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Influence of External Carbon Source Addition on The Performance of The Modified Contact Stabilization EBPR System

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ABSTRACT: *The overall goal of this study is to investigate the effect of sodium acetate addition, as an external carbon source, on the performance of the modified contact stabilization (MCS) system. The MCT system in an application of Enhanced Biological Phosphorous Removal (EBPR), which involved an additional anaerobic thickener to act as a release zone. Results showed that sodium acetate addition caused a decrease in the biodegradability represented in COD/BOD$_5$ ratio, in the anaerobic thickener as a release zone, to reach five times. Moreover, addition of sodium acetate caused a turbulence in phosphorus release efficiency in the release zone where it reached -96%. It can be concluded that addition of sodium acetate to the anaerobic zone did not improve the performance of the overall system in general and the release efficiency in particular. Results showed the removal efficiencies of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD$_5$) and Total Phosphorus (TP) were 86%, 85% and 59%, respectively.*

Keywords: *Carbon addition, contact stabilization, EBPR, phosphorus release, wastewater treatment*

I. INTRODUCTION

Nutrients removal is a crucial step in wastewater treatment process to protect the discharge receiving water bodies. Excess phosphorus concentration in wastewater treatment plants' (WWTPs) effluents causes massive increase in the growth of aquatic plants and algae, causing eutrophication. Therefore, there are enormous efforts done globally to improve the quality of WWTPs effluents. Enhanced biological phosphorus removal (EBPR) processes are applied in many full-scale activated sludge WWTPs where phosphorus accumulating organisms (PAOs) are stimulated to remove soluble phosphorus from the water stream through intercellular storage, then removal of phosphorus is finally accomplished through wasting of sludge. Biological alternatives of phosphorus removal are preferable on chemical alternatives due to the large amounts of sludge and the high operation cost associated with the later [1].

Contact stabilization (CS) is a well-known activated sludge wastewater treatment process that can remove organic matter effectively. Although CS process has many advantages, such as small footprint and low capital and operation cost relative to traditional activated sludge systems, it lacks to nutrient removal capability. The theory of biological phosphorus removal depends on alternating anaerobic and aerobic conditions, which are considered the uptake and release zones, respectively. These alternating cycles stimulate PAOs to function and, hence, remove Phosphorus from the water stream. In the MCS, this complete cycle is fulfilled by the addition of the anaerobic thickener, which is considered the phosphorus release zone. Previous studies showed high phosphorus removal efficiency of MCS in influent low P concentrations, up to 5 ppm. However, in higher concentrations, the performance of the system in total, and the performance of the anaerobic thickener in particular, were imbalanced and low results were achieved for P removal. It was suggested that the reason for that decrease in efficiency is the imbalanced COD:N:P ratio in the anaerobic thickener, which is recommended to be around 250:5:1 in anaerobic conditions as mentioned in the literature [2]. Therefore, the objective of this study is to investigate the feasibility of adding sodium acetate as a carbon source and its influence on the performance of the MCS system.

II. MATERIALS AND METHODS

2.1. Water Source

This study was performed on a pilot plant installed at Quhafa WWTP (a full-scale WWTP)which is located in Al-Fayoum, Egypt. The influent source of Quhafa WWTP is mainly municipal with some other various sources such as small industries. The influent of the pilot plant was taken from the effluent of the preliminary works, screens and grit removal chamber, of the full-scale WWTP. Water was delivered to the pilot plant using a submersible pump installed downstream the preliminary works to feed a polyethylene equalization tank, which directly feeds the pilot plant. The function of the equalization tank was to damp the influent hydraulic pulses as the submersible pump worked intermittently. Characteristics of the pilot plant's influent are shown in Table 1.

Table 1: Physical and chemical characteristics of raw wastewater

Parameter	Unit	Minimum	Maximum	Average
pH	-	6.7	7.8	7.2
Total Phosphorus (TP)	mg/l	0.27	8.65	2.94
Chemical Oxygen Demand (COD)	mg/l	134	1081	593
Biochemical Oxygen Demand (BOD_5)	mg/l	69	590	305
Dissolved Oxygen (DO)	mg/l	0.30	1.90	1.12

2.2. Pilot Plant Description

The MCS pilot plant is composed of a number units and a piping system as shown in Fig. 1. Table 2 shows the dimensions of The pilot plant's units, while Table 3 shows the details of the piping system.

