© 2016 IJEDR | Volume 4, Issue 2 | ISSN: 2321-9939

Activated Sludge Treatment Process – Concept and System Design

Dr. Akshey Bhargava,
Professor (M.tech, Ph.D., LLB)
Department of Civil Engineering
Global Institute of Engineering and Technology, Hyderabad, India

***Abstract* - Activated Sludge Treatment is a biological wastewater treatment process which speeds up waste decomposition by adding Activated sludge into wastewater, and the mixture is aerated and agitated for a specified amount of time there by allowing the activated sludge to settle out by sedimentation and is disposed of (wasted) or reused (returned to the aeration tank). It is to everyone's advantage for a community to be able to treat its wastewater in the most economical way. The activated sludge process has the advantage of producing a high quality effluent for a reasonable operating and maintenance costs. The activated sludge process uses microorganisms to feed on organic contaminants in wastewater, producing a high-quality effluent. The basic principle behind all activated sludge processes is that as microorganisms grow, they form particles that clump together. These particles (floc) are allowed to settle to the bottom of the tank, leaving a relatively clear liquid free of organic material and suspended solids. An attempt has been made in the present paper to explain and conceptualize designed parameters relevant to Activated Sludge Treatment Process.**

I. INTRODUCTION

Activated sludge is a sludge particles reduced in wastewater by the growth of organisms in aeration tanks. The term 'activated' comes from the fact that the particles teem with bacteria, fungi, and protozoa and is different from primary sludge in the sense that the sludge particles contain many living organisms that can feed on the incoming wastewater. Described simply, screened wastewater is mixed with varying amounts of recycled liquid containing a high proportion of organisms taken from a secondary clarifying tank, and it becomes a product called mixed liquor. This mixture is stirred and injected with large quantities of air, to provide oxygen and keep solids in suspension. After a period of time, mixed liquor flows to a clarifier where it is allowed to settle. A portion of the bacteria is removed as it settles, and the partially cleaned water flows on for further treatment. The resulting settled solids, the *activated sludge*, are returned to the first tank to begin the process again. Today a number of variations of the basic process have been developed. This issue of *Pipeline* includes descriptions of three of the most common variations: Extended aeration, sequencing batch reactors, and oxidation ditches. The activated sludge plant is the most popular biological treatment process for larger installations. A glossary of terms that are used in activated sludge process is reflected as under:
Aerobic – a condition where oxygen is present
BOD – biological oxygen demand. Measure of oxygen organic material in the water requires.
Bulking – sludge that forms clouds in the secondary clarifiers when the sludge does not settle properly, usually caused by filamentous bacteria
F: M – Food to microbe ratio
Floc – clumps of bacteria
Flocculation – agitating wastewater to induce the small, suspended particles to bunch together into heavier particles (floc) and settle out.
Loading - a quantity of material added to the process at one time
MLSS – mixed-liquor suspended solids
MLVSS – volatile mixed-liquor suspended solids
Mixed liquor – activated sludge mixed with raw wastewater
Package plant – pre-manufactured treatment facility small communities or individual properties use to treat wastewater
SRT – solids retention time
Sludge – the solids that settle out during the process
Supernatant – the liquid that is removed from settled sludge. It commonly refers to the liquid between the sludge on the bottom and the scum on the surface.
TSS – total suspended solids
Wasting – removing excess microorganism's small package plants being used today. These plants are capable of producing a high quality effluent for the price. Other advantages of the activated sludge process are the low construction cost and the relatively small land requirement. The activated sludge process is widely used by large cities and communities where large volumes of wastewater must be highly treated economically. Activated sludge process plants are good choices too for isolated facilities, such as hospitals or hotels, cluster situations, subdivisions, and small communities.

II. THE PROCESS

A basic activated sludge process consists of several interrelated components: • An aeration tank where the biological reactions occur • An aeration source that provides oxygen and mixing • A tank, known as the clarifier, where the solids settle and are separated from treated wastewater • A means of collecting the solids either to return them to the aeration tank, (return activated sludge [RAS]), or to remove them from the process (waste activated sludge [WAS]). Aerobic bacteria thrive as they travel through the aeration tank. They multiply rapidly with sufficient food and oxygen. By the time the waste reaches the end of the tank (between four to eight hours), the bacteria has used most of the organic matter to produce new cells. The organisms settle to the bottom of the clarifier tank, water. This sludge is pumped back to the aeration tank where it is mixed with the incoming wastewater or removed from the system as excess, a process called wasting. The relatively clear liquid above the sludge, the supernatant, is sent on for further treatment as required.

