Influence of Different Chlorine Injection Methods on the Filamentous Bulking Problem

Salem. Salem, Medhat. Mostafa, and Walid. Ibrahim

***Abstract*—** Although the extensive researches that have been done on sludge bulking, it still occurs world-wide. Chlorine is one of the most popular methods used to control filamentous bulking phenomena. This research was executed in activated sludge plant which was subjected to filamentous bulking problem because of high sludge retention time (SRT) and low DO concentration. This work aims to study the effect of chlorine injection on bulking problem, microorganisms, filamentous organisms and plant performance. The chlorine was injected in three different scenarios. In the first scenario, the doses of chlorine were 1.0, 2.0 and 7.0 mg/lit added continuously. In the second & third scenarios, the chlorine dose of 1.0 mg/lit was added regularly in six batches per day and one time injection respectively. In all scenarios, the chlorine was added to the returned sludge at its inlet to the aeration tank. In all previous scenarios, there were similarity and dissimilarity points between them.

The similarity points between scenarios were: the chlorine has successfully controlled bulking problem, SVI values decreased to about 80 ml/gm, both of SS & BOD removal efficiencies increased after chlorine injection and MLSS, MLVSS and SSReturn decreased during chlorine injection, while their values increased again after chlorine injection. The dissimilarity point between scenarios was the influence of chlorine on MLSS & MLVSS which varied from one scenario to another.

***Keywords*—** Filamentous Bulking, chlorine, SRT.

I. Introduction

THE activated sludge process is the most commonly used technology for biological wastewater treatment. However, filamentous bulking is one of the drawbacks of the activated sludge plants [1]. Filamentous bulking problem occurs when one or more environmental conditions encourage filamentous organisms' development (low DO, low pH, low F/M, septic wastes, high sludge age and nutrient deficiency). They become the predominant organisms. When this occurs, filamentous organisms cause poor sludge settling, sludge settles more slowly than normal sludge, and increases the value of sludge volume index (SVI) (SVI > 120 ml/gm) [2]. Despite small presence of filamentous microorganisms is an essential part of the floc population in the activated sludge process. The filaments form the backbone to which floc-forming bacteria adhere [3]. Many filamentous bacteria are not available in pure cultures, preventing a detailed study of these organisms [4].

Chlorine is one of the oldest disinfection agents used [5]. Although chlorine is a very potent inactivating agent of filamentous microorganisms, it is not selective, affecting floc-forming organisms as well [6]. Chlorine solution must be added in a point with an excellent initial mixing. Without excellent initial mixing, a large part of the RAS might not be contacted by the chlorine while a small part of the RAS might be overdosed [7].

Lakay et al. [8] reported doses of 8 $mgCl_2\ (gVSS)^{-1}$ to control filamentous bulking, while Jenkins et al. [7] recommended doses between 1 and 15 $mgCl_2\ (gVSS)^{-1}$ [1]. Jenkins presented sludge chlorination as a method of choice in the United States to combat filamentous bulking. They reported several case histories of successful control of bulking at full-scale treatment plants using chlorine and described the method as a "universal success" with any filamentous bacteria. Madoni et al. [9] reported in a survey in Italy that using of chlorination was successful in only 63% of the cases [10].

II. Plant Layout

This study was conducted on Edko wastewater treatment plant (WWTP) which works with activated sludge system. The plant was designed to treat a maximum flow of 20000 m^3/day of municipal wastewater. After preliminary treatment, the influent wastewater is divided into 4 similar lines. Each line consists of primary circular sedimentation tank followed by aeration tank and final circular sedimentation tank. Each aeration tank contains three surface aerators. During the study, line no (3) was out of service due to the annual maintenance. The plant also contains two wet well which receive return sludge from the final clarifier. Each well receive return sludge from two lines, line 1 & 2 are connected and line 3 & 4 are also connected.

III. Experimental Work

The plant was monitored from 19 April to 10 July 2010, this period was classified into three phases:-

i. The first phase (before chlorine injection from 19 April to 4

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June 2010) aims to find out the factors which caused filamentous bulking problem.

ii. In the second phase (during chlorine injection from 5 June to 23 June 2010): the chlorine was injected into the aeration tanks in three different scenarios "Fig. 1". The influence of different chlorine injection methods & doses in all scenarios was investigated via the following parameters:Sludge settleability (SV & SVI), Microorganisms (measured as MLSS) and Filamentous organisms.

iii. The third phase: general evaluation of the study.

