IFAS Wastewater Treatment Plants Performance Evaluation Using a Dynamic Model Approach

Aly Moursy [a)], Medhat Moustafa, Walid Elbarqi, Mai Fayd

Alexandria University, Faculty of Engineering, Sanitary Engineering Department, Alexandria 21544, Egypt

Abstract— **This study concerns the upgrading of a real domestic wastewater treatment plant (WWTP) supported by simulation. The main aims of this work are to: (1) Improve wastewater treatment plant performance Using integrated fixed film activated sludge (IFAS), and (2) perform a cost estimation analysis for proposed solution. The model used was calibrated based on data from the existing WWTP, namely, Eastern plant and located in Alexandria, Egypt. The activated sludge model No. 1 (ASM1) was considered in the model analysis by GPS-X 7 software. Steady-state analysis revealed that high performances corresponded to high compliance with Egyptian standards were achieved by IFAS technique.**

Keywords— **Activated sludge process; Integrated Fixed Film Activated Sludge; nutrient removal; wastewater treatment plant upgrading.**

I. Introduction

Many wastewater treatment plants, in Egypt, need to be upgraded in capacity and to remove also nitrogen and phosphorus, simulation scenarios can be performed over an extensive variety of process working conditions, in this study eastern treatment plant was developed with the aid of the process model [1]. Since 1970, there have been various studies on activated sludge modeling [2]. Based on the carbon oxidation processes, nitrification and denitrification and biological phosphorus removal, activated sludge models (ASM1, ASM2/ASM2d and ASM3) proved to be fantastic devices for biological modeling [3]. These models are currently applied in many commercial software's, such as GPS-X, SIMBA, AQUASIM, Bio Win, EFOR, STOAT and WEST [4].

Biofilms are small ecosystems usually consisting of three layers of differing thickness, which change in thickness and composition with location and over time [5]. In the first phase of colonization, macromolecules are adsorbed at clean solid surfaces (proteins, polysaccharides) lignin [6], because they are transported from the bulk liquid to the solid surface faster than the microorganisms are. As a consequence of this adsorption, the coverage of the solid surface with water is reduced. During the second phase, microbial cells attach to this prepared surface. Frequently, they do not form closed layers of uniform thickness, rather they form small attached colonies, which may spread by growth and further attachment.

Usually, these cells are supplied with substrate and oxygen and are able to grow at their maximum rate. During this process, they produce organic molecules, which diffuse through the cell wall and to extracellular polymeric substances (EPS) catalyzed by exoenzymes. These EPS molecules are necessary for the formation of a stable biofilm [6].

In the third phase, the biofilm may consist of bacteria and EPS, the thickness of which is a function of growth rate and depends on the stability of the biofilm and the shear stress of the flowing water [7]. At lower shear stresses, eukaryotic organisms 36 (protozoa, insects, their eggs and larvae) typically establish themselves. All these organisms live in a community. Materials such as substrates and oxygen are transported into the biofilm by diffusion and convection and the products are transported out of the biofilm. (protozoa, insects, their eggs and larvae) typically establish themselves. All these organisms live in a community. Materials such as substrates and oxygen are transported into the biofilm by diffusion and convection and the products are transported out of the biofilm. Protozoa, insects, their eggs and larvae typically establish themselves. All these organisms live in a community. Materials such as substrates and oxygen are transported into the biofilm by diffusion and convection and the products are transported out of the biofilm.