III. SLUDGE CHARACTERISTICS

By analyzing the different characteristics of the activated sludge or the sludge quality, plant operators are able to monitor how effective the treatment plant’s process is. Efficient operation is ensured by keeping accurate, up-to-date records; routinely evaluating operating and laboratory data; and troubleshooting, to solve separating from the clearer problems before they become serious. A wide range of laboratory and visual and physical test methods are recommended. Principally, these include floc and settleability performance using a jar test, microscopic identification of the predominant types of bacteria, and analysis of various chemical parameters. The treatment environment directly affects microorganisms. Changes in food, dissolved oxygen, temperature pH, and total dissolved solids, sludge age.

IV. APPLICABILITY

Activated sludge treatment is suitable for use at places where the waste is organic chemical in nature like municipal sewage, pulp and paper industries, oil refineries, food processing units, textile processing units etc.

Activated-sludge process

The activated-sludge process is an aerobic, continuous-flow system containing a mass of activated micro-organisms that are capable of stabilizing organic matter. The process consists of delivering clarified waste-water, after primary settling, into an aeration basin where it is mixed with an active mass of microorganisms, mainly bacteria and protozoa, which aerobically degrade organic matter into carbon dioxide, water, new cells, and other end products. The bacteria involved in activated sludge systems are primarily 15 Gram-negative species, including carbon oxidizers, nitrogen oxidizers, floc formers and non-floc formers, and aerobes and facultative anaerobes. The protozoa, for their part, include flagellates, amoebas and ciliates. An aerobic environment is maintained in the basin by means of diffused or mechanical aeration, which also serves to keep the contents of the reactor (or mixed liquor) completely mixed. After a specific retention time, the mixed liquor passes into the secondary clarifier, where the sludge is allowed to settle and a clarified effluent is produced for discharge. The process recycles a portion of the settled sludge back to the aeration basin to maintain the required activated sludge concentration (see figure 1). The process also intentionally wastes a portion of the settled sludge to maintain the required solids retention time (SRT) for effective organic removal.

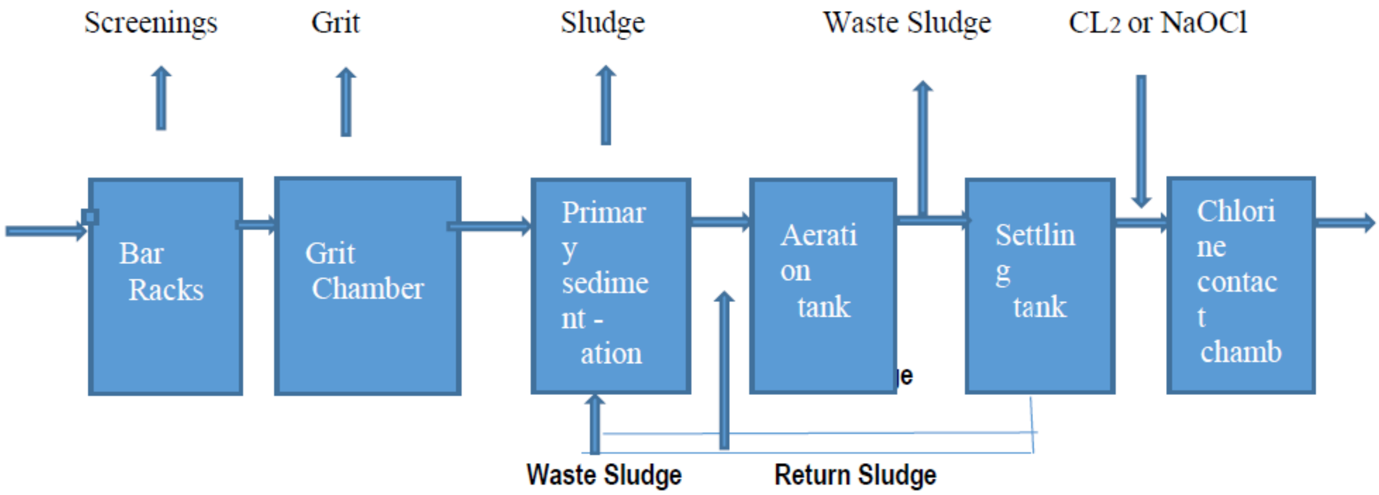

Figure 1. Typical flow diagram for an activated-sludge process

Control of the activated-sludge process is important to maintain a high treatment performance level under a wide range of operating conditions. The principal factors in process control are the following:

(a) Maintenance of dissolved oxygen levels in the aeration tanks;
(b) Regulation of the amount of returning activated sludge;
(c) Control of the waste activated sludge.

