APPLICATION OF ADVANCED OXIDATION PROCESS FOR REDUCING THE VOLUME OF AN AERATION TANK OF A CONVENTIONAL WASTEWATER TREATMENT PLANT

تطبيق عملية الاكسدة المتقدمة في اختزال حجم احواض الاكسدة الهوائية لمحطة معالجة مياه ثقيلة تقليدية

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ABSTRACT

Iraqi government is actively promoting wastewater reclamation because of urgent water needs. Wastewater reuse is governed by stringent regulations to protect public health against waterborne diseases and any other adverse environmental effects. This study is aimed at determining the type and level of advanced treatment needed for effective treatment of 60000 m^3**.**day^{-1} domestic wastewater of an Iraqi city without major modification of plant layout. An urgent request by the Iraqi government to implement nutrients and phosphorous removal units for an under construction project. Extensive investigations were carried out to size and add both Phosphorus & Nitrogen (P & N) removal units into the plant layout. Due to limitation of site land, it was found itself obliged to work on redesigning the aeration basin of the WWTP. The aeration basin consists of eight cells of (25x25x5) m^3volume. The redesign approach adopted here involved two main objectives; one objective is to utilize part of the aeration basin as Phosphorus & Nitrogen (P & N) removal units while the second objective is to raise the efficiency of the aeration basin to handle the original influent with the remaining cells to deliver the standard effluent specifications. A cost effective study was carried out to use Advanced Oxidation Process (AOP) based on Fenton's process to achieve both objectives mentioned above. Fenton's process using H_2O_2 to react with wastewater in the presence of Fe^{++} prior to the aeration tank resulted in considerable reduction of BOD entering the aeration tank. The study has revealed that AOP is effectively accomplishing the target, and reducing the volume of the aeration basin to less than 60% of its original volume (capacity). The cost analysis shows a cut in per unit cost from (0.17 $\$/m^3$) to (0.16 $\$/m^3$).

Key Words: Advanced Oxidation Process, advanced wastewater treatment, Fenton's process, BOD**,** aeration basin.

الملخص

في ضوء الحاجة الملحة الى اعادة استخدام مياة المجاري لاغراض سقي المزروعات بسبب ازمة المياة في العالم عامة و العراق بصورة خاصة. تخضع مواصفات المياة الخارجة من وحدات معالجة المياة الثقيلة الى محددات بيئية دقيقة تهدف الى حماية الصحة العامة. يهدف هذا البحث الى تحديد نوع و مستوى المعالجة المتقدمة المطلوبة لتحديث محطة معالجة مياة ثقيلة تقليدية سعة 60000 م^3\يوم (لمشروع تحت الانشاء). وجد ان اضافة وحدة ازالة الفسفور و النتروجين ضرورية لتحقيق مواصفات مطابقة للمحددات البيئية. برزت الحاجة الى اعادة تصميم حوض التهوية مع اضافة وحدة اكسدة متقدمة بطريقة (FENTON) بعد احواض الترسيب االابتدائية. جرت عملية تقييم فني و اقتصادي لوحدة FENTON وتحققت نتائج ايجابية تلخصت بخفض قيمة BOD الداخل الى حوض التهوية و اختزال حجم الاكسدة الى اقل من 60% من الحجم الاصلي بالاضافة الى خفض كلفة معالجة المتر المكعب من المياه الثقيلة من ($0.17\ \$/m^3$) الى ($0.16\ \$/m^3$).

INTRODUCTION

Biological treatment of wastewater (commonly activated sludge processes) is considered to be the most economical process in comparison to other alternatives of treatment options. Organic materials in wastewater among other suspended or dissolved materials are more degradable. Their ability to undergo biological degradation is dependent on concentration, chemical structure, pH and presence of inhibitory compounds. Unfortunately, conventional activated sludge treatment processes are not sufficient to reduce phosphorous and nitrogen compounds to environmentally acceptable limits that enable governments to reuse wastewater treatment plants effluents for irrigation purposes. Total nitrogen removal is encouraged to prevent the potential adverse effects of harmful forms of nitrogen; for example, Ammonia can create a dissolved oxygen sag and nitrate can result in excessive algae blooms in receiving waters. The Iraqi government, under the pressure of water short supply, has launched a major water management program to maximize the wastewater reclamation policy. An urgent request to implement nutrient and phosphorus (N-P) removal units into a Wastewater Treatment Plant (WWTP) of 60000 $m^3.day^{-1}$ capacity was considered in this research. It is a conventional activated sludge process type as shown in Fig. (1), in which the raw wastewater passes three stages of treatment; primary treatment where suspended solids settled or retained, secondary treatment where biological process is taken place to transform dissolved and suspended organics into simple compounds, then the third stage where sludge stabilization takes place in digestion systems.