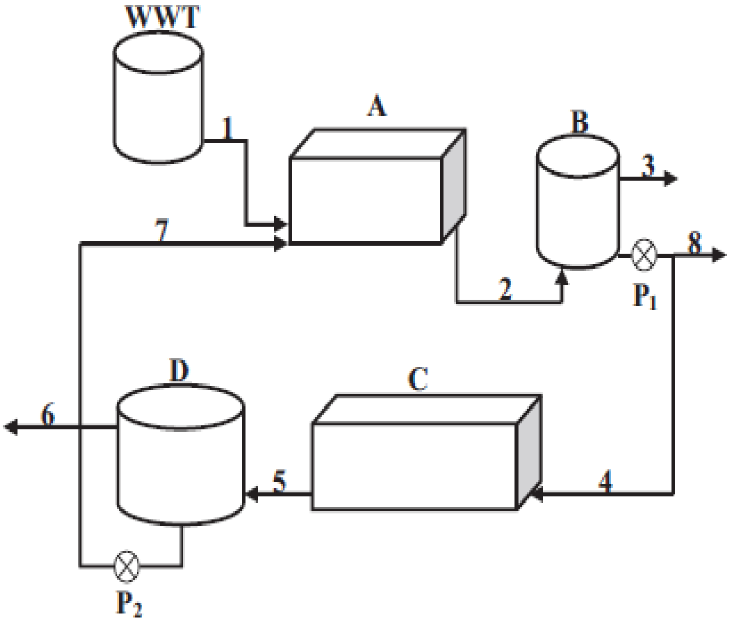

Figure 1: Pilot plant flow diagram

Table 2: Description of pilot plant units and piping system

Symbol	Description
WWT	Equalization tank
A	Contact tank
B	Final sedimentation tank
C	Stabilization tank
D	Thickener tank
P1	F.S.T sludge pump (pumped to stabilization tank)
P2	Thickener sludge pump (returned to contact tank)
Pipe 1	Main influent pipe of diameter 1 inch with a main control ball valve
Pipe 2	Delivery pipe of diameter 1 inch with a main control ball valve from the contact tank to the final sedimentation tank
Pipe 3	Effluent pipe from final sedimentation tank
Pipe 4	Delivery pipe of diameter 1 inch for return sludge from the final sedimentation tank to stabilization tank
Pipe 5	Delivery pipe of diameter 1 inch with a main control ball valve from the stabilization tank to the thickener tank
Pipe 6	Drain pipe of diameter 1 inch from supernatant zone in thickener
Pipe 7	Delivery pipe of diameter 1 inch for return sludge from thickener tank to contact tank
Pipe 8	Waste sludge pipe of diameter 1 inch from the sludge zone in F.S.T

Table 3: Dimensions and operation parameters of pilot plant units

Dimension	Unit	Tank			
		A	B	C	D
Flow rate	l/min	-	5.6	-	2.0
Raw sewage flow	l/min	4.1	-	-	-
Return sludge flow	l/min	1.5	-	2.0	-
Return sludge ratio	l/min	35	-	-	-
Average MLSS	mg/l	3200	-	-	-
Length	cm	110	-	115	-
Diameter	cm	-	100	-	150
Width	cm	80	-	100	-
Depth	cm	75	100	100	100
Volume	l	660	78.5	1150	1765
HRT	min	120	140	575	880
SLR	$m^3/m^2/d$	-	10.27	-	1.63

2.3. Operation Conditions

The pilot plant was operated continuously under the natural environmental conditions, such as day and nightand temperature. No pretreatment was done for the influent except the preliminary treatment of the full-scale plant. The pilot plant received the inflow with natural fluctuation in physical characteristics, except the addition of phosphorus source in the effluent, to study the pilot plant's performance under different P concentration, and the addition of sodium acetate as a carbon source, to investigate its influence on the performance of the system. Sodium Acetate was being fed just upstream the anaerobic thickener, in other words, at the effluent weir of the stabilization tank.The study was performed on two stages of operation: the first stage is considered the startup stage and the second stage is the core stage of study.