The main operational problem encountered in a system of this kind is sludge bulking, which can be caused by the absence of phosphorus, nitrogen and trace elements and wide fluctuations in pH, temperature and dissolved oxygen (DO). Bulky sludge has poor settleability and compactibility due to the excessive growth of filamentous micro-organisms. This problem can be controlled by chlorination of the return sludge. Table 1 presents a description of conventional activated-sludge processes and various modifications.

TABLE 1. DESCRIPTION OF ACTIVATED-SLUDGE PROCESSES AND PROCESS MODIFICATIONS:

Process or process Modification	**Description**	**BOD removal efficiency (Percentage)**
Conventional plugflow	Settled waste-water and recycled activated sludge enter the head of the aeration tank and are mixed by diffused air or mechanical aeration. Air application is generally uniform throughout the tank length. During the aeration period, adsorption, flocculation, and oxidation of organic matter occur. Activated-sludge solids are separated in a secondary settling tank	85-95
Complete-mix	Process is an application of the flow regime of a continuous-flow stirred tank reactor. Settled waste-water and recycled activated sludge are typically introduced at several points in the aeration tank. The organic load on the aeration tank and the oxygen demand are uniform throughout the tank length.	85-95
Tapered aeration	Tapered aeration is a modification of the conventional plug-flow process. Varying aeration rates are applied over the tank length, depending on the oxygen demand. Greater amounts of air are supplied to the head end of the aeration tank, and the amounts diminish as the mixed liquor approaches the effluent end. Tapered aeration is usually achieved by using different spacing of the air diffusers over the tank length.	
Step-feed aeration	Step feed is a modification of the conventional plug-flow process in which the settled waste-water is introduced at several points in the aeration tank to equalize the food to micro-organism (F/M) ratio, thus lowering peak oxygen demand. Three or more parallel channels are commonly used. Flexibility of operation is one of the important features of this process.	85-95
Modified aeration	Modified aeration is similar to the conventional plug-flow process except that shorter aeration times and higher F/M ratios are used. BOD removal efficiency is lower than in the case of other activated-sludge processes	60-75
Contact stabilization	Contact stabilization uses two separate tanks for the treatment of the waste-water and the stabilization of the activated sludge. The stabilized activated sludge is mixed with the influent (either raw or settled) wastewater in a contact tank. The mixed liquor is settled in a secondary settling tank and return sludge is aerated separately in a re-aeration basin for stabilization of the organic matter. Aeration volume requirements are typically 50 percent less than in the case of conventional plug flow.	80-90
Extended aeration	The extended aeration process is similar to the conventional plug-flow process except that it operates in the endogenous respiration phase of the growth curve, which requires a low organic loading and long aeration time. The process is used extensively for prefabricated package plants for small communities	75-95
High-rate aeration	High-rate aeration is a process modification in which high mixed liquor suspended solids (MLSS) concentrations are combined with high volumetric loadings. The combination allows high F/M ratios and low mean cell-residence times with relatively short hydraulic detention times. Adequate mixing is very important.	75-90
Kraus process	The Kraus process is a variation of the step aeration process used to treat waste-water with low nitrogen levels. Digester supernatant is added as a nutrient source to a portion of the return sludge in a separate aeration tank designed to nitrify. The resulting mixed liquor is then added to the main plug-flow aeration system.	85-95
High-purity oxygen	High-purity oxygen is used instead of air in the activated-sludge process. The oxygen is diffused into covered aeration tanks and is recirculated. A portion of the gas is wasted to reduce the concentration of carbon dioxide. pH adjustment may also be required. The amount of oxygen added is about four times greater than the amount that can be added by conventional aeration systems	85-95
Oxidation ditch	The oxidation ditch consists of a ring- or oval-shaped channel and is equipped with mechanical aeration devices. Screened waste-water enters the ditch, is aerated, and circulates about 0.8 to 1.2 ft/s (0.25 to 0.35 m/s). Oxidation ditches typically operate in an extended aeration mode with long detention and solids retention times. Secondary sedimentation tanks are used for most applications.	75-95
Sequencing batch	The sequencing batch reactor is a fill-and-draw type reactor system involving a single complete-mix reactor in which all steps of the	85-95