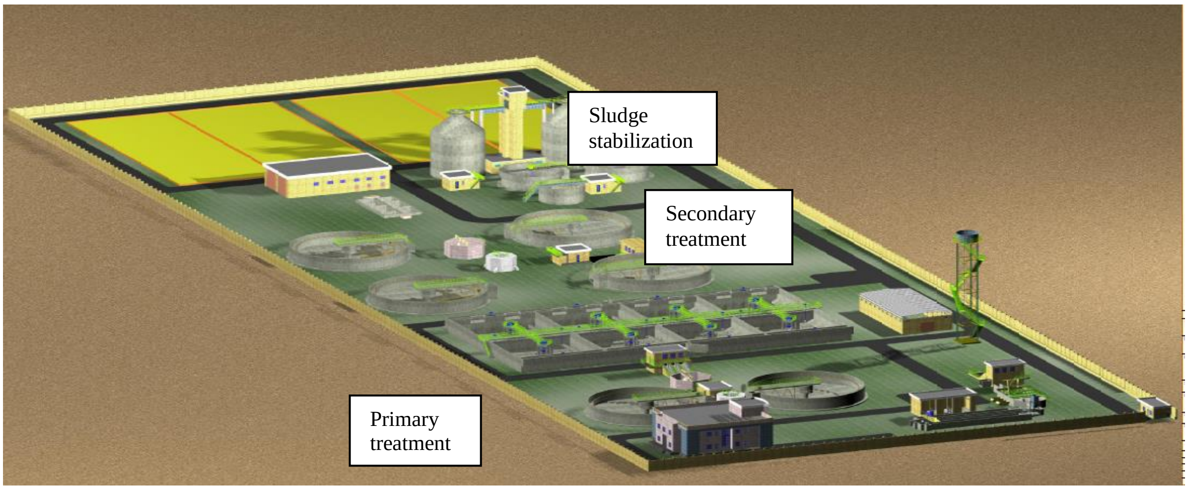

Fig. 1. General layout of the WWTP.

Redesigning the process to implement Phosphorus & Nitrogen (N-P) removal units into the conventional plants showed that about 50% of the aeration basins volume must be added as shown in Fig. (2). The aeration basins need to be laterally and longitudinally expanded to accommodate the new units. The expansion limits exceed the boundaries of plant site.