2.4. Measurements

Samples were collected from seven different points on the pilot plant. The measured parameters included pH, COD, BOD_5 and total phosphorus (TP).

III. RESULTS AND DISCUSSION

3.1. First/Startup Stage

Fig. 2 shows a fluctuation in COD concentrations in influent however they are in the range of medium strength wastewater[2]. by The system achieved a steady state removal of organic matter within the first stagewith an average of 92%.Similarly, Fig. 3 shows a fluctuation in BOD_5. BOD_5 removal efficiency 91% in average. In general, these values of removal comply with the acceptable range of CT system.

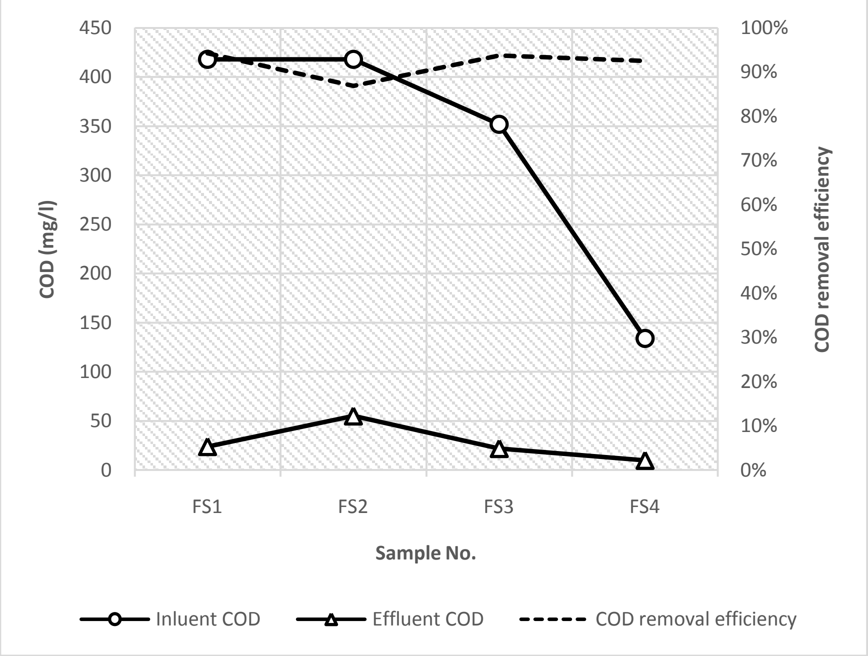

Figure 2: COD concentrations and removal efficiency at first stage

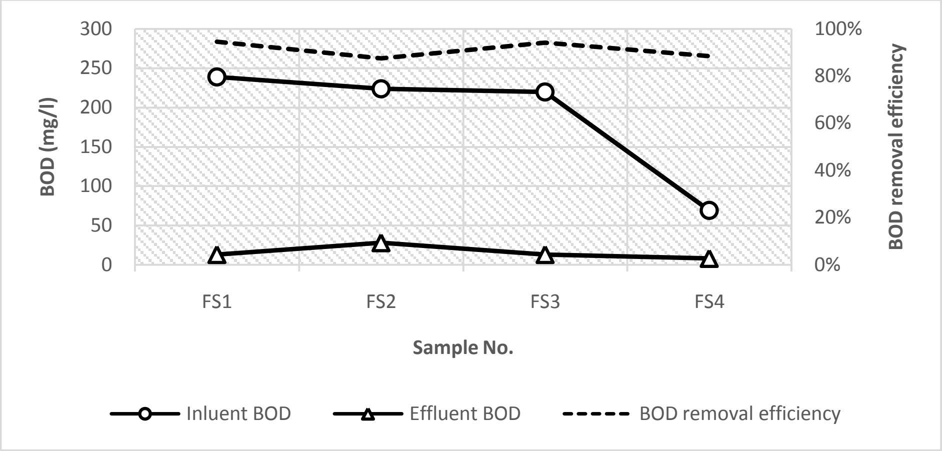

Figure 3: BOD_5 concentrations and removal efficiency at first stage

Fig. 4 shows that TP concentrations in raw wastewater were lower than the common range for Quhafa WWTP. In normal conditions, average TP concentration in raw wastewater is 3 mg/l which as reported in the previous studies[3], [4]. Comparing concentration of TP during the first stage, it ranged from 0.27 to 0.54 mg/l with an average of 0.35 mg/l, which is considered about one tenth of the common average concentrations. On the other hand, Fig. 4 shows that the removal efficiency of TP during the first stage was unstable. It started with a high efficiency with a removal ratio of 78 % then the efficiency decreased to reach a minimum value of 37% with an average TP removal ratio of 53% for the startup stage. In