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Enhancement of A^2O Process with Integrated Fixed-film Activated Sludge (by GPS-X)

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Abstract

The A^2O process is one of the conventional processes used for nutrient and BOD removal. This process is associated with issues such as high sludge production and low SRT during operation. Also, wastewater treatment plants (WWTP) overloading forces operators to produce more sludge in order to meet effluent quality standards. In this paper, enhancing conventional A^2O to IFAS was investigated by simulation. GPS-X was used for modeling, simulation, and analyzing the process. The Integrated Fixed-film Activated Sludge (IFAS) process simultaneously consists of suspended sludge and attached biofilm. The enhancement was carried out through two scenarios using media with a filling factor of 50% and adding a new liquid line. Results showed that adding suspended media and the new liquid line (upgraded-A^2O) reduced waste sludge by 15% and met the standards for wastewater quality. Also, IFAS showed a fourfold increase in SRT. IFAS can be applied as a better method of sludge stabilization and reduction. Although the IFAS and extended aeration processes operate similarly, IFAS involves high oxygen consumption at high SRT. Hence, economic evaluation is needed for both IFAS and upgraded-A^2O. Based on the results, IFAS has 29% more energy consumption and 54% greater total operating costs Compared to upgraded-A2O. The total cost of wastewater for IFAS is 0.008 \$/ (m^3.d) less than that of upgraded-A^2O.

Keywords: A^2O, GPS-X, Sludge Reduction, IFAS, Simulation

1. INTRODUCTION

It has been about a century since activated sludge (AS) was first used as a significant method in wastewater treatment plants (WWTP). Over the years, AS processes and configurations have been improved [1]. Among these improvements is the anaerobic/anoxic/aerobic (A^2O) process, which removes nitrogen, phosphorous and organic compounds (CNP) in three stages.

All AS-based processes generate residue sludge as a byproduct [2]. Although the amount of sludge is about 1-3 wt. % of raw wastewater, its treatment, and disposal cause additional problems [3, 4, and 5]. Residue sludge increases footprint, capital investment, and operating costs. Excess sludge emits various pollutants and pathogens. Sludge thickening and digestion are currently used to manage excess sludge, but these techniques consume large amounts of energy. Accordingly, processes that produce less sludge are more valuable since they could reduce further sludge treatment and disposal [6].

The Integrated Fixed-film Activated Sludge (IFAS) process simultaneously consists of suspended sludge and attached biofilm [7]. The process can be utilized to enhance nitrification or reduce the effects of shock [7, 8]. Other advantages of this process are its capability of being added to other configurations and footprint reduction. Combining IFAS with A^2O (modified A^2O) represents a higher CNP removal. The first large plant was at Broomfield, Colorado, USA (30,000 m3/d), which was upgraded from a traditional BNR plant to an IFAS in 2003[1]. As shown in Fig 1, IFAS refers to a configuration consisting of separate anaerobic/anoxic stages without carriers, followed by an IFAS stage which is considered aerobic. Operational control is one of the major problems in such a process. Removal efficiency is affected by filling factor, hydraulic retention time (HRT), sludge retention time (SRT), and return activated sludge (RAS). with an 18% filling factor of 64 m^2/m^3, achieved complete nitrification with about 40% lower suspended biomass aerobic SRT than without carriers [1]. Also, better AS settling properties have been reported after introducing IFAS into an existing AS plant [1].

Municipal WWTPs are designed according to population growth and the predicted capacity. The predictions are made based on sociological variables, water consumption, climate, and precipitation. Municipal WWTPs are also directly associated with sewerage. In some cases, it is needed to operate WWTPs at a much higher capacity than predicted. These conditions arise due to the changes in wastewater generation, which may have been incorrectly evaluated in the study phase or may have changed during the operational phase. Hence, one of the important issues in WWTPs is upgrading existing plants to increase their capacity compared to the initial design.

In this paper, it is assumed that the capacity of a wastewater treatment plant (WWTP) has increased from 11,000 m^3/d to 18,000 m^3/d (about 64% increase), such that the discharge no longer meets the surface water standards stipulated by Iran's Department of Environment. Then, aeration tank enhancement and addition of a new liquid line were investigated. Combining fixed-film and suspended growth was simulated in an IFAS system using the filling factor of media. GPS-X was used for modeling, simulation, and analyzing the process. The mantis2lib was used as the library [9, 10]. This comprehensive library can provide carbon, nitrogen, phosphorus, and pH changing calculations with about 52 state variables [11]. Given the complexity of the process due to the presence of activated sludge and biofilm, it was required to consider several parameters and solve several equations for IFAS [7, 12].