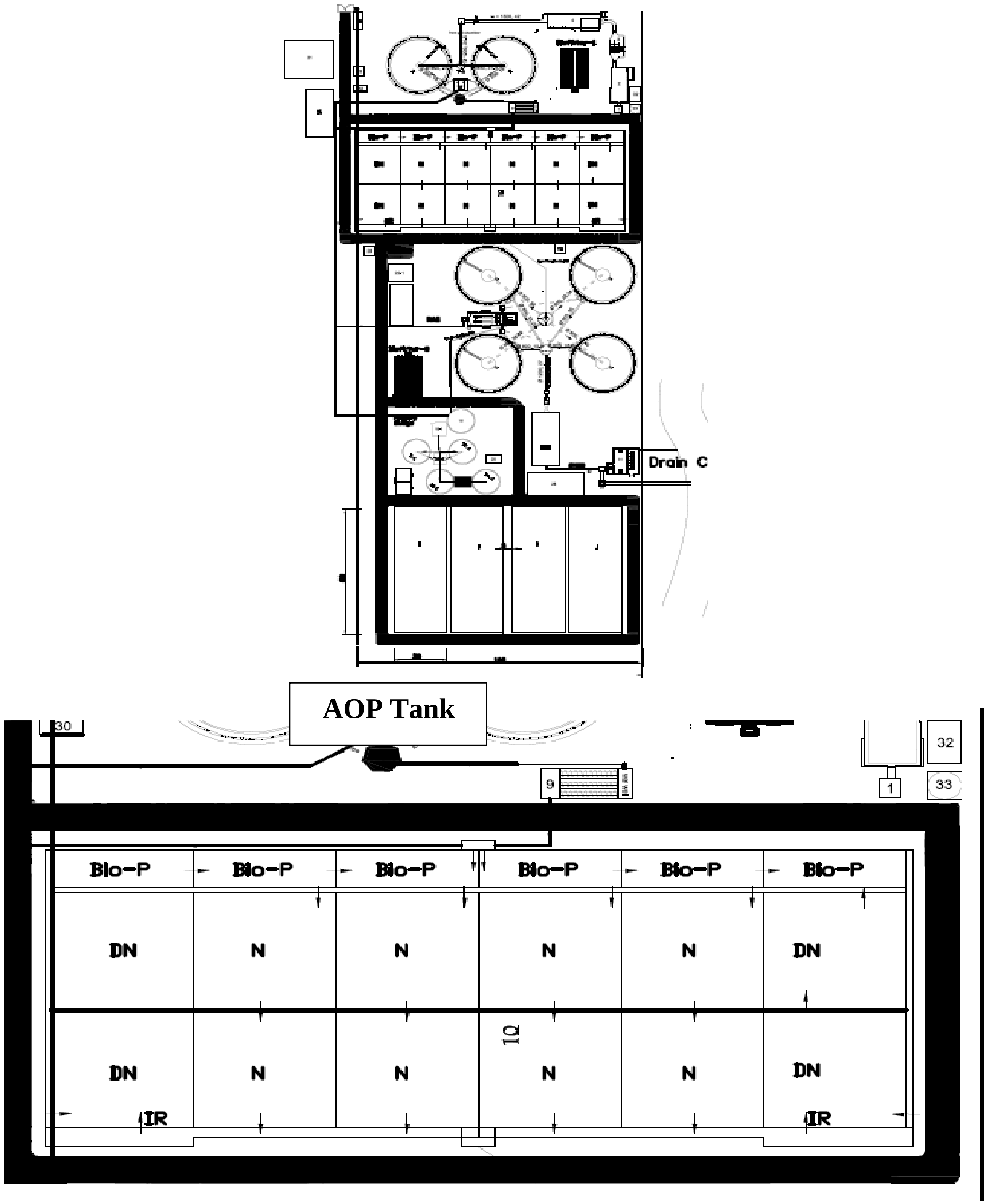

Fig. 2. General layout including Phosphorus & Nitrogen (P-N) removal units.

Due to limitation of site land, a research has been launched to apply new technologies in an attempt to trim the volume of the aeration basins down. Recently, advanced oxidation processes (AOP) have been reported to be used to reduce organic loads and toxicity of different wastewaters [1]. Fenton's process has been considered to be very promising AOP process among many AOPs processes [2].

In this process, wastewater reacts with hydrogen peroxide (H_2O_2) in a non-pressurized reactor, at low temperatures, in the presence of a low-cost catalyst (e.g., iron sulfate), yielding carbon dioxide and water and/or other oxidation products [3]. Fenton oxidation is quite complex, as evidenced by some of the proposed mechanisms found in the literature [4,5].

$$Fe^{+2} + H_2O_2 \longrightarrow Fe^{+3} + OH^- + OH^{\cdot} \quad (1)$$
$$Fe^{+3} + H_2O_2 \longrightarrow Fe\text{-} OOH^{+2} + H^+ \quad (2)$$
$$Fe\text{-} + OOH^{+2} \longrightarrow HO^{\cdot}_2 + Fe^{+2} \quad (3)$$
$$Fe^{+3} + HO^{\cdot}_2 \longrightarrow Fe^{+2} + O_2 + H^+ \quad (4)$$
$$Fe^{+2} + OH^{\cdot} \longrightarrow Fe^{+3} + OH^- \quad (5)$$
$$H_2O_2 + OH^{\cdot} \longrightarrow HO^{\cdot}_2 + H_2O \quad (6)$$

This network of consecutive and parallel reactions results in complex reaction kinetics. The efficiency of the Fenton oxidation process depends on the H_2O_2:organic carbon ratio, organic matter content, temperature and Fe^{+2} concentration [3]. The pH, Fe^{+2} :H_2O_2 ratio and H_2O_2 concentration are also crucial [6]. Overall kinetics can be described by a second-order followed by a zero-order rate equation and the apparent kinetic constants at 30^o are k_1 = 2.3 x 10^{-4} mg L^{-1} min^{-1} and k_2 = 26.0 mg L^{-1} min^{-1}, respectively [2].

$$-r_1 = k_1 C_{OH^{\cdot}} C^2_{TOC} - k_1 C^2_{TOC} \quad (7)$$
$$-r_2 = k_2 C^0_{TOC} - k_2 \quad (8)$$

Where r_1 and r_2 represent reaction rates, k_1 and k_2 are kinetics constants.
A combined process (Fenton AOP - Biological Process) was adopted for the above mentioned WWTPs as shown in Fig. (3). The Fenton AOP was used as a pre-treatment process in order to increase the biodegradability of wastewater and significantly reduce its BOD. The oxidation of organic compounds in water with AOPs usually produces oxygenated organic products and low molecular weight acids that are more biodegradable. As the volume of the aeration basin is strongly dependent on the BOD, then, any reduction in the BOD results in a significant reduction in the aeration basin volume.