general, due to low TP concentrations in influent during the first stage, TP concentrations were very small accordingly in effluent regardless the removal efficiency. Therefore, the first stage is not very influential in system evaluation.

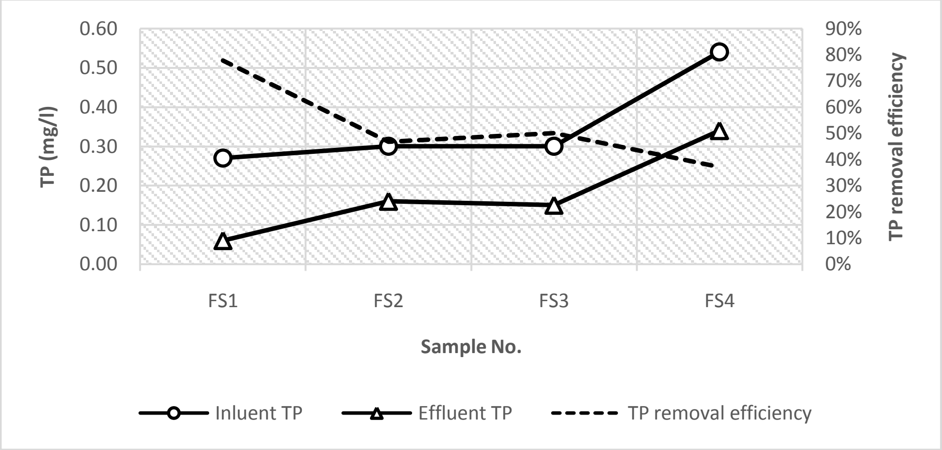

Figure 4: TP concentrations and removal efficiency at first stage

Results showedthat COD/BOD_5 ratio in the supernatant of the anaerobic thickener ranged between 1.57 and 2.67 during the first stage, where there was no addition of sodium acetate. This range of ratio is common in domestic wastewater. The ratio COD/BOD_5 represents the biodegradability of organic matter which is an indication to the easiness of degradation of organic matter biologically by the microorganisms. In other words, the higher the COD/BOD_5 ratio the lower the biodegradability of organic matter. Thus, during the first stage, and without addition of external carbon source, the biodegradability of organic matter in the release zone was stable for domestic wastewater.

Fig. 5 shows TP concentration in supernatant bulk liquid. This concentration of TP is considered as the released phosphorus from cells of microorganisms as a result of exposing to the anaerobic zone. It is obvious that concentrations of released phosphorus are relatively low due to the low TP in influent. As shown in Fig. 5, release efficiency was high at the start of the first stage with a value of 79% then started to decrease to reach a value of 45% at the end of the stage with an average of 68% for the overall stage.