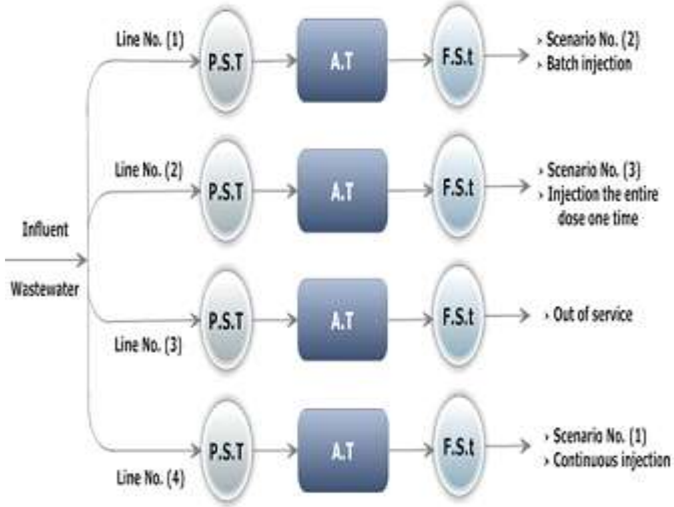

Fig. 1 Distribution of chlorine injection scenarios on aeration tanks.

A. The First Phase: Factors Responsible for the Filamentous Bulking Problem

Each one of DO concentration, F/M ratio, pH value, sludge retention time, nutrient deficiency and presence of septic wastes were investigated to know the parameter or parameters which are responsible for filamentous bulking problem. Do concentrations were about 0.8 mg/lit because the middle surface aerator was stopped due to defect. SRT values were investigated for all aeration tanks, and their values in tank no (1) ranged from 11 to 26 d, while their values in tank No. (2) were from 8 to 29 d, whereas the sludge age values in tank no (4) were from 13 to 27 d. The common value for the conventional activated sludge is between 5 to 8 days [11]. The rest parameters were in the allowable ranges. Consequently, low DO concentration and high SRT were the responsible parameters for filamentous bulking problem.

B. The Second Phase: Scenarios of Chlorine Injection

Two strategies were employed to control filamentous bulking problem. In the first strategy, DO concentration and sludge age were adjusted according to specifications and recommendations. DO concentration was controlled to be between 2.0 to 3.0 mg/lit (Metcalf & eddy, 2004) by repairing the middle surface aerator. While, Sludge age value was adjusted between 5 to 8 days (Metcalf & eddy, 2004).

In the second strategy, chlorine was used to control filamentous bulking problem. Powder calcium hypochlorite was used to control filamentous bulking problem. Calcium hypochlorite contains about 65% available chlorine. The solution is prepared by mixing calcium hypochlorite powdered with a small flow. The conventional method of water purification used calcium hypochlorite. Consequently, calcium hypochlorite has purification properties [12].

1. Injection Scenarios

The chlorine was injected to the return activated sludge pipe at its inlet to the aeration tank. The main two parameters that change from one scenario to another are injection type and the chlorine injection doses.

i. 1st scenario: 1.0, 2.0 & 7.0 mg/lit chlorine doses were used as incremental dosing in this scenario. The constancy of SV values was the reason of increasing chlorine dose from 1.0 mg/lit to 2.0 mg/lit to decrease the SV value as shown in table 1, while the dose of chlorine was increased from 2.0 mg/lit to 7.0 mg/lit for two reasons. Firstly, the SV values were slowly decreased as shown in table 1. So, a higher dose of chlorine was used to make a rapid reduction in the SV value. Secondly, the dose of chlorine was sharply increased to investigate the influence of high chlorine dose on SV value, SVI value, microorganisms' concentration and SS concentration in the return sludge.

ii. 2nd scenario: 1mg/lit chlorine dose was used. The entire daily quantity was divided into six doses to be regularly injected each four hours in the aeration tank.

iii. 3rd scenario: 1mg/lit chlorine dose was used. The entire daily quantity was injected one time to the tank.

