mass of settled sludge per milliliter volume of settled sludge. The index value ranging between 40 and 120 mL/g indicates excellent settleability. Eight SVI values determined at separate occasions had an average of 150 mL/g with maximum and maximum of 200 and 125 respectively. In addition, physical appearance of the Jahra clarifiers (Fig. 2) shows lots of floating sludge indicating rising sludge characteristics. These observations prompted the investigators to carry a sludge settlement test in laboratory for longer duration with variable concentrations of initial sludge-solid contents. Sludge settling test apparatus is shown in Fig. 3. Subsidence rate of sludge-blanket (interface of sludge and top clean-water) with time was measured at various times. Collected data along with calculated linear blanket subsidence-velocity and solids flux due to gravity are shown in Table 5.

SVI is defined as the volume in milliliters occupied by one gram of activated sludge after a one-liter mixed liquor sample has been allowed to settle in a graduated cylinder for a period of 30 minutes, or

$$SVI\ (\frac{ml}{g}) = \frac{setlled\ sludge\ volume,(\frac{ml}{l})}{suspended\ solid\ concentraion, mg/l} * \frac{1000mg}{g}$$

Fig. 2 Floating sludge in clarifier.

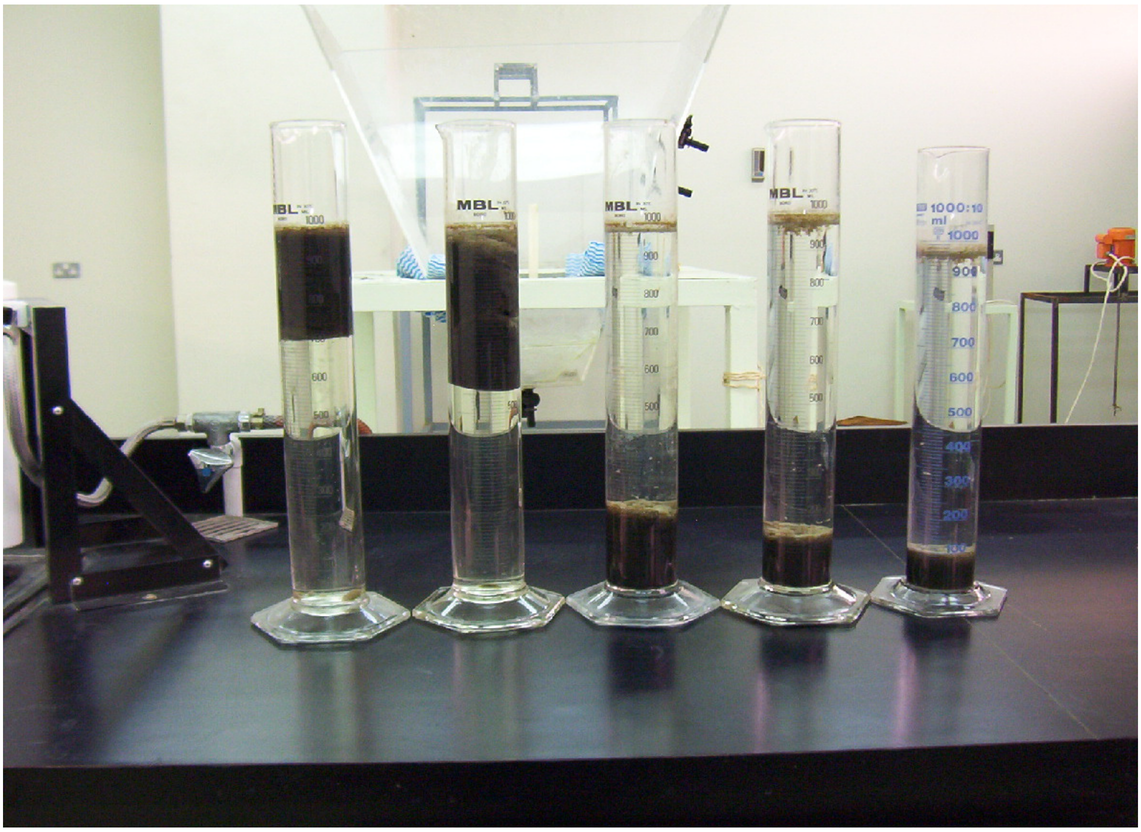

Fig. 3 Cylinder tests for secondary sludge settlement.