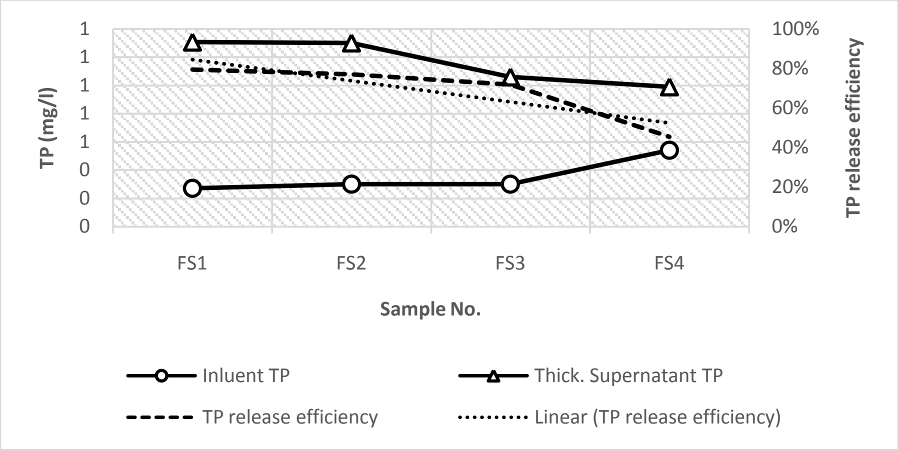

Figure 5: TP concentrations in influent and thickener supernatant and release efficiency

3.2. Second/Core Stage

Results showed fluctuation in COD concentrations in influent with an average of 742 mg/l. This range of COD is considered as a medium to high strength wastewater according to Metcalf and Eddy[2]. COD removal efficiency ranged from 74% to 95% with an average of 86%.Similarly, there was a fluctuation in BOD_5 concentrations in influent which ranged from 119 to 590 mg/l with an average of 372 mg/l. BOD_5 removal efficiency ranged from 68% to 94% with an average of 85%.

It is obvious that during the second stage, the removal efficiencies of COD and BOD_5 were slightly decreased from 95% to 74% and from 95% to 68%, respectively. This decrease is likely owing to two reasons. The first one is related to the behavior of the microorganism. It is obvious in organic matter removal and TP removal and release as will be discussed later that a change in the metabolic behavior of the microorganism occurred after addition of sodium acetate. This change is due to addition of external source of substrate which is somehow strange to the system which caused that kind of losing stability of operation. The second reason is that the feeding of additional carbon source to the thickener which in turn increased the organic matter in the return sludge. In general, high and acceptable COD and BOD_5 removal efficiencies were achieved according to. the acceptable range of contact stabilization system [5]. On the other hand, these values of removal are very close to previous results[3], [4].

Fig. 6 shows that the TP removal efficiency during the second stage increased to reach a maximum value of 94% which is about 1.21 times the maximum value at the first stage. The minimum achieved TP removal efficiency during the second stage was 42% which is higher than the minimum value of the first stage by 1.13 times. The average TP removal efficiency of the second stage is 59%.Comparing theseresults to the previous work, it could be concluded that the addition of Sodium Acetate affected the efficiency of TP removal efficiency diversely as it is decreased from an average value of 83% to 59%[3], [4]. This can be attributed to the poor uptake of carbon source during the anaerobic zone caused a lack of PHB formation. Randall and Liu observed that issue will cause poor phosphorus uptake phosphorus uptake during the aerobic phase[6].