Nitrification is a microbial process that converts ammonia into nitrite and ultimately into nitrate. Ammonia in wastewater comes primarily from two sources: intense use of nitrogen-rich fertilizers such as urea and organic nitrogen from proteins. Wastewaters from the fishery, meat, and poultry industries contain substantial amounts of proteins. By the time these proteins reach the collection facilities of the WWTPs, most of them have been converted into peptides and amino acids by extracellular proteolytic enzymes and ultimately into ammonia. The nitrification process in biological wastewater treatment, i.e., the use of a limited group of autotrophic nitrifying bacteria to convert ammonia into nitrite and eventually nitrate, is often used in the so-called advanced phase of a wastewater treatment scheme if the concentration of ammonia in wastewater streams is high enough to warrant the treatment. Nitrification is a two-step process: (a) ammonia is first converted into nitrite by a group of bacteria called Nitrosomonas and (b) further conversion of nitrite leads to nitrate by another group of bacteria named Nitrobacter. Most nitrifying bacteria are autotrophic and utilize carbon dioxide as

the carbon source. For oxidation of ammonia, the biochemical reaction is expressed as the following (Equation 1) [8];

$$13NH_4^+ + 15CO_2 \rightarrow 10NO_2 + 3C_3H_7O_2N + 3.5CO_2^- + 23H^+ + 4H_2O \quad (1)$$

Denitrification can be viewed in some ways as a reversal of nitrification; however, although the denitrification does go through a two-step biochemical transformation, the end product of the denitrification is not ammonia or organic nitrogen; rather, it is inert gaseous nitrogen [9]. Denitrification can only be operated under anoxic conditions when the free oxygen level is very low, but not necessarily zero, and when a carbon source, such as methanol or settled sewer (which has low dissolved oxygen), is available. The biochemical reaction characterizing the denitrification process is brought about by a wide range of bacterial genera, mostly facultative anaerobes often present in wastewater streams [10].

The mixed liquor suspended solids (MLSS) of wastewater in the aeration basin consists mostly of microorganisms, no biodegradable suspended organic matter, and other inert suspended matter. The microorganisms in MLSS are composed of 70% to 90% organic and 10% to 30% inorganic matter. The types of bacterial cell vary, depending on the chemical characteristics of the influent wastewater tank conditions and the specific characteristics of the microorganisms in the flocs. Microbial growth in the mixed liquor is maintained in the declining or endogenous growth phase to insure good settling properties. After a certain reaction time (4 to 14 h) [1], the mixed liquor is discharged from the aeration tank to a secondary sedimentation basin (settling tank, clarifier) where the suspended solids are settled out from the treated wastewater by gravity. Most concentrated biological settled sludge is recycled back to the aeration tank (so-called return activated sludge, RAS) to maintain a high population of microorganisms to achieve rapid breakdown of the organics in the wastewater.

Placing the media has several advantages: Significant organic removal will have already taken place, the ammonia concentration is highest in early stages of the reactor favoring the nitrification capacity of the attached biomass, the DO may be reduced in the last compartment of the aerobic reactor so less DO is recycled back to the anoxic reactor, low intensity of mixing in the last com-apartment improves flocculation, and the last compartment is seeded with nitrifies from the media increasing the suspended AS nitrification in the last compartment.

The denitrification occurs when dissolved oxygen is depleted and nitrate is the dominant electron acceptor in the sewer system [11]. With the operational conditions in Bassussarry, this denitrification condition is partially carried out in the process. It can be possible that the system is oversaturated with oxygen avoiding fully anoxic conditions or instead the denitrification required longer anoxic conditions in the tank.

The following shows cost considerations by comparing IFAS systems vis-a-vis the conventional activated sludge as well as a comparative analysis between the two basic configurations of said systems.

- IFAS systems have lower capital cost requirement compared with the conventional activated sludge system.

- For system upgrade of existing activated sludge systems to increase capacity and enhance biological nutrient removal, savings are generated from not needing to require funds to provide additional volume storage otherwise needed to increase an activated sludge system capacity.

- While the need for continuous supply of oxygen remains, IFAS systems require little or no additional operational costs or personnel compared with the conventional activated sludge systems.

- Compared with fixed media, dispersed systems require funds for additional components (e.g., media-retaining sieves, air knives and/or pumps for sponge regeneration).

- In conducting the capital cost comparison of different IFAS media systems, the cost of removing a specific load of ammoniacal nitrogen (NH3-N) can be used as a good comparative tool.