Table 5 Sludge balnket settlement with time and gravitational solids flux.

MLSS Concentration (g/m^3)	Time of Settlement (min)	Sludge blanket depth from water surface (cm)	Linear velocity of blanket settlement (m/h)	Solids gravity flux ($kg/m^2/h$)
15,345	60	14.5	0.14	2.15
10,200	60	24.3	0.24	2.45
5,830	20	24	0.72	4.2
4,660	15	31.5	1.3	6.06
3,490	5	26.3	3.15	11
1,400	5	30	3.6	5.26

SVI value is an important indicator of sludge settlement. SVI values were consistently found to be above 150 mL/g. The SVI values of good settling sludge range from 40 to 120 mL/g. [9]. Though it is not an absolute test for classifying poor settlement, however, its consistent higher values have significance. Sludge bulking and rising were noticed in the laboratory tests within 24 h of retention (Fig. 3). Two anticipated causes for floating sludge are Rising sludge and Bulking sludge.

4.5 Rising Sludge

Occasionally sludge that has even good settling characteristics will be observed to rise or float to the surface after a relatively short settling period. The causes of this phenomenon are denitrification. Nitrogen gas produced in the process makes the sludge mass buoyant causing sludge rise. In extended aeration process such as Jahra, a significant portion of nitrogen is converted to nitrate. Long period of detention of sludge in the clarifier is prone to generating such gas. From the observation of floating sludge in the clarifiers, gas entrapment remains to be a viable cause. Rising sludge problem can be overcome by:

1. Increasing sludge recycle rate from the bottom of the clarifier.
2. Decreasing the rate of inflow into the offending tank provided sludge depth could not be reduced by increasing recycle rate.
3. Decreasing the mean cell residence time (sludge retention time in the process) by increasing the sludge wastage rate.
4. Gentle stirring to release the trapped gas bubbles.

4.6 Bulking Sludge

A bulked sludge is one that has poor settling characteristics and poor compaction. From the measured suspended solids in the recycle line, Jahra plant has poor compaction with compaction factor much less than expected. In this respect, sludge can fall in bulking sludge group also. However, as mentioned earlier further study exploring all possible causes is necessary to confirm the major cause(s). Main causes of sludge bulking include fluctuations in flow and waste strength, pH, temperature, staleness, nutrient content and nature of wastewater components. The Jahra plant is operating at its average design conditions. Therefore, design limitations are not expected to be a major factor. Plant operation should be checked for maintaining proper oxygen level in aerator, recycle flow according to inflow conditions and overall cleanliness of channels and tanks to keep them free of grease accumulation, algae growth, scum accumulation etc. Nitrogen and phosphorus levels in the aerator tank appear to be normal (Table 3). However, if industrial waste is introduced intermittently, nitrogen and phosphorus levels should be carefully checked. They may favor certain type of bacterial growth such as algae making imbalance in bacterial population distribution in the process. Algae has poor settling behavior. The region's high ambient temperature and sunny conditions favor algae growth. Limited dissolved oxygen is more frequently noted than any other cause for sludge bulking. The data collected on oxygen level in the aerator are consistently around 0.5 mg/L. It is expected to be in between 1-2.5 mg/L. Therefore, it is recommended that under the conditions, to confirm whether the oxygen level is the cause, the blowers should be operated at full capacity to maintain at least 2 mg/L oxygen. Operating the system under this condition for a while and observing sludge settling characteristics simultaneously may confirm oxygen deficiency as one of the causes. If this level of oxygen cannot be maintained, the solution to the problem may require the installation of additional blowers.

5. Conclusion

Clarifier has the tendency of carrying over suspended solids occasionally, which may create increased maintenance problem of subsequent tertiary units such as sand filter. Secondary sludge was found to have poor settling characteristics creating problems of floating sludge in the clarifier and relatively low solids concentration in the clarifier bottom sludge. A primary sedimentation tank is essential to reduce the existing suspended solids in aerator.

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