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# IMPROVED NONLINEAR HETEROGENEOUS MODEL FOR WASTEWATER TREATMENT

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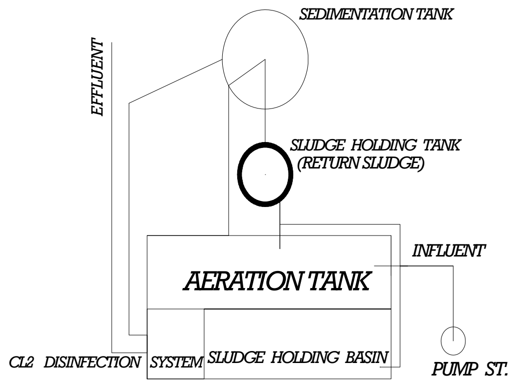
**Abstract**-The important aim in this research is to decrease BOD5 amount equal to 80-90 percent. The main approach of present work was the changes study on behavior of the wastewater fluids flow state and its effect on pure Oxygen penetration in wastewater flow. Comparison between laboratory observations on fluid streamlines in pipes for three cases including: laminar flow-transient flow and turbulent flow showed that the little error in the results.

**Keywords:** Pure Oxygen, Wastewater Treatment, Activated Sludge, Porous Diffusers.

## I. INTRODUCTION

Irreversibility of fluid dynamics phenomenon is an important case study about heterogeneous model with varying state within the system for designer engineers. In this research, miscible wastewater interpenetration happened when they move themselves in the separated pipes toward the common joint and pipe in aeration tank. Fluid condition for example: velocity; pressure; temperature and the other properties in the pipes were homogeneous .In this work pure Oxygen was introduced in wastewater by a 40 (lit) pure $O_2$ container. By submerged porous diffusers and air nozzles pure $O_2$ was entered to aeration tank by transient flow. Microorganisms by received pure $O_2$ grown quickly is illustrated in Figure 1. This paper presents the computational performance of numerical methods for modeling of pure Oxygen diffusion in wastewater transient flow. This Model was defined by method of the Eulerian based expressed in a method of characteristics "MOC" based on finite difference form. Pure Oxygen has been diffused in the activated sludge wastewater treatment process (pipeline and aeration tank). This method needs to low detention time and low structural space for wastewater treatment plant [1]. In model studies and analysis of prototype problems, similarity law for flow in pumping is generally valid for one-phase flow. Present guidelines and standards for equivalent model and prototype analysis accept that similarity of flow in model and prototype turbomachines (pump stations) exist before the critical cavitation coefficients are reached.




**Conventional Activated Sludge**

Figure 1. Wastewater flow diagram in conventional activated sludge system (A.T. = aeration tank, S.T. = sludge tank)

Between the zone of incipient cavitation and critical cavitation, similarity is considered to be satisfactory for the analyses of internal flow in pumping. However, for flow in the downstream of the pump station and pipe system, a small quantity of Oxygen gas bubbles will change system wave speed characteristics and the similarity for the model. The study of hydraulic transient and hydraulic vibration problems may be difficult to satisfy. When pump stations operate in the zone of cavitation, air bubbles or Oxygen will flow through the pump resulting in two-phase flow in the downstream of the fluid system. Though deaeration devices may be used to minimize the air content, some air will still remain in the fluid system. Since it is almost impossible to predict the quantity of air getting through the pump and remain downstream of the system, systematic analysis has to be carried out. It is assumed with various amount of Oxygen content in the model analysis of the transient fluid flow problem. The first study on the effects of air content on wave speed in a transient fluid system was conducted by

Whiteman and Pearsall (1959). Detail survey on effects of air on wave speed in fluid systems was given by Lee (1991) [2]. Oxygen diffusion in wastewater first was conducted by Union Carbide Corporation (1974). This work is the first research on the effects of Oxygen diffusion in wastewater transient flow.