- The treatment cost per pound of NH3-N daily using a fixed media IFAS system is a third less than that of the dispersed media.

II. Materials and Methods

Case study

The study was conducted on Eastern WWTP in Alexandria, which contains an inlet chamber (influent) that receives the wastewater to be treated, followed by the mechanical screens and 10 grit removal chambers with volume of 320 m3, followed by 16 primary circular sedimentation tanks with 3700 m3 volume, followed by 12 rectangular activated sludge tanks of 10000 m3, then followed by 24 final rectangular sedimentation tanks of 5500 m3 volume. Thus, the whole plant treats an influent wastewater flow of 650000 m3/day in 2016 (the year of study). The WWTP was designed to treat wastewater until year 2022 with a discharge of 804000 m3/day, but according to Alexandria master plan 2037, Eastern Treatment plant will serve 2.5 million persons with 1,200,000 m3/day. This study was

conducted to improve WWTP capacity to 1,200,000 m3/day. All experiments were conducted in Eastern WWTP laboratory and those included biological oxygen demand(BOD), chemical oxygen demand(COD), suspended solids(SS), total suspended solids(TSS), temperature, dissolved oxygen (DO), and ph. For upgrading the Eastern WWTP Conventional activated sludge process with fixed media (IFAS) were proposed,

Model calibration

The model parameters were adjusted so that a satisfactory agreement between the process and the model was achieved. From the suggested values of kinetic and stoichiometric parameters in GPS-X, only the following adjustments were considered as illustrated in Table (1). The real influent

concentrations used for model validation, for 10 days in December 2016, are as follow: TKN = 40 gm/m3, Ammonia = 30 gm/m3, Liquid temperature = 20°C, MLSS = 2000 gm/m3, Dissolved oxygen = 2 gm O2/m3, Sludge age = 6 days, flow rate = 30 % of waste flow from final settler = 6000 m3/day, and (COD, BOD and TSS) concentrations are presented in Table (2). The important step in this process is to assure the compatibility between the results obtained in the laboratory to those calculated from the model for BOD5, COD, TSS, and TKN to be able to rely on the simulated results from the program. It can be noted that the simulation results showed a similar quality of agreement with the actual results from the laboratory, as shown in Figure (1). All effluent data are accepted according to Egyptian code. Note that the average value of TKN removal efficiency is 70%, thus, the nitrogen removal efficiency is not enough to meet the Egyptian code requirements (5.0 mg/L) as the total nitrogen effluent concentration is about 27 mg/L.

TABLE 1. Stoichiometric and kinetic parameters values for ASM1.

ASM1 parameter	Symbol	20 °C	10 °C	Literature	Unit
Heterotrophic Yield	Y_H	0.67	0.67	0.38-0.75	g(cellCOD formed) /g(COD oxidized)
Autotrophic Yield	Y_A	0.24	0.24	0.07-0.28	g(cellCOD formed) /g(N oxidized)
Fraction of biomass yielding part. prod.	f_P	0.08	0.08	–	dimensionless
(Mass N)/(Mass COD) in biomass	i_{XB}	0.086	0.086	–	gN/gCOD
(Mass N)/(Mass COD) prod. from biomass	i_{XP}	0.06	0.06	–	gN/gCOD
Heterotrophic max. specific growth rate	μ_H	6.0	3.0	0.6-13.2	1/d
Half Saturation Coeff. (hsc) for heterotrophs	K_{SH}	20.0	20.0	5-225	gCOD/m3
Oxygen hsc for heterotrophs	K_{OH}	0.20	0.20	0.01-0.20	gO2/m3
Nitrate hsc for heterotrophs	K_{NO}	0.50	0.50	0.10-0.50	gNO3 − N/m3
Heterotrophic decay rate	b_H	0.62	0.20	0.05-1.60	1/d
Correction factor for growth for het.	η_g	0.80	0.80	0.60-1.0	dimensionless
Autotrophic max. specific growth rate	μ_A	0.80	0.30	0.20-1.0	1/d
Ammonia hsc for autotrophs	K_{NH}	1.0	1.0	–	gNH3 − N/m3
Oxygen hsc for autotrophs	K_{OA}	0.40	0.40	0.40-2.0	gO2/m3
Autotrophic decay rate	b_A	0.20	0.10	0.05-0.20	1/d
Ammonification rate	k_a	0.08	0.04	–	m3 /gCOD/d
Max. specific hydrolisys rate	k_h	3.0	1.0	–	g(slowly biodegr.COD) /g(cellCOD)/d
Hsc for hydrolysis of slowly biodegr. sub.	K_X	0.03	0.01	–	g(slowly biodegr.COD) /g(cellCOD)/d
Correction factor for anoxic hydrolysis	η_h	0.40	0.40	–	dimensionless