2. SIMULATION

The raw wastewater from a city in Iran was considered as the influent of the WWTP with a flowrate of 11000 m^3/d. This WWTP is located near the city with a high population density in the north of Iran, where land is scarce, and extending the WWTP is difficult and expensive. On the other hand, extending the WWTP is inevitable due to increases in the volume of influent wastewater. The characteristics of the influent are shown in Table 1. A primary clarifier was used before the biological unit.

Table 1- Influent characteristics

Composition	Unit	Value
COD	gBOD/m^3	451
BOD	gCOD/m^3	227.3
TKN	gN/m3	39
NH_4-N	gN/m^3	28
TP	gP/m^3	8
Ortho-phosphate	gP/m^3	7
TSS	g/m^3	268.4
VSS	g/m^3	182.5
pCOD	gCOD/m^3	320.2
nbCOD	gCOD/m^3	85.6
nbsCOD	gCOD/m^3	18
rbCOD	gCOD/m^3	90.2

Generally, this WWTP is divided into two parts: a liquid line and a solid line. The liquid line includes primary and secondary clarifiers and three biological tanks. The solid line contains the thickener, anaerobic digester, and dewatering units. The design temperature of the influent was 20°C. Return activated sludge (RAS) flow was applied at 0.6 of the influent flow. The primary clarifier was used before the biological unit. The

WWTP was designed based on the 5th edition of Metcalf & Eddy (2014) [5]. The design dimension parameters are presented in Table 2.

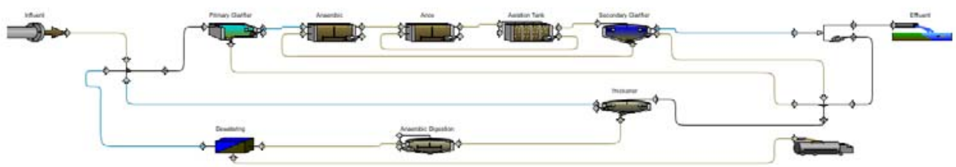

Figure 1- Flow chart of the A^{2}O process

Table 2- Design dimension parameters of the A^{2}O objects

Object	Parameters	Unit	Value
Primary clarifier	Surface Overflow Rate	$m^3/m^2.d$	32
	Primary Sludge Production	m^3/d	83
Anaerobic tank	Maximum Liquid Volume	m^3	500
	HRT	h	1.1
Anoxic tank	Maximum Liquid Volume	m^3	1000
	HRT	h	2.2
Aeration tank	Maximum Liquid Volume	m^3	3000
	Airflow	m^3/h	4150
Thickener	Hyd. Loading Rate	$m^3/(m^2.d)$	4
	Solids Loading Rate	$kg/(m^2.d)$	25.21
Anaerobic digestion	SRT	d	22.4

It was assumed that the capacity of WWTP had risen to 18,000 m^3/d and the hydraulic loading rate had increased from 3.66 $m^3/(m^2.d)$ to 6 $m^3/(m^2.d)$, as shown in Figs. 2a and 2b. At this capacity, WWTP discharge does not meet surface water standards. Also, by increasing waste activated sludge (WAS) flow to meet discharge standards, the solid line faced operating problems. Figs. 2a and 2b show that for A^{2}O, the WAS flow should increase up to 320 m^3/d in order to satisfy discharge standards. These observations indicate that the current processes cannot meet the requirements. Consequently, upgrading the WWTP was investigated in two scenarios.

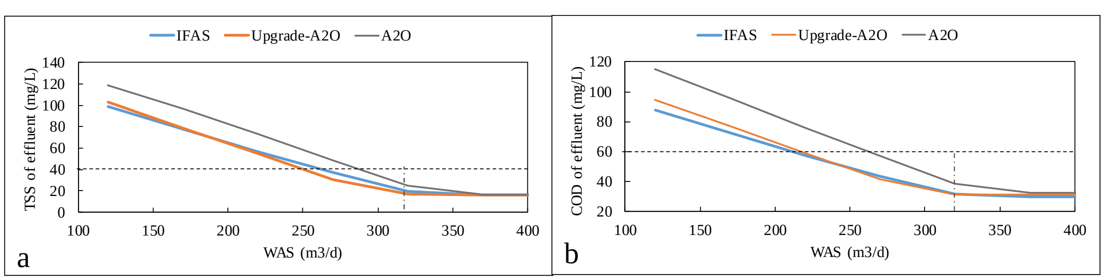

Figure 2- Comparison of conventional and modified A^{2}O process
(a: WAS vs COD of effluent and b: WAS vs TSS of effluent)

2.2 IFAS

Without increasing footprint, media was added into the aerobic tank. However DO increase up to 5 mg/L, Inevitably. Since better settling of IFAS processes, clarifiers did not need to retrofit. Figs. 2a and 2b show that for A^2O, the WAS flow should increase up to 320 m^3/d in order to meet the discharge standards. Esmaeili et al. demonstrated that the appropriate range of filling factor is about 40%-60% [13]. Media parameters are shown in Table 3. By adding media, WAS flow reduction and discharge standards can be achieved without increasing footprint. According to standards, COD and TSS thresholds are 60 and 40 mg/L, respectively. With a filling factor of 50% and WAS of 270 m^3/d, the process can meet the stipulated surface water standards.