## II. MATERIALS AND METHODS

This paper presents the application of computational performance of a numerical method by a dynamic model. The model has been presented by the method of Eulerian expressed in a method of characteristics (MOC). It has been defined by finite difference form for heterogeneous model with varying state in the system. The present work offered MOC as a computational approach from theory to practice in numerical analysis modeling. Therefore it is computationally efficient for transient flow irreversibility prediction in a practical case. The difference or improvement of the methods and analysis study is based upon the physical conservation laws of mass, momentum, and energy. The mathematical statements of these laws may be written in either integral or differential form. The integral form is useful for large-scale analyses and provides answers that are sometimes very good and sometimes not, but that are always useful, particularly for engineering applications. The differential form of the equations is used for small-scale analyses. In principle, the differential forms may be used for any problem, but exact solutions can be found only for a small number of specialized flows. Solutions for most problems must be obtained by using numerical techniques, and these are limited by the computer's inability to model small-scale processes. Water hammer (hydrodynamics instability) is caused by a pressure wave or shock wave that travels faster than the sound through the pipes. It is resulted by a sudden stop in the velocity of the water, or a change in the direction. It's also described as a rumbling, shaking vibration in the pipes. Various methods have been developed to solve transient flow in pipes. These ranges of methods are included by approximate equations to numerical solutions of the nonlinear Navier-Stokes equations. In this work a case study with experimental and computational approach on hydrodynamics instability for a wastewater pipeline has been presented. Present work used the method of characteristics "MOC" to solve virtually any hydraulic transient problems of wastewater flow in conventional activated sludge system. Dateline for field tests & lab. Model data collection was: at 10:00 a.m., 10/02/08 until 09/02/09. The method of characteristics "MOC" is based on a finite difference technique, where pressures are computed along the pipe for each time step. Two cases are considered for modeling:

1- The combined elasticity of both the wastewater and the pipe walls is characterized by the pressure wave speed (Arithmetic method combination of Joukowski (1) formula & Allievi (2) formula) [3]:

$$H_2 - H_1 = (C/g)(v_2 - v_1) = \rho C(v_2 - v_1) \tag{1}$$

(Joukowski formula)

$$c = 1/\left[\rho\left((1/k) + (d.C_1/E.e)\right)\right]1/2 \tag{2}$$

(Allievi formula)

With combination of Joukowski Formula & Allievi formula (3) and (4):

$$\lambda\begin{bmatrix}(\partial v/\partial t) + (1/\rho)(\partial p/\partial s) + \\ g(dz/ds) + (f/2D)v|v|\end{bmatrix} +$$

$$C^2(\partial v/\partial s) + (1/p)(\partial p/\partial t) = 0, \tag{3}$$

$$\lambda =^{+} c \quad \& \quad \lambda =^{-} c$$

Hence, water hammer pressure or surge pressure (*ΔH*) is a function of independent variables (*X*) such as:

$$\Delta H \approx \rho, K, d, C_1, fe, V, g \tag{4}$$

2- The method of characteristics (MOC) based on a finite difference technique where pressures (5) and (6) are computed along the pipe for each time step

$$H_P = \frac{1}{2}\begin{pmatrix} C/g(V_{Le} - V_{ri}) + (H_{Le} + H_{ri}) \\ -C/g(f\,\Delta t/2D)(V_{Le}\;|V_{Le}| - V_{ri}|V_{ri}|)\end{pmatrix} \tag{5}$$

$$V_P = \frac{1}{2}\begin{pmatrix} (V_{Le} + V_{ri}) + (g/c)(H_{Le} - H_{ri}) \\ -(f\,\Delta t/2D)(V_{Le}\;|V_{Le}| + V_{ri}|V_{ri}|)\end{pmatrix} \tag{6}$$

Transient analysis results that are not comparable with actual system measurements are generally caused by inappropriate system data (especially boundary conditions) and inappropriate assumptions [4].

Behavior of the wastewater fluids flow state as a combination of the diffusing process and remixing process have been studied. In this process high speed treatment has been achieved. Also $CO_2$ is released and $O_2$ is utilized by micro – organisms as result of their activity. In this work the formulation of process in wastewater transmission line and aeration tank are as flowing [5].

$$V = L_O / B_V \tag{7}$$

$$B_V = MLSS \times MLVSS \tag{8}$$

$$R_t = V/Q \tag{9}$$

In the case of low *F/M*, micro-organisms feed by organic material in wastewater or feed by other micro-organisms.

In order to save balancing condition, we need to high return sludge and high MLSS. On the base of European standard, for Days without rain [4], the ratio of *RS* per max influent become 100 percent (10) and can be achieved from the flowing relations:

$$RS/Q_{\max} = \left[MLSS/(SMLSS - MLSS)\right] \times 100 \tag{10}$$

There was a problem in the treatment process when Sludge volume index (SVI) was become more than 200. In this condition, sedimentation was failed. By decreasing SVI, aeration time was decreased.