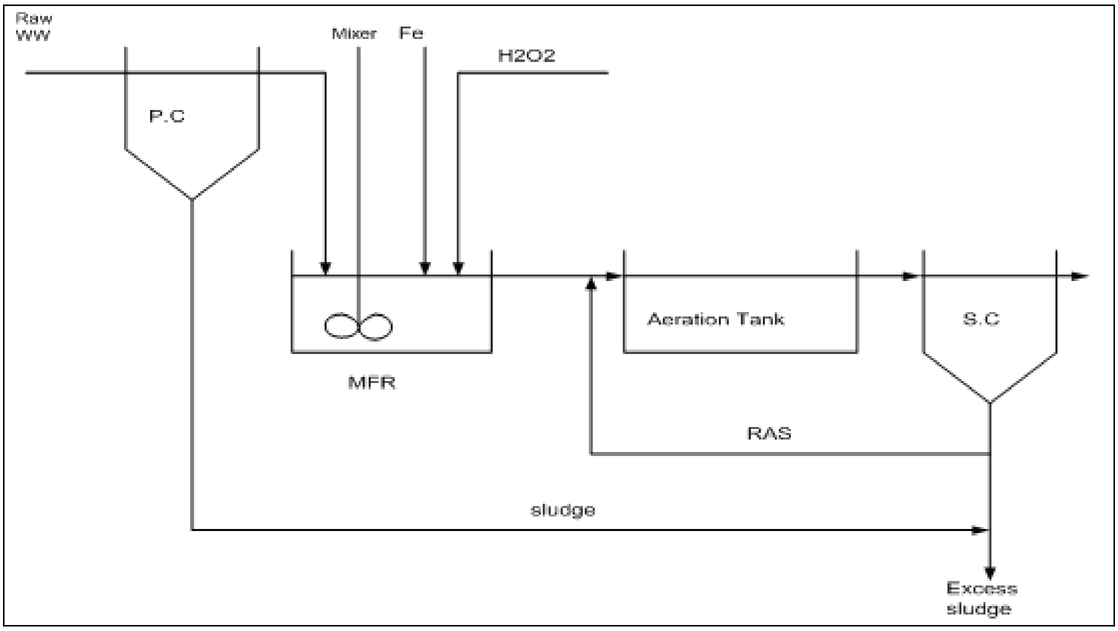

Fig. 3. Schematic representation of the **proposed** combined process

RESULT AND DISCUSSIONS

Sizing The Biological Reactor Tank (Aeration Tank (A.T))

Sizing the aeration tank is strongly dependent on BOD loading. The inlet BOD to the aeration tank was assumed to depend on the primary sedimentation efficiency in case of conventional process and depend on both the primary sedimentation and the AOP process efficiencies in case of the integrated process (Fenton-biological process). The volume of the biological reactor tank was considered as a parameter of evaluation for the AOP effect. As AOP consumes significant portion of the BOD that comes from the primary sedimentation tank before it enters the A.T, the size of the A.T will be considerably decreased. The calculations were performed in three steps; the first was to estimate the volume of the conventional A.T., the second to size the A.T. with Phosphorus & Nitrogen (P-N) removal units being added to the conventional process and the third to size the volume of the integrated Fenton- biological A.T.

1-Conventional Activated Sludge Process:
Basic flow rates and design parameters of the original WWTPs were used for the purpose of this research. The average daily flow rate was taken as 0.7 m^3/s and the BOD loading was estimated on 33% efficiency of the primary sedimentation. So the BOD falls from 360 $mg.L^{-1}$ to 241.5 $mg.\ L^{-1}$. The value of the mixed liquor suspended solids (MLSS) was taken as the maximum of the typical range (3000 $mg.\ L^{-1}$). The ratio of MLVSS/MLSS was 0.7, while the food to microorganism (F/M) was considered to be 0.2 as the minimum limit of the typical range. Accordingly, the mass load of the BOD was obtained using the above values of the design parameters and it was 14472 $KgBOD.day^{-1}$. This value resulted in 25000 m^3 volume of the A.T. and 8 hrs detention time. Typical depth (5 m) of the A.T. was assumed resulting in 5000 m^2 total area of the aeration tank divided into eight cells of 625 m^2 each as shown in Fig. (4).