Table 3- Technical characterization of the media used in the simulation

Parameter	Unit	Value
Specific surface of media	m^2/m^3	400
Filling factor	m^3/m^3	50%
Specific density of media	kg/m^3	940

2.1. NEW BIOLOGICAL LIQUID LINE

To solve the problem of increased influent, a new liquid line can be added; so as to proportionately increase the volume of the three biological tanks (anaerobic, anoxic, and aerobic) with the increased influent flow rate, as much as 7000 m^3/d. This new liquid line can provide more HRT for the three biological tanks. With the addition of new tanks, equipment related to these tanks must also be added to the system. Similar to the IFAS process, the appropriate amount of WAS for upgraded-A^2O was about 270 m^3/d. It should be noted that the clarifiers were designed based on the 5th edition of Metcalf & Eddy, which recommends relatively larger volumes for equipment. The acceptable range for surface overflow loading was 16-28 $m^3/(m^2.d)$ which for a flow rate of 11000 m^3/d is 16.5 $m^3/(m^2.d)$, and for 18000 m^3/d is 26.5 $m^3/(m^2.d)$. Therefore, the surface of the clarifiers did not need to be increased.

3. RESULTS AND DISCUSSION

3.1 TECHNICAL

Fig. 3a illustrates the relationship between WAS flow changes and Mixed Liquor Suspended Solid (MLSS) in the aerobic reactor. Also, Fig. 3a presents which conventional A^2O needs more WAS for achieving required MLSS in the aerobic reactor. Meanwhile, at those WAS values, total suspended solids (TSS) of sludge is much higher, as can be seen in Fig. 3b. Given a WAS of 320 m^3/d, MLSS would need to be about 4000 mg/L, while it should be 4280 mg/L for conventional A^2O. Furthermore, the TSS of sludge decreased by 4.5% in IFAS and upgraded-A^2O.

Increasing the concentration of sludge causes disposal and treatment problems. Also, reducing the concentration of MLSS reduces throughput. According to the results of the simulation, a 15% sludge reduction can be achieved by upgrading conventional A^2O to the modified A^2O process. Therefore, this upgraded can help with enhancing waste sludge quality, WAS reduction, and retaining biomass in the reactor.

According to Fig. 3c, SRT increased about 250% in the presence of media and about 67% in upgraded-A^2O. This SRT increasing can lead the microorganisms into the endogenous respiration and reduced the biomass-to-TSS ratio.

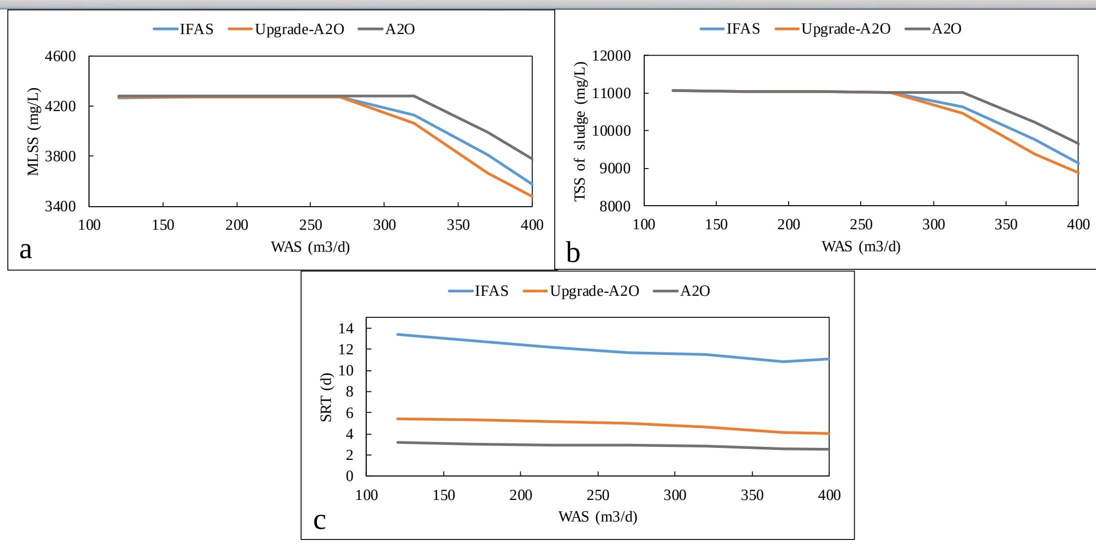

Figure 3- Comparison of conventional and modified A^2O process
(a: MLSS vs WAS, b: TSS of sludge vs WAS, c: SRT vs WAS)

IFAS operates similar to an extended aeration process without the need to increase the volume of the aeration tank. Also, IFAS does not require the removal of the primary clarifier and does not increase primary sludge. Moreover, the major problem of extended aeration is the inability to use an anaerobic digester due to the stabilized sludge. However, IFAS processes consist of both suspended sludge and attached biofilm with younger sludge. Because these processes produce primary sludge, all sludge can be fed to an anaerobic digester.