reactor	activated-sludge process occur. Mixed liquor remains in the reactor during all cycles, and this eliminates the need for separate secondary sedimentation tanks.	
Deep shaft reactor	The deep vertical shaft reactor is a form of the activated-sludge process. A vertical shaft about 400 to 500 ft (120 to 150 m) deep replaces the primary clarifiers and aeration basin. The shaft is lined with a steel shell and fitted with a concentric pipe to form an annular reactor. Mixed liquor and air are forced down the centre of the shaft and allowed to rise upward through the annulus	85-95
Single-stage Nitrification	In single-stage nitrification, both BOD and ammonia reduction occur in a single biological stage. Reactor configurations may be either a series of complete-mix reactors or plug-flow	85-95
Separate-stage Nitrification	In separate-stage nitrification, a separate reactor is used for nitrification, operating on a feed waste from a preceding biological treatment unit. The advantage of this system is that operation can be optimized to conform to nitrification needs	85-95

V. DESIGN CONSIDERATION

. The items for consideration in the design of activated sludge plant are aeration tank capacity and dimensions, aeration facilities, secondary sludge settling and recycle and excess sludge wasting

Aeration Tank

The volume of aeration tank is calculated for the selected value of θ_c by assuming a suitable value of MLSS concentration, X.

$$VX = \frac{YQ\theta_c(S_O - S)}{1+k_d\theta_c}$$

Alternately, the tank capacity may be designed from

$$F/M = QS_O / XV$$

Hence, the first step in designing is to choose a suitable value of θ_c (or F/M) which depends on the expected winter temperature of mixed liquor, the type of reactor, expected settling characteristics of the sludge and the nitrification required. The choice generally lies between 5 days in warmer climates to 10 days in temperate zones where nitrification is desired along with good BOD removal, and complete mixing systems are employed.

The second step is to select two interrelated parameters HRT, t and MLSS concentration. It is seen that economy in reactor volume can be achieved by assuming a large value of X. However, it is seldom taken to be more than 5000 g/m3. For typical domestic sewage, the MLSS value of 2000-3000 mg/l if conventional plug flow type aeration system is provided, or 3000-5000 mg/l for completely mixed types. Considerations which govern the upper limit are: initial and running cost of sludge recirculation system to maintain a high value of MLSS, limitations of oxygen transfer equipment to supply oxygen at required rate in small reactor volume, increased solids loading on secondary clarifier which may necessitate a larger surface area, design criteria for the tank and minimum HRT for the aeration tank.

The length of the tank depends upon the type of activated sludge plant. Except in the case of extended aeration plants and completely mixed plants, the aeration tanks are designed as long narrow channels. The width and depth of the aeration tank depends on the type of aeration equipment employed. The depth control the aeration efficiency and usually ranges from 3 to 4.5 m. The width controls the mixing and is usually kept between 5 to 10 m. Width-depth ratio should be adjusted to be between 1.2 to 2.2. The length should not be less than 30 or not ordinarily longer than 100 m.

Oxygen Requirements

Oxygen is required in the activated sludge process for the oxidation of a part of the influent organic matter and also for the endogenous respiration of the micro-organisms in the system. The total oxygen requirement of the process may be formulated as follows:

$$O_2 \text{ required (g/d)} = \frac{Q(S_O - S)}{f} - 1.42\, Q_w X_r$$

where, f = ratio of BOD_5 to ultimate BOD and 1.42 = oxygen demand of biomass (g/g)

The formula does not allow for nitrification but allows only for carbonaceous BOD removal.

Aeration Facilities

The aeration facilities of the activated sludge plant are designed to provide the calculated oxygen demand of the wastewater against a specific level of dissolved oxygen in the wastewater.

Secondary Settling

Secondary settling tanks, which receive the biologically treated flow undergo zone or compression settling. Zone settling occurs beyond a certain concentration when the particles are close enough together that interparticulate forces may hold the particles fixed relative to one another so that the whole mass tends to settle as a single layer or "blanket" of sludge. The rate at which a sludge blanket settles can be determined by timing its position in a settling column test whose results can be plotted as shown in figure.

Compression settling may occur at the bottom of a tank if particles are in such a concentration as to be in physical contact with one another. The weight of particles is partly supported by the lower layers of particles, leading to progressively greater compression with depth and thickening of sludge. From the settling column test, the limiting solids flux required to reach any desired underflow concentration can be estimated, from which the required tank area can be computed.