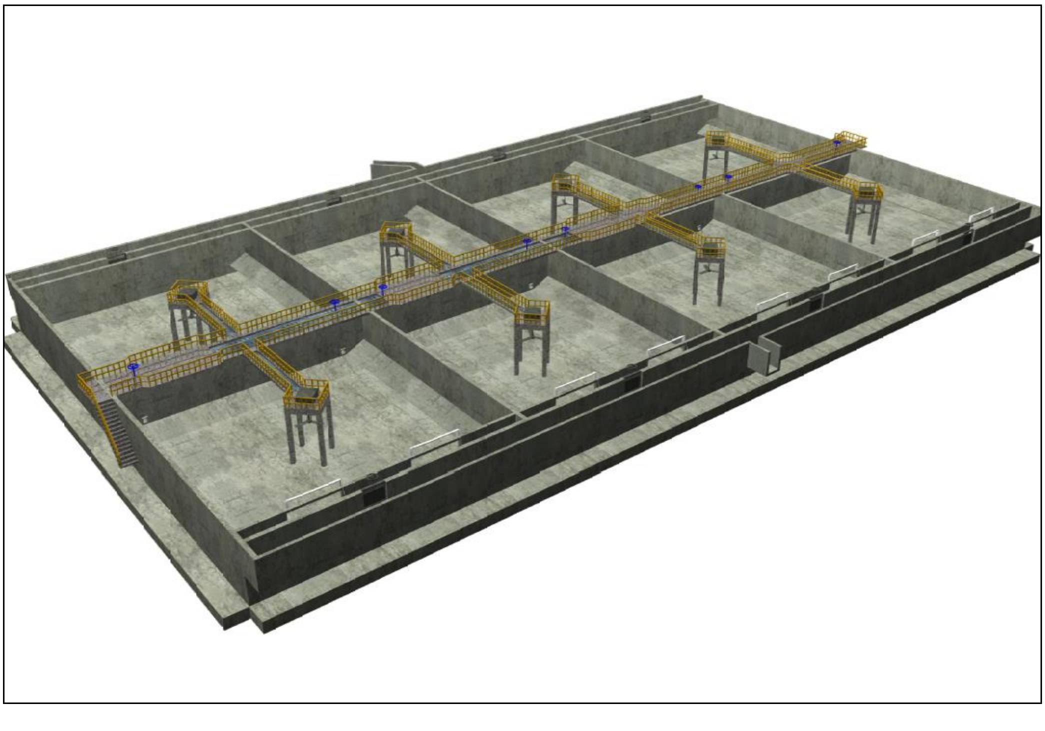

Fig. 4. Isometric representation of the conventional process aeration tank

2-Conventional Plus P-N Removal Units:
Anoxic/aerobic configuration as shown in Fig. (5) was adopted for the conventional- Phosphorus & Nitrogen (P&N) removal process. Both flow rate and design parameters of the conventional activated sludge were used in sizing the A.T and Phosphorus & Nitrogen (P& N) removal units. 37500 m^3 total volume was obtained. This new volume represents 150% of the conventional A.T. volume. The additional area that accommodates the P-N removal units was estimated to be 2500 m^2. This extra area for these new units cannot be met due to the site limitations of the WWTP. Therefore, the present research (introducing advanced oxidation processes) was approached in an attempt to overcome the problem.