Secondary sludge is reduced in the IFAS process but like extended aeration processes, more aeration is still needed to provide high dissolved oxygen (DO). Therefore, DO increase up to 5 mg/L, which is a major problem. Additionally, total airflow increased in upgraded-A^2O due to the new liquid line. It is recommended that economic evaluation be carried out for better comparison since both processes were similar technically.

3.2 ECONOMIC EVALUATION

The two scenarios were investigated economically based on total operating cost and total capital cost. By enhancing convectional A^2O to IFAS or upgraded-A^2O, a rise in a subset of capital costs increases the total cost of wastewater treatment. Some major items for IFAS include purchasing blowers, diffusers, media, and pumps. For upgraded-A^2O, costs include purchasing land, pumps, blowers, diffusers, and concreting. The total capital cost of IFAS is 58% less than upgraded-A^2O. Also, in terms of increased operating costs, the energy was an important item in both scenarios. IFAS has 29% more energy consumption and consequently, 54% greater total operating cost. Figure 4 shows energy distribution in both scenarios; the largest portion of energy in both scenarios was used for aeration. However, IFAS required with 39% more aeration power.

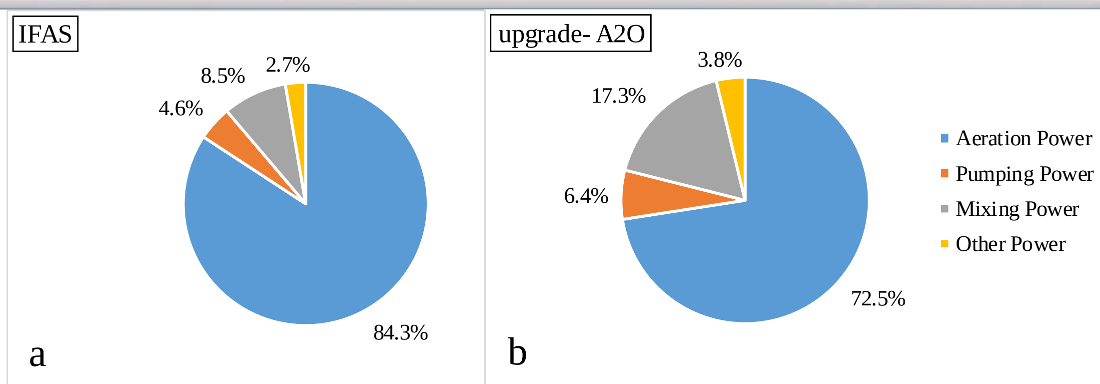

Figure 4- Energy distribution for IFAS and upgraded-A2O.

Finally, IFAS was the preferred economic scenario since its cost of wastewater was 0.008 $/($m^3$.d) less than that of upgraded-A^2O. However, other critical parameters need to be investigated for better evaluation. High energy consumption is a negative item for the IFAS process due to its high DO requirement. A large footprint is a problem for the upgraded-A^2O process because the studied WWTP is located in a city with high population density. The requirement footprint for an IFAS is typically 40–60% of that for an equivalent conventional AS [1].

4. Conclusion

To enhance the conventional A^2O process, adding suspended media at a filling factor of 50% and the addition of a new liquid line were investigated. The results showed that as the capacity of the WWTP increased by 64% and hydraulic loading rate increased from 3.66 $m^3/(m^2.d)$ to 6 $m^3/(m^2.d)$, the amount of secondary waste sludge rose by 77% for conventional A^2O and 50% for IFAS and upgraded-A^2O processes, in which case discharge quality standards could be met. Also, sludge concatenation reduced and its treatment and disposal improved. SRT rose to 12 d and 4.7 d for IFAS and upgraded-A^2O, respectively. By adding media, conventional A^2O operates similar to an extended aeration process without the need to increase the volume of the aeration tank or physical expansion of WWTP, and the solid line can be operated at better conditions even when overloaded. IFAS required 39% more aeration power compared to upgraded-A^2O but had 0.008 $/($m^3$.d) less total wastewater cost than upgraded-A^2O.

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