2. Comparison between the Influence of Chlorine Injection on the Sludge Settleability (SV & SVI) in the Different Scenarios

The influence of chlorine injection on SV & SVI is similar in all scenarios (fig 2). As stated before, the behavior of SVI value passed through 4 stages during and after chlorine injection.

i. In the first stage: The SVI values increased because the injected chlorine did not affect the SV values while chlorine injection reduced MLSS concentration (fig 2).

ii. In the second stage: The SVI values decreased because of a great reduction of SV values. The SV values decreased due to the effect of chlorine which was added in a form of calcium hypochlorite which has the ability to purify the water by gathering the flocs (calcium hypochlorite works as a coagulant) [12].

iii. In the third stage: The SVI values increased again. In this stage the flocs were small, spherical, compact, and relatively weak. Such flocs take long time to settle.

iv. In the fourth stage: The SVI values decreased again. The size of the flocs in this stage increased because the floc-forming bacteria began to collect floc. So, it settled well.

Although the chlorine dose of 1 mg/lit was used in all scenarios, but its influence varies from one scenario to another because of the difference between injection methods. In the first scenario where the chlorine was injected continuously in tank no (4), the effect of chlorine on MLSS was the lowest (about 3.7%). While in the second scenario where the chlorine was injected on batches in tank no (1), the chlorine had medium influence on the MLSS concentration (6.5%). While in the third scenario where the whole dose of chlorine was injected one time in the aeration tank no (2), the chlorine had the most influence on the MLSS (10.7%) as shown in Table 2.

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TABLE I
THE VALUES OF CL2 DOSE, SV, SVI & MLVSS REDUCTION PERCENTAGE DURING THE CHLORINE INJECTION FOR AERATION TANK NO. 4

Time	CL_2 dose	SV value	SVI value	MLVSS concentration	% MLVSS reduction	
	mg/lit	ml/lit	ml/gm	mg/lit		
4/6/2010	0	960	218	3700	-----	
5/6/2010	1	980	228	3500	-----	
6/6/2010	1	950	235	3300	5.7	
7/6/2010	1	950	250	3100	6.1	
8/6/2010	1	950	257	3000	3.2	
9/6/2010	1	950	264	2950	1.7	
10/6/2010	1	950	271	2850	3.4	
11/6/2010	1	950	279	2750	3.5	
12/6/2010	1	950	288	2700	1.8	**Ave.= 3.6%**
13/6/2010	2	870	300	2400	11.1	
14/6/2010	2	750	300	2050	14.6	
15/6/2010	2	600	273	1800	12.2	
16/6/2010	2	530	265	1650	8.3	**Ave.= 11.6%**
17/6/2010	7	310	182	1400	15.2	
18/6/2010	0	280	147	1450	-----	
19/6/2010	7	180	106	1250	13.8	
20/6/2010	7	140	97	1100	12.0	
21/6/2010	0	140	83	1400	-----	**Ave.= 13.6%**