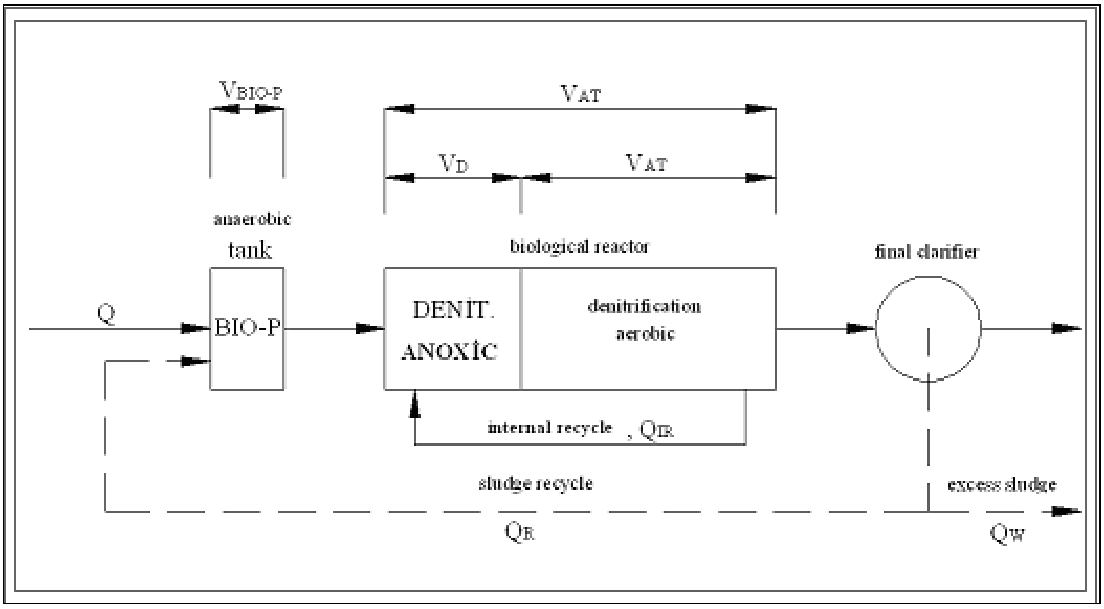

Fig. 5. Anoxic/Aerobic process with Phosphorus & Nitrogen (P-N) removal units.

3- Integrated Fenton-biological process:
The Fenton process among many AOP processes has been chosen in this research for many reasons; its simplicity, availability of both H_2O_2 and transition metal Ion (Fe^{++}), and it needs less energy to operate. It can be summarized as follows:

$$Fe^{++} + H_2O_2 \longrightarrow Fe^{+++} + HO^- + HO^\cdot \qquad (9)$$

Where M is a transition metal such as Fe. In the absence of light and ligands other than water, the most accepted mechanism of H_2O_2 decomposition in acid homogeneous aqueous solution, involves the formation of hydroxylperoxyl ($HO_2^\cdot/O_2^-$) and hydroxyl radicals $HO^\cdot$ [7]. The stoichiometric coefficient for the Fenton reaction was approximately 0.5 mol of organic compound.mol^{-1} H_2O_2 [8]. Accordingly, the general objective of this work was to study the effectiveness of the AOPs mentioned above in the degradation and mineralization of organics, as well as the influence of this process in the biodegradability enhancement of a wastewater. For this latter objective, a general strategy focused on the estimation of the BOD reduction out of the Fenton process and how much this reduction will be reflected on the size (volume) of the aeration tank has been established to accommodate the new P-N removal units without violating the site limitations. Fenton process which was devised in this research exploits the collection box unit that collects primary sedimentation tanks effluents as shown in Fig. (6; a, b).