TABLE 2. Discharge, COD, BOD, and TSS input data, for verification, in Dec 2016.

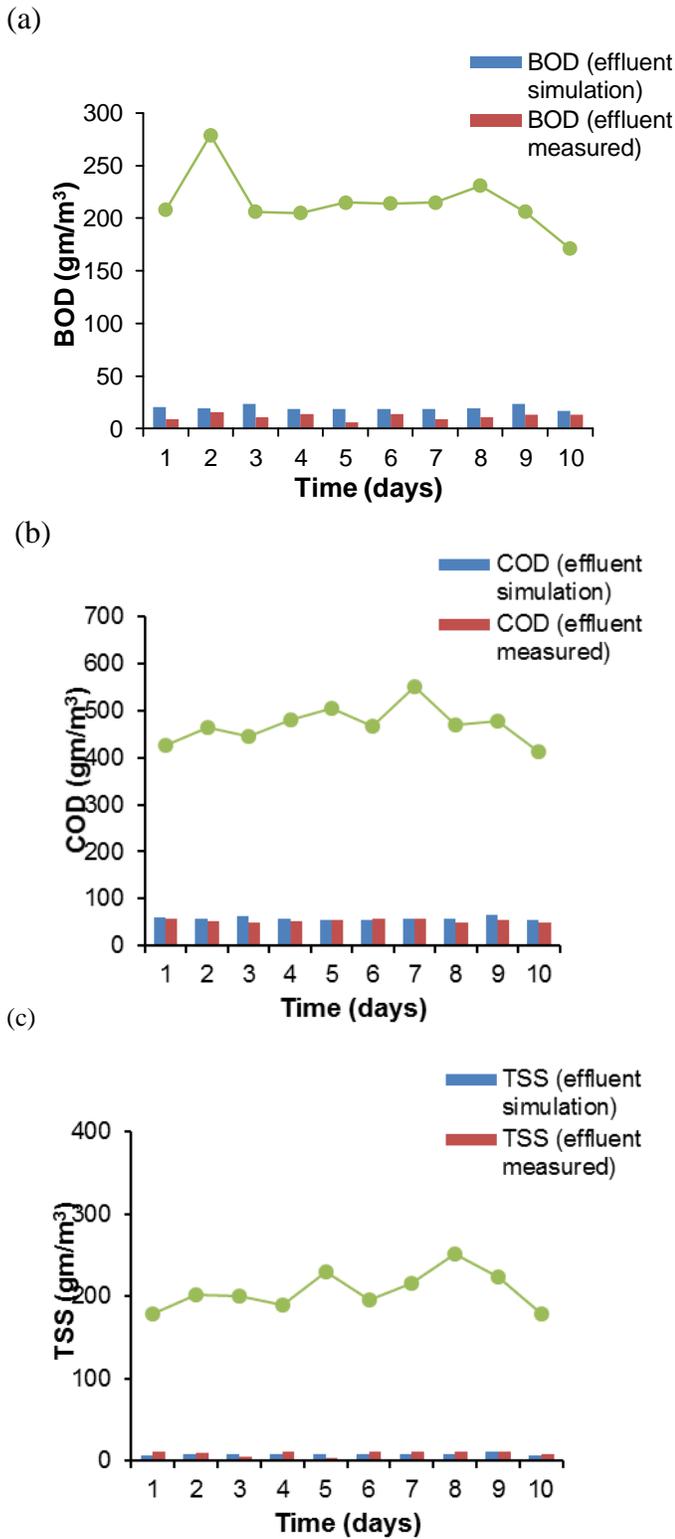| Time(days) Dec 2016	6	7	8	9	10	11	12	13	14	15
Q (m^3/day) × 1000	716	684	704	692	676	684	712	780	624	676
COD (gm/m^3)	427	465	445	480	505	467	551	471	477	413
BOD (gm/m^3)	208	297	206	205	215	214	215	231	206	171
TSS (gm/m^3)	178	202	200	190	230	196	216	252	224	178