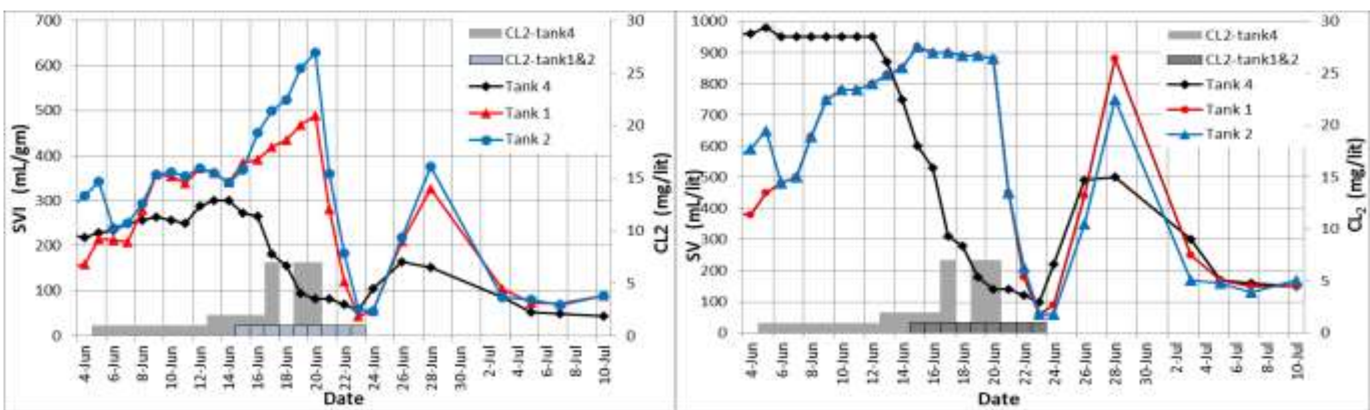

Fig. 2 SVI & SV Values for all Aeration Tanks

3. Comparison between the Influence of Chlorine Injection on microorganisms in the Different Scenarios

Although the chlorine dose of 1 mg/lit was used in all scenarios, but its influence varies from one scenario to another because of the difference between injection methods. In the first scenario where the chlorine was injected continuously in tank no (4), the effect of chlorine on MLSS was the lowest (about 3.7%). While in the second scenario where the chlorine was injected on batches in tank no (1), the chlorine had medium influence on the MLSS concentration (6.5%). While in the third scenario where the whole dose of chlorine was injected one time in the aeration tank no (2), the chlorine had the most influence on the MLSS (10.7%) as shown in Table 2.

From the above, it can be concluded that the continuous injection is the best injection method, while the batch injection method can be used if there was a difficulty in the supply or execution of continuous method. While the injection of the whole dose of chlorine one time caused a huge reduction in MLSS concentration in comparison with the earlier two cases. The misgiving and objection on the previous third method

TABLE II
MLSS CONCENTRATIONS AND THEIR REDUCTION PERCENTAGE VALUES DURING CHLORINE INJECTION FOR ALL SCENARIOS

Time	Tank 1&2	Tank 1 (injection on batches)		Tank 2 (injection the whole dose one time)	
	CL_2 mg/lit	MLSS mg/lit	% MLSS reduction	MLSS mg/lit	% MLSS reduction
15-Jun	1	2400	-----	2500	-----
16-Jun	1	2300	-4.2	2000	-20.0
17-Jun	1	2150	-6.5	1800	-10.0
18-Jun	1	2050	-4.7	1700	-5.6
19-Jun	1	1900	-7.3	1500	-11.8
20-Jun	1	1800	-5.3	1400	-6.7
21-Jun	1	1600	-11.1	1250	-10.7
22-Jun	1	1500	-6.3	1150	-8.0
23-Jun	1	1400	-6.7	1000	-13.0
			Ave.=-6.5%		**Ave.=-10.7%**

Time	Tank 4 (continuous injection)			
	CL_2 mg/lit	MLSS mg/lit	% MLSS reduction	
5-Jun	1	4300	-----	
6-Jun	1	4050	-5.8	
7-Jun	1	3800	-6.2	
8-Jun	1	3700	-2.6	
9-Jun	1	3600	-2.7	
10-Jun	1	3500	-2.8	
11-Jun	1	3400	-2.9	
12-Jun	1	3300	-2.9	**Ave.= -3.7%**
13-Jun	2	2900	-12.1	
14-Jun	2	2500	-13.8	
15-Jun	2	2200	-12.0	
16-Jun	2	2000	-9.1	**Ave.= -11.8%**
17-Jun	7	1700	-15.0	
18-Jun	0	1900	-----	
19-Jun	7	1700	-10.5	
20-Jun	7	1450	-14.7	**Ave.= -13.4%**

(injection the whole dose one time) comes from the high losing of MLSS which was result from low chlorine concentration. So, with a high chlorine dose, the rate of MLSS lost will increase dangerously. Consequently, plant startup can occur.

4. Comparison between the Influence of Chlorine injection on filamentous organisms in the Different Scenarios

During all scenarios, photos were daily taken to observe any change in filamentous organisms' density, protozoa presence and flocs size. The influence of chlorine on these factors was similar. The chlorine was successfully used to control the filamentous bulking by destroying filamentous organisms.

As shown in fig. 3, Photo 3.a was taken before chlorine injection which illustrates high density of filamentous organisms with absence of protozoa. Photos 3.b & c were taken during chlorine injection and they shown that protozoa began to appear and filamentous organisms' density began to decrease. Photo 3.d was taken after chlorine injection, it illustrates that protozoa began to increase, filamentous bulking approximately disappeared and flocs size began to increase.