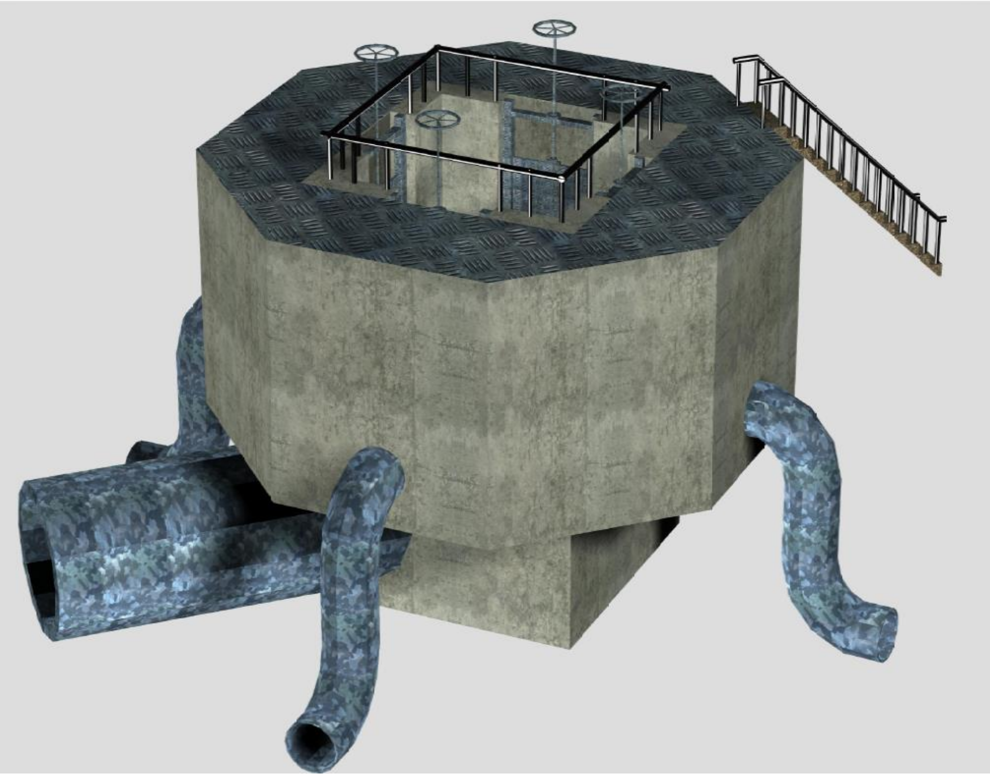

Fig. 6a. Isometric representation of collection box used for Fenton process.

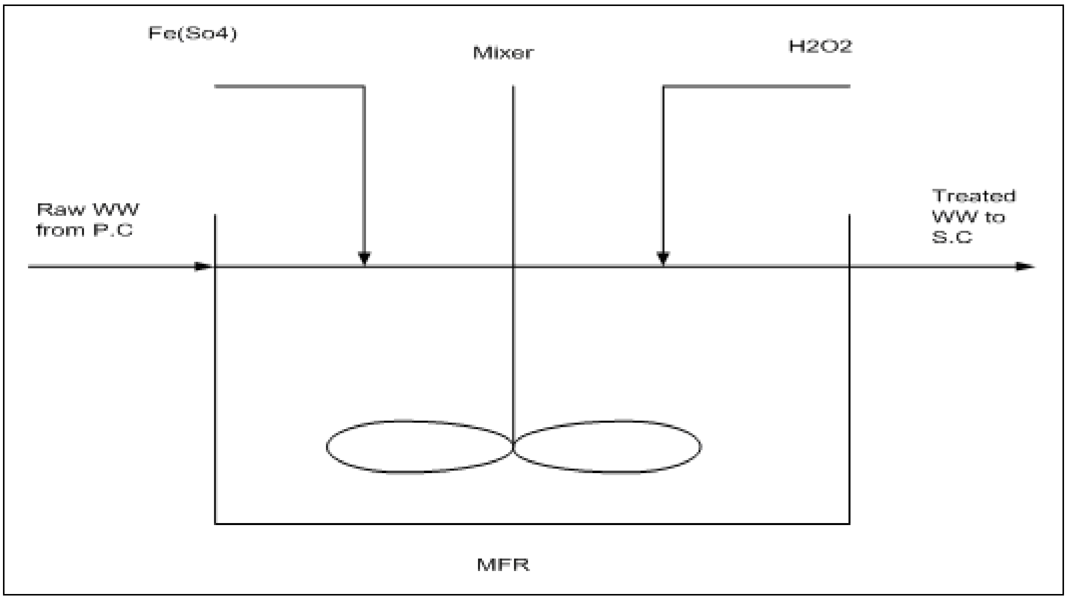

Fig. 6b. Simplified representation of Fenton process proposed for the WWTPs.

Fe^{+2}:H_2O_2 mass ratio ranges from 1:2 to 1:10 [9]. It was assumed (1:4) for this work purposes. H_2O_2:Organics mass ratio was assumed (1:2). Fenton reaction rate proceeds in accordance with approximate second-order kinetics for the first two minutes of the reaction, then, followed by zero order reaction [2]. The kinetics constants of the two reactions were reported within the range (k_1= 2.3 x 10^{-4} L mg L^{-1} min^{-1}, k_2= 26 mg L^{-1} min^{-1}) [2]. Space time (reaction time) was calculated using Mixed Flow Reactor (MFR) model.

$$k\tau = \frac{C_{Ao} - C_A}{c_A^2} \quad (10)$$

$$c_A = \frac{-1 + \sqrt{1 + 4k\tau C_A}}{2k\tau} \quad (11)$$

For optimization and comparison purposes, three cases of investigations were conducted in this research. 25%, 40% and 50% of the incoming BOD were assumed to be consumed in the MFR. Accordingly, detention time, H_2O_2 consumption rate and the volume of the aeration tank (including P-N units) were estimated for each case.

$$t_{ST} = t_{sa} \cdot \frac{1}{1 - \frac{V_D}{V}} = 4{,}93 \cdot \frac{1}{1 - 0{,}36} = 7.70\,day \quad (12)$$

$$WAS_{d,c} = (BOD_5\,load)\left(0{,}75 + 0{,}6\frac{X_0}{C_{BOD,0}} - \frac{(1-0{,}2).0{,}75.t_{ST}.0{,}17.1{,}072^{(T-15)}}{1 + t_{ST}.0{,}17.1{,}072^{(T-15)}}\right) \quad (13)$$

$$V = \frac{Mss}{X_{AT}} \quad (14)$$

Where:

t_{st}: Total sludge age (day), t_{sa} : Sludge age for nitrification (day), $WAS_{d,c}$: sludge produced by carbon removal kg. day^{-1}, V_D/V: Volumetric ratio for denitrification, Xo : Concentration of organic nitrogen mg.l^{-1}, X_{AT} : Sludge concentration mg.l^{-1}, and M_{SS} : Sludge mass kg.