### A. Sludge Volume Index (SVI)

The amount of surplus sludge (11) that must be removed from the settling tank was related to Biochemical oxygen demand «BOD5» of influent entrance to aeration tank and settling tank output.

$$\text{Sludge age} = (MLSS) \times (V)/(SS_e \times Q + SLS) \tag{11}$$

### B. Oxygenation Calculation

A Portion of absorbed pure Oxygen spent informs of energy consumption and multiplying of Bacteria. The other part of $O_2$ spent for oxidation (12) of organic carbonate and organic nitrogenous material [5].

$$Q_V = A_Y B_V + B(MLSS) + 3 - 4(ON) \quad (12)$$

### C. Process Design

$$O_C = \left[C_S / A(F)(C_S - C_X)\right] \times \left[0.5YB_V + 0.1MLSS + 3.4ON\right] \quad (13)$$

### D. Design Criteria

The air phase; it is suggested to incorporate the air-phase flow component to the mixed flow model. Influent production per person = 200 (lit/day)

Max influent factor = 1.71 (per 14 hours)

$B_V = 0.5\left(\text{kgBOD5/m}^3\text{day}\right)$

$B_V / MLVSS = F / M = .15$

$BOD5 = 60(\text{gr/p-d}) = 0.06(\text{kg/p-d})$

Wastewater Temperature=20 ∘C

## III. RESULTS AND DISCUSSIONS

In this work pure oxygen was introduced in to the wastewater from a 40 lit pure $O_2$ container. By submerged porous diffusers and by air nozzles pure $O_2$ was entered to aeration tank. Then micro-organisms by received pure $O_2$ was grown quickly.

### A. Research Approach

Pollution Decreasing is illustrated in Figures 2-3 to 20 (mg/lit) for BOD5.

- Influent pollution calculation:
- Fixed population=700
-Office workers=500
-Total population=1200

$Q_m^d = (700)(0.2) + 500(0.05) = 165\left(\text{m}^3/\text{day}\right)$

Max Influent per hour are illustrated in Figure 3:

$Q_m^d = 165/14 = 12\left(\text{m}^3/\text{h}\right) = 3.3(\text{lit/sec}),$

Total amount of Influent pollution:

$0.06(1200) = 72(\text{kg/p-day})$

Average amount of influent pollution:

$72/165 = 0.45(\text{kg/m}^3) = 450(\text{mg/lit})$

Due to pollution-detention curves, decrease of influent pollution relation with detention time is detention time:

$R_t = V/Q =$ Tank Volume / influent flow rate

$R_t + 200/12 = 17(\text{h})$

Pollution Decreasing percent = 0.35

$450(1-0.35) = 293(\text{mg/lit})$

Average amount of influent pollution:

(Per 24 hours) = 0.293(165) = 48.5(kg BOD/day)

### B. Oxygen Required Calculation

From Figure 2:

$C_S = 9.17$ & $A$=0.9 & $Y$=0.925 & $F$=0.85

$MLSS = 3.3(\text{kg/m}^3)$

$3.4(ON)$=0.23

$$O_C = \left[C_S / A(F)(C_S - C_X)\right] \times \left[0.5(Y)B_V + 0.1(MLSS) + 3.4(ON)\right] \quad (14)$$

$O_C = \left[9.17/0.9(.85)(9.17-1.5)\right] \times \left[0.5(0.925)0.5 + 0.1(3.3) + 3.4(ON)\right]$

$O_C = 1.2366(\text{kgO}^2/\text{m}^3.\text{day})$

$\Sigma O_C = [200(1.2366)]/24 = 10.3(\text{kgO}^2/\text{h})$

Detention time in aeration tank (h)

### C. Research's Results

Aeration Tank Volume (real value) =200(m$^3$)

Detention time (real value):

$R_t = V/Q =$ 200/12 = 17(h)

Theoretical required volume (existence data)

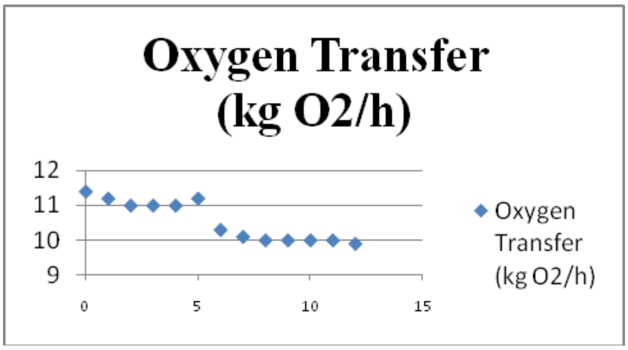
$V = L_O / B_V = 72/0.5 = 144(\text{m}^3)$

Theoretical detention time

$R_t = V/Q =$ 144/12 = 12(h)

### D. Air (Pure $O_2$) Entrance Approaches

Modeling of air or pure $O_2$ injection in wastewater at present work, is influenced on hydraulic similarity.