C. The third phase: general evaluation of the study

1. BOD Removal Efficiencies During the Study

BOD removal efficiency passed through three stages:

i. In the first stage (before chlorine injection): The BOD removal efficiency was 88% which is considered low removal efficiency, while the BOD concentration in the effluent was more than the allowable concentration (40 mg/lit) according to Egyptian law no 48 / 1982. These conditions can be related to bulking problem.

ii. In the second stage (during chlorine injection): The BOD removal efficiency decrease to 85% because of the reduction in MLSS concentration due to the toxic influence of chlorine. The BOD concentration in the effluent was also more than the allowable concentration (40 mg/lit).

iii. In the third stage (after chlorine injection): The BOD removal efficiency improved to become 92%. This improvement of BOD removal efficiency can be related to increasing in MLSS concentration. The effluent BOD concentration was lower than the allowable concentration. Consequently improving biological treatment in the plant.

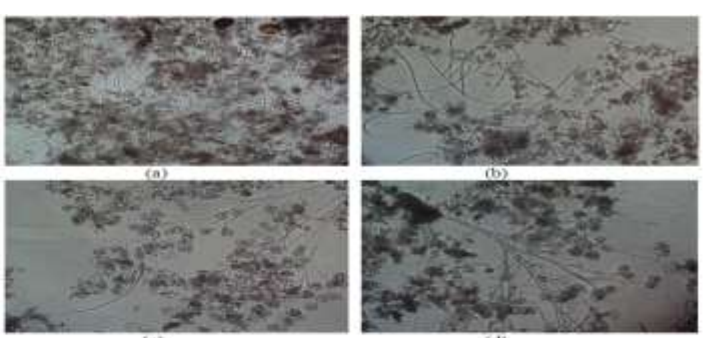

Fig. 3 Microscopic photos illustrate the development stages of floc, protozoa and filamentous organisms during the study (before & after chlorine injection)

2. SS removal efficiencies during the study

SS removal efficiency during the study was be divided into three stages:

i. In the first stage (before chlorine injection): The SS concentration in the effluent was unstable. Sometimes, its concentration lower than the allowable value (60 mg/lit) according to Egyptian law no 48 / 1982 and sometimes higher than the allowable concentration. The percentage of the SS removal efficiency was low (87%).

ii. In the second stage (during the chlorine injection): during this stage most of SS concentrations in the effluent was acceptable, while the SS removal efficiency barely increased 1% to become 88% during chlorine injection. This constancy of SS removal efficiency can be related to continuity the exposure of the plant to bulking problem which associated with increasing in SVI values. During this stage, chlorine was injected to overcome the past conditions.

iii. In the third stage (after chlorine injection): all of the SS concentrations in the effluent were acceptable and the SS removal efficiency improved to become 92%. This improvement of SS removal can be related to the decreasing in SV & SVI values which produced decreasing in sludge level with clear effluent SS.

IV. Conclusions

Based on observing the obtained results, the following points were concluded:

iv. The two factors which encouraged the growth of filamentous organisms in the plant were increasing of sludge age above 8 days and decreasing of DO concentration less than 1.0 mg/lit.

v. Chlorine does not remove the causes of filamentous bulking problem but it kills filamentous organisms in the activated sludge and thus eliminates the symptoms of bulking.

vi. Although the chlorine dose of 1 mg/lit was used in all scenarios, but its influence varies from one scenario to another because of the difference between injection methods.

vii. Continuous injection is the best injection method. while the batch injection can be used if there was a difficulty in the supply or execution of continuous injection. Whereas th\e injection of the whole dose of chlorine one time caused a huge reduction in MLSS concentration. Although, the used chlorine concentration was very low (1.0 mg/lit).

viii. Small chlorine dose is applied to control filamentous bulking problem and their influence on SV, SVI and MLSS must be investigated. If the used dose doesn't achieve the required effect, the dose will be slightly increased.

ix. If a rapid influence is required, a higher chlorine dose must be used regardless of the economical cost.

x. SS removal efficiency was partially weak but acceptable before chlorine injection (during filamentous bulking problem) because of increasing in sludge level in the final clarifier.

xi. SS removal efficiency increased after chlorine injection because of decreasing in SV value which produced decreasing in sludge level with clear effluent SS.

xii. BOD removal efficiency decreased during chlorine injection because of toxic influence of chlorine which destroyed the biomass.

xiii. BOD removal efficiency immediate increased after chlorine injection because of increasing in MLSS and return sludge concentration. Consequently, improving biological treatment.

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