Table (1) shows the results obtained.

Table 1. Integrated Fenton-Biological Calculation Results

Case No.	Incoming BOD (mg. L^{-1})	Outgoing BOD (mg. L^{-1})	MFR detention time (min)	Volume of A.T. (m^3)	Sludge age (days)	H_2O_2 consumption rate (kg.hr^{-1})
1	241.5	181	4.5	24719	7.7	76
2	241.5	145	7	29128	8	120
3	241.5	120.75	9	32148	8	151

Case 1 had met the objectives of this work in terms of reducing the volume of the aeration tank. The corresponding estimated H_2O_2 consumption rate was used for cost analysis to trade off capital cost reduction against the additional operating costs.

COST ANALYSIS

Capital and operating costs of the conventional wastewater treatment plant were estimated and compared to that of the researched plant. The per cost ($/m^3) was determined using the today prices of labor, energy, chemicals and construction works in Iraq.

($ / m^3) = [Annualized Project Cost + Annual O & M Cost] $.year^{-1} ÷ [Average Design Flow, m^3.day^{-1} x 365 days.year^{-1}] (15)

Annualized Project Cost = Unit Process Construction Including Equipments + Land Cost (16)

Annual O & M Cost = Labor Cost + Materials And Chemicals Cost + Energy Cost (17)

Table 2. Summarizes The Obtained Results Of Cost Analysis.

Process type	Capital cost ($)	Annualized capital cost ($/year)	Annualized O & M cost ($/year)	Total annualized cost ($/year)	Per unit cost ($/m^3)
Conventional	69825000	2327500	1400000	3727500	0.17
Fenton Integrated	66000000	2200000	1409120	3609120	0.16

It is clearly shown that Fenton- integrated process for wastewater treatment is a cost effective process. It has been proven that AOP processes not only improve water quality, but it may result in noticeable cuts in annualized cost of wastewater treatment plants. As AOP can reduce the incoming BOD to aeration tank, the volume of the aeration tank is considerably decreased because it is strongly dependent on BOD value.

CONCLUSIONS

The following conclusions can be drawn:

1. AOP processes are increasingly used in wastewater treatment as biological processes cannot remove complex and toxic materials from effluent water.
2. When Fenton (AOP) process integrated and properly positioned in biological wastewater treatment plant, it improves the treatment efficiency without extra annualized total costs because it saves in capital costs.
3. Considerable improvement in effluent water out of wastewater treatment plant that uses AOP processes can justify the little increase of the annualized operating costs of these processes.
4. Upgrading wastewater treatment plants may not require area extension when AOP processes is implemented and properly used. As nutrient removal units were required for reclamation, 50% increase in the volume of the aeration tank to accommodate those units is needed, but, when Fenton (AOP) process implemented, no extra volume is needed.

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Nomenclature:

C : concentration $mg.l^{-1}$
k : reaction rate constant
k_1, k_2 : kinetic constants
M : Transition Metal
M_{SS} : Sludge mass kg
r_1, r_2 : reaction rate
t_{st}: Total sludge age (day)
t_{sa} : Sludge age for nitrification (day)
V : Biological reactor volume m^3
V_D/V: Volumetric ratio for denitrification
$WAS_{d,c}$: sludge produced by carbon removal $kg.\ day^{-1}$
Xo : Concentration of organic nitrogen $mg.l^{-1}$
X_{AT} : Sludge concentration $mg.l^{-1}$

AOP : Advanced Oxidation Process
A.T : Aeration Tank
BOD: Biochemical Oxygen Demand
(F/M) : Food to Microorganism Ratio
MFR: Mixed Flow Reactor
MLSS: Mixed Liquor Suspended Solid $mg.l^{-1}$
MLVSS: Mixed Liquor Volatile Suspended Solid $mg.l^{-1}$
P.C : Primary Clarifier
S.C : Secondary Clarifier
TOC: Total Organic Carbon $mg.l^{-1}$