III. Results and Discussion
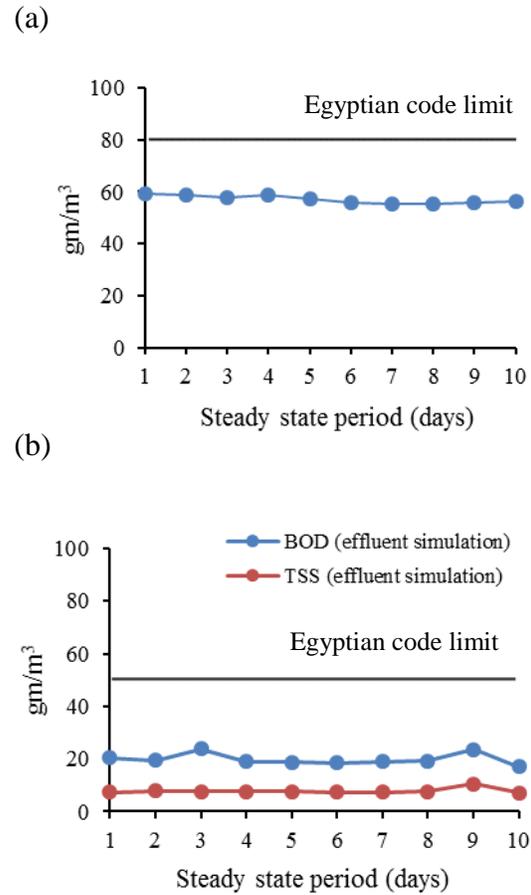
Steady-state analysis of IFAS

The models were used to evaluate the performance of IFAS system. The analysis was made based on the steady state performance. A constant influent discharge for year 2037 according to Alexandria master plan (1,200,000 m3/d) was considered, along with the same influent COD, BOD and TSS concentrations, as depicted in Table (1). IFAS plant was designed to use 40 sheets of biofilm media at each tank, with specific surface of 1000 1/m and density of 940 kg/m3, it can be noticed that effluent concentration still be accepted according to Egyptian code (BOD and TSS< 50 gm/m3) and (COD < 80 gm/m3), as shown in Figures (2). Nonetheless, TKN effluent concentration still not accepted complied with the Egyptian code requirements (5.00 mg/L). TKN effluent concentration is ~27 mg /L with an average removal efficiency of 30%.

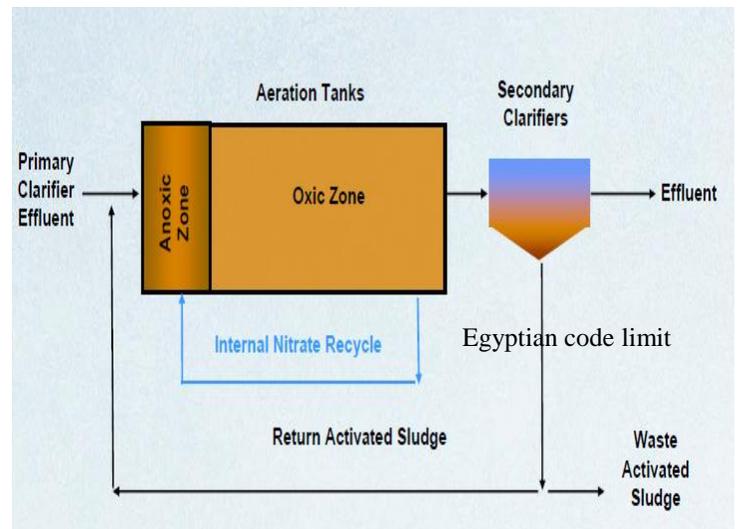WWTP nitrogen removal by year 2037 using IFAS