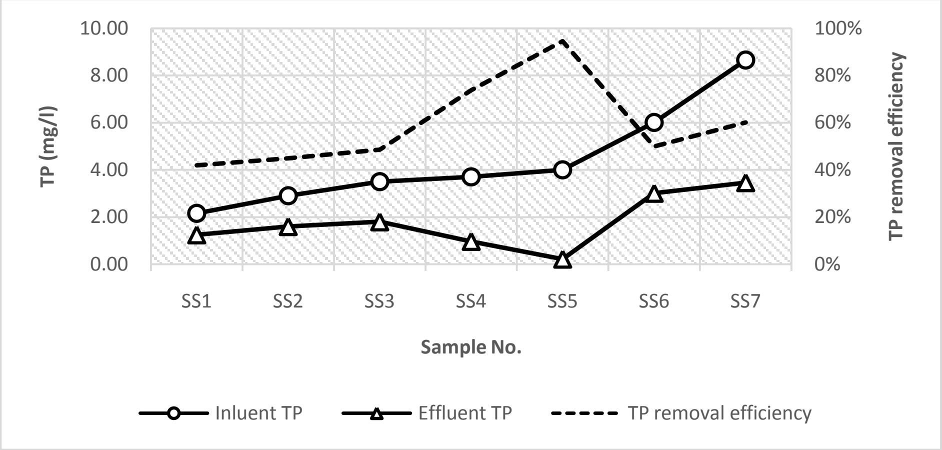

Figure 6: TP concentrations and removal efficiency at second stage

Results of COD and BOD_5in the anaerobic thickener showed that the ratio between the two parameters ranged from 3.58 to 5.63 with an average ratio of 4.42.Comparing results of the first stage to results of the second stage, it can be observed that addition of sodium acetate to the release zone has increased the COD/BOD_5 ratio dramatically. This indicates low organic matter biodegradability which can be shown in the high organic matter residual. This observation illustrates the change in performance of the system comparing to normal condition without addition of external carbon source. Addition of an external carbon source, sodium acetate, converted the characteristics of the wastewater to be very similar to the industrial wastewater. Thus, an overall disturbance occurred to the system and in turn diversely affected its performance not only the release efficiency but also the uptake efficiency and the overall performance of the system.

Fig. 7 shows TP concentration in thickener supernatant bulk liquid during the second stage. This concentration of TP is considered as the released phosphorus from cells of microorganisms as a result of exposing to the anaerobic zone. It is observed that during the second stage, the TP release efficiency was highly fluctuated. A decrease in phosphorus release observed to reach negative values at most of operating points. Phosphorus release efficiency ranged between -406% and 22% with an average of -96%. These negative values indicate accumulation of phosphorus in interior cells. The fluctuation and decrease of TP release efficiency were observed simultaneously with the addition of sodium acetate. Comparing to results in previous studies, the minimum phosphorus release efficiency was -17%[3], [4]. During the previous studies, no external carbon source was added and formation of PHB depended on organic matter in raw wastewater only.

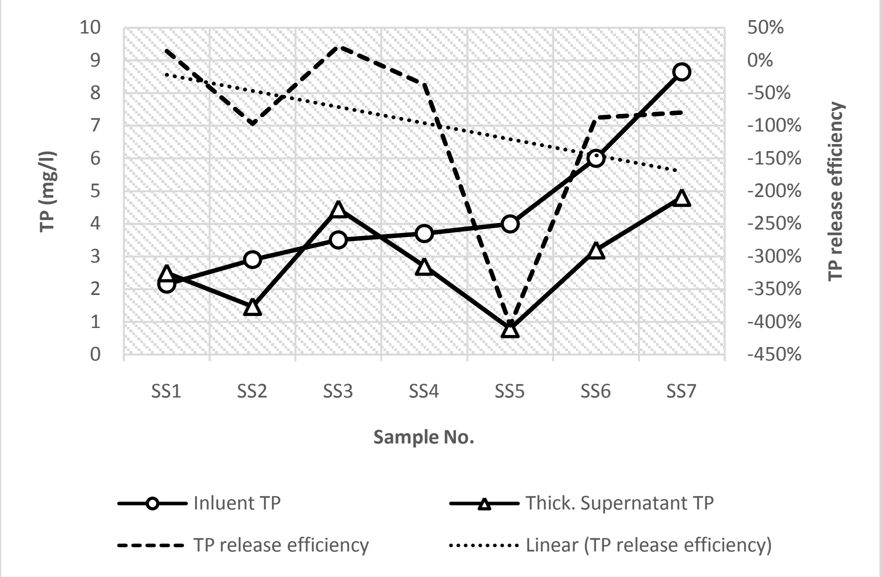

Figure 7: TP concentrations in influent and thickener supernatant and release efficiency

IV. CONCLUSION

It can be concluded that using of sodium acetate as an external carbon source in contact stabilization technology proved to be unsuccessful as it did not improve the performance of the system, in general, and the phosphorus release efficiency, in particular. Also, sodium acetate addition decreased the biodegradability of the organic matter in the release zone. This can be attributed to the sudden increases of VFA loading which caused imbalance between phosphorus release and uptake.The decreased carbon source uptake caused decreased PHB formation rate and TP uptake efficiency in turn.TP removal efficiency decreased from 80% to 59% and TP release efficiency in thickener decreased to -96% after addition of sodium acetate to the anaerobic zone. Removal efficiency of both COD and BOD_5 was about 85%.Overall, addition of sodium acetate as an external carbon source to the anaerobic zone in the modified contact stabilization activated sludge system do not improve quality of wastewater effluent.

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