The solids load on the clarifier is estimated in terms of (Q+R)X, while the overflow rate or surface loading is estimated in terms of flow Q only (not Q+R) since the quantity R is withdrawn from the bottom and does not contribute to the overflow from the tank. The secondary settling tank is particularly sensitive to fluctuations in flow rate and on this account it is recommended that the units be designed not only for average overflow rate but also for peak overflow rates. Beyond an MLSS concentration of 2000 mg/l the clarifier design is often controlled by the solids loading rate rather than the overflow rate. Recommended design values for treating domestic sewage in final clarifiers and mechanical thickeners (which also fall in this category of compression settling) are given in lecture 22.

Design of Completely Mixed Activated Sludge System

Design a completely mixed activated sludge system to serve 60000 people that will give a final effluent that is nitrified and has 5-day BOD not exceeding 25 mg/l. The following design data is available.

Sewage flow = 150 l/person-day = 9000 m3/day
BOD5 = 54 g/person-day = 360 mg/l ; BODu = 1.47 BOD5
Total kjeldahl nitrogen (TKN) = 8 g/person-day = 53 mg/l
Phosphorus = 2 g/person-day = 13.3 mg/l
Winter temperature in aeration tank = 18°C
Yield coefficient Y = 0.6 ; Decay constant Kd = 0.07 per day ; Specific substrate utilization rate = (0.038 mg/l)-1 (h)-1 at 18°C
Assume 30% raw BOD5 is removed in primary sedimentation, and BOD5 going to aeration is, therefore, 252 mg/l (0.7 x 360 mg/l).

Sludge Recycle

The MLSS concentration in the aeration tank is controlled by the sludge recirculation rate and the sludge settleability and thickening in the secondary sedimentation tank.

$$\frac{Qr}{Q} = \frac{X}{Xr-X}$$

where Qr = Sludge recirculation rate, m3/d

The sludge settleability is determined by sludge volume index (SVI) defined as volume occupied in mL by one gram of solids in the mixed liquor after settling for 30 min. If it is assumed that sedimentation of suspended solids in the laboratory is similar to that in sedimentation tank, then Xr = 106/SVI. Values of SVI between 100 and 150 ml/g indicate good settling of suspended solids. The Xr value may not be taken more than 10,000 g/m3 unless separate thickeners are provided to concentrate the settled solids or secondary sedimentation tank is designed to yield a higher value.

Excess Sludge Wasting

The sludge in the aeration tank has to be wasted to maintain a steady level of MLSS in the system. The excess sludge quantity will increase with increasing F/M and decrease with increasing temperature. Excess sludge may be wasted either from the sludge return line or directly from the aeration tank as mixed liquor. The latter is preferred as the sludge concentration is fairly steady in that case. The excess sludge generated under steady state operation may be estimated by

$$\square c = \frac{VX}{QwXr}$$

Design

Selection of □c, t and MLSS concentration

Considering the operating temperature and the desire to have nitrification and good sludge settling characteristics, adopt □c = 5d. As there is no special fear of toxic inflows, the HRT, t may be kept between 3-4 h, and MLSS = 4000 mg/l.

Effluent BOD5

$$\text{Substrate concentration, } S = \frac{1}{qY}(1/\square c + kd) = \frac{1}{(0.038)(0.6)}(1/\square\square + 0.07)$$

S = 12 mg/l.

Assume suspended solids (SS) in effluent = 20 mg/l and VSS/SS =0.8.

If degradable fraction of volatile suspended solids (VSS) =0.7 (check later), BOD5 of VSS in effluent = 0.7(0.8x20) = 11mg/l.

Thus, total effluent BOD5 = 12 + 11 = 23 mg/l (acceptable).

Aeration Tank

$$VX = \frac{YQ\square c(SO - S)}{1+ kd\square c} \quad \text{where } X = 0.8(4000) = 3200 \text{ mg/l}$$

$$\text{or } 3200\,V = \frac{(0.6)(5)(9000)(252-12)}{[1 + (0.07)(5)]}$$

$$V = 1500 \text{ m3}$$

$$\text{Detention time, } t = \frac{1500 \times 24}{9000} = 4\text{h}$$

$$F/M = \frac{(252-12)(9000)}{(3200)(1500)} = 0.45 \text{ kg BOD5 per kg MLSS per day}$$

Let the aeration tank be in the form of four square shaped compartments operated in two parallel rows, each with two cells measuring 11m x 11m x 3.1m