IN this scenario fixed media was added to aeration tanks to increase tanks efficiency, in addition to using two tanks before every aeration tank, the first one is the anaerobic tank with 5000 m3 volume, second one is anoxic tank with 5000 m3 volume, the internal recycle between aeration tank and anoxic tank equal aeration tank discharge = 100,000 m3/day. Number of biofilm media in one tank is 40 sheets, with specific surface 1000 1/m and density of 940 kg / m3 (according to program specifications), Note that fixed media installed in the existing aeration tanks Figure (3). Average COD effluent concentration is 35 mg/l, Figure (5), BOD effluent = 2.5 mg/l, TSS effluent = 6.5 mg/l and TKN effluent = 1.2 mg/l.

7

(a)

(a)

(b)

(b)

FIGURE 2. (a) COD effluent concentrations (IFAS), and (b) BOD and TSS effluent concentrations (IFAS).

(c)

FIGURE 1. (a) COD, (b)BOD and (c)TSS measured effluent and simulated effluent concentrations for Eastern WWTP (verification)

FIGURE 3 TKN removal tanks modifications (year 2037) for Eastern WWTP (IFAS).

8
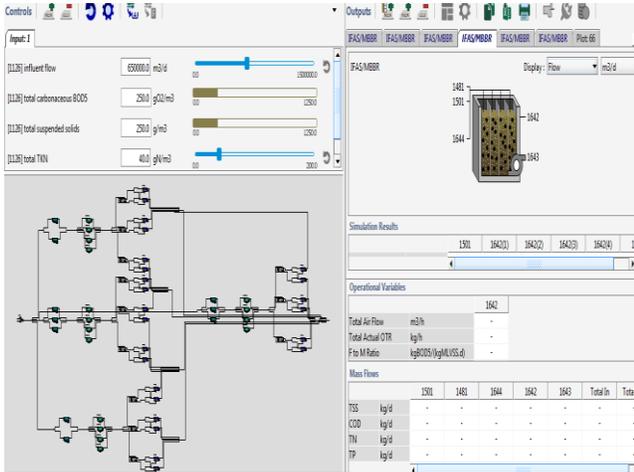
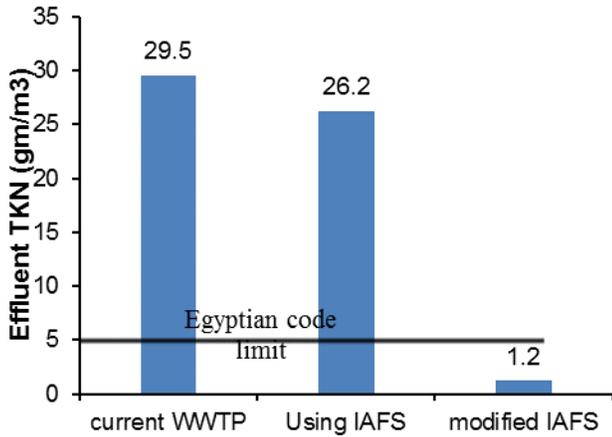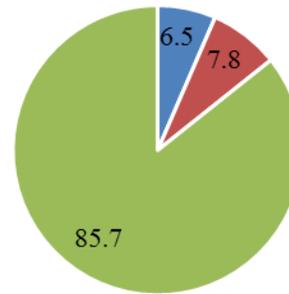**FIGURE 4** TKN removal using IFAS (GPS X 7 - simulation mode) by year 2037

TABLE 3. Daily predicted running cost for IFAS plant in 2037.