Return Sludge Pumping

If suspended solids concentration of return flow is 1% = 10,000 mg/l

$$R = \frac{MLSS}{(10000)-MLSS} = 0.67$$

Qr = 0.67 x 9000 = 6000 m3/d

Surplus Sludge Production

$$\text{Net VSS produced } Q_wX_r = \frac{VX}{\square c} = \frac{(3200)(1500)(103/106)}{(5)} = 960 \text{ kg/d}$$

or SS produced =960/0.8 = 1200 kg/d

If SS are removed as underflow with solids concentration 1% and assuming specific gravity of sludge as 1.0,

Liquid sludge to be removed = 1200 x 100/1 = 120,000 kg/d

= 120 m3/d

Oxygen Requirement

1. For carbonaceous demand,

oxygen required = (BODu removed) - (BODu of solids leaving)

= 1.47 (2160 kg/d) - 1.42 (960 kg/d)

= 72.5 kg/h

2. For nitrification,

oxygen required = 4.33 (TKN oxidized, kg/d)

Incoming TKN at 8.0 g/ person-day = 480 kg/day. Assume 30% is removed in primary sedimentation and the balance 336 kg/day is oxidized to nitrates. Thus, oxygen required

= 4.33 x 336 = 1455 kg/day = 60.6 kg/h

3. Total oxygen required

= 72.5 + 60.6 = 133 kg/h = 1.0 kg/kg of BODu removed.

Oxygen uptake rate per unit tank volume = 133/1500

= 90.6 mg/h/l tank volume

Power Requirement

Assume oxygenation capacity of aerators at field conditions is only 70% of the capacity at standard conditions and mechanical aerators are capable of giving 2 kg oxygen per kWh at standard conditions.

$$\text{Power required} = \frac{136}{0.7 \times 2} = 97 \text{ kW (130 hp)}$$

= (97 x 24 x 365) / 60,000 = 14.2 kWh/year/person

VI. CONCLUSIONS

Activated sludge treatment process is widely used in the treatment of municipal sewage and industrial waste waters due to the fact that it's economically viable and reasonably safe to operate. Such a system can be used in large installations. However it's very important to have compatible design parameters to be infused while designing Activated Treatment Plant. Moreover, air requirement, MLSS, MLVSS, etc. are very important parameters to be maintained in the system. The present paper deals with these aspects to impart an over view of the conceptualization along with system design.

VII. REFERENCES

[1] Abdul-Malik, Q.Y. Yemen's Water Resources and Treated Wastewater. Sana'a: Ministry of Agriculture and Irrigation of Yemen, n.d. Available at: Adham, S, J. Jacangelo and J.M. Lainé. "Characteristics and costs of MF and UF plants". Journal AWWA, May 1996.
[2] American Water Works Association and American Society of Civil Engineers. Water Treatment Plan Design. New York: McGraw-Hill, 1990.
[3] Balkema, A. Sustainability criteria for the comparison of wastewater treatment technologies. Paper prepared for the Eleventh European Junior Scientist Meeting, "The Myth of Cycles versus Sustainable 4. 4. Water and Material Flux Management", Wildpark Eekholt, Germany, 12-15 February 1998.
[4] Bataineh, F., M. Najjar and S. Malkawi. Wastewater Reuse. Paper presented at the Water Demand Management Forum, Amman, Jordan, March 2002. Available at:.Black and Veatch.
[5] Gabal Al Asfar Treatment Plant. Available at: http://www.bbv-ltd.com/Projects/WSTD/GlobslEIATP.htm.
[6] Faeth, P. Fertile ground: Nutrient Trading's Potential to Cost-effectively Improve Water Quality. Washington, D.C.: World Research Institute, 2000.
[7] Fluid Knowledge. Background on Water and Wastewater Industry. 2000. Available at: http://www.fluidknowledge.com/waterlist/html/waterindustry.html.
[8] Garrett, T.M. Jr. "Instrumentation, Control and Automation Progress in the United States in the Last 24 Years". Water Science and Technology, 37, pp. 21-25.

[9] Droste, R.L. Theory and Practice of Water and Wastewater Treatment. New York: John Wiley and Sons, 1996

[10] Liu, D.H.F. and B.G. Lipták. Wastewater Treatment. Boca Raton, Florida: Lewis, 1999.

[11] McGhee, T.J. Water Supply and Sewerage. New York: McGraw-Hill, 1991.

[12] Metcalf and Eddy, Inc. Wastewater Engineering: Treatment Disposal and Reuse, third edition. New York: McGraw-Hill, 1991.

[13] Metcalf and Eddy, Inc. Wastewater Engineering: Treatment and Reuse, fourth edition. New York: McGraw-Hill, 2003.