Unit	Aeration cost	Pumping cost	Miscellaneous Cost	Chemical dosage cost	Sludge disposal cost	Number of tanks	Total cost $/d
Primary settling	0.00	0.02	0.59	0.0	0.0	16	9.6
Aeration tank with fixed media	13.0	0.0	168	0.0	0.0	12	2172
Final sedimentation tank	0.00	7.36	1.68	0.0	0.0	24	216.96
Total cost							2398.56

FIGURE 5 TKN effluent concentrations by year 2037(nitrogen removal using IFAS).

FIGURE 6. Distribution of costs for IFAS.

A. Cost analysis for IFAS

Tables (3) and Figure (6) show the total daily running cost of IFAS plant, based on different power consumptions and the ratio of total running cost $/day, as resulted by GPS-X cost analysis application. The mathematical models of the system were designed and simulated by GPS-X 7 software. The model was calibrated based on Eastern plant operation criteria.

IV. Conclusion

• GPS-X model simulation showed good agreement with the measured data; simulation results are slightly lower than measured results, according to the optimum operational conditions considered in the model.

• The WWTP showed a poor nitrogen removal efficiency.

• The predicted efficiencies of IFAS reactor in 2037is complying with the Egyptian code standards (COD, BOD and TSS).

• The daily estimated cost of IFAS is slightly high, however, the capital cost of IFAS is low compared with other methods.

Acknowledgment

supported me. My heartfelt gratitude for engineer Yassin for his advice, help, and support.

References

[1] Grau, P., De Gracia, M., Vanrolleghem, P. A. & Ayesa, E.A new plant-wide modelling methodology for WWTPs. WaterResearch 41 (19), 4357–4372.

[2] Siegrist, H. & Tschui, M. Interpretation of experimental data with regard to the activated sludge model no. 1 and calibration of the model for municipal wastewater treatment plants. Water Science and Technology 25 (6), 167–183.

[3] Nuhoglu, A., Keskinler, B. & Yildiz, E. Mathematical modelling of the activated sludge process – the Erzincan case. Process Biochemistry 40 (7), 2467–2473.

[4] Olsson, G. & Newell, B.Wastewater Treatment Systems: Modelling, Diagnosis and Control. IWA publishing.

[5] David S. Meyer and Suzanne Staggenborg American Journal of Sociology Vol. 101, No. 6 (May, 1996), pp. 1628-1660.

[6] Wingender, J., Neu, T. & Flemming, H.-C. in Microbial Extracellular Polymeric Substances (eds Wingender, J., Neu, T. & Flemming, H.-C.) 1–19 (Springer, Heidelberg,1999).

[7] VAN LOOSDRECHT MCM (2008) Innovative nitrogen removal. Chapter 6. In: Henze M, Van Loosdrecht MCM, Ekama GA and Brdjanovic D (eds) Biological Wastewater Treatment: Principles, Modelling and Design. IWA Publishing, London. 528 pp. ISBN: 10:1843391880; 13:9781843391883.

[8] Liu, S.X., "Food and Agricultural Wastewater Utilization and Treatment," 1st edition. Blackwell Publishing, USA, 2007.

[9] Liu, S.X., "Food and Agricultural Wastewater Utilization and Treatment," 2 second edition. Blackwell Publishing, USA, 2004.

[10] Painter, H.A., "A review of the literature on inorganic nitrogen metabolism," Water Research V4, pp. 393–450, 1970.

[11] Edalat, F. (2008). Activated Carbon Application in Leachate Treatment. Lund: Water and
Environmental Engineering, Department of Chemical Engineering, LTH, Lund University.

About Author :

Aly Ahmed Moursy, PhD Student.
• Assistant Teacher
Department of sanitary Engineering, Faculty of Engineering, Alexandria University, Egypt.