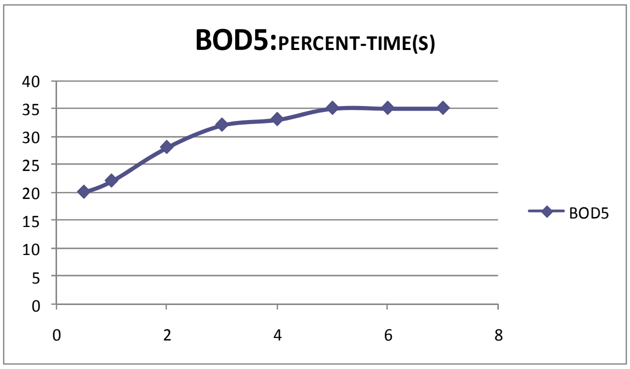
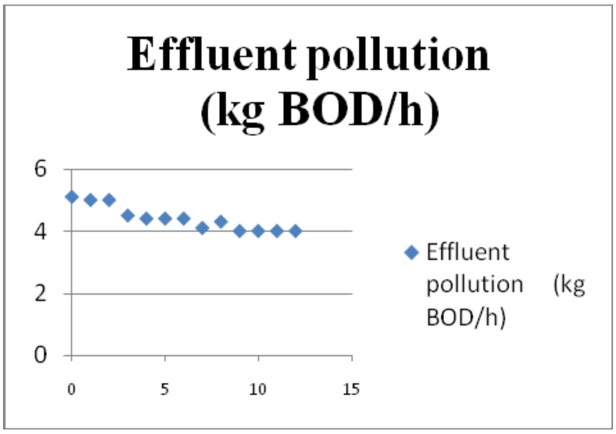




Figure 2. Oxygen required for pollution decreasing due to detention time

Two different types of air content models have been proposed in the literature in predicting the transient pressure behavior: the concentrated vaporous cavity model (Brown 1968 and Provoost, 1976) and the discrete air release model [2]. The concentrated vaporous cavity model produces satisfactory results in slow transients, but produces unstable solutions for rapid transients, such as pump's stoppage with reflux valve closure. The discrete air release model produces satisfactory results in pump shut down cases, but is susceptible to long term numerical damping (Ewing, 1980 and Jonsson, 1985).

Typically, in the discrete air release model, the wave speed distribution along a pipeline (with node points $i$=0, 1, ..., $N$) was given by Lee (1991) [2]. In this work, at first step it was a simulated transient pressure in the system due to an emergency power failure without any protective equipment in service. After a careful examination of results, it was selected protective equipment and simulated the system again using modeling to assess the effectiveness of the devices which selected to control transient pressures.



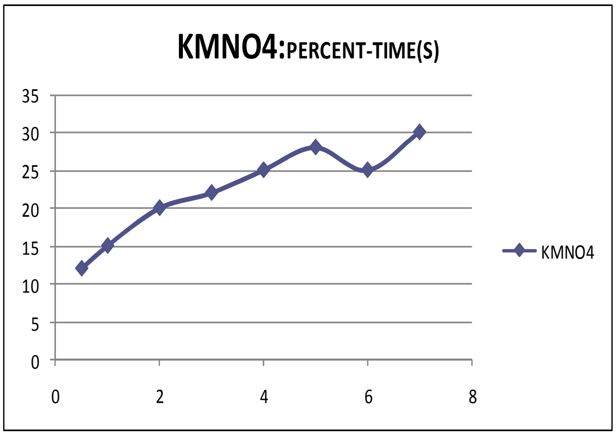




Figure 3. Oxygen required for pollution decreasing due to detention time

The formulated models can accurately describe complex flow features such as wastewater vacuum system-pressurized flow interfaces, interface reversals, and open- pressurized pipeline surges. Much of the complex dynamics in unsteady sewer flow is due to it is suggested to incorporate the air-phase flow component to the mixed flow model. Transient-state pressures were monitored by high-frequency-response pressure detectors at two locations. By comparing the simulated results using the MOC and the proposed scheme, it can be seen that the pressure traces computed using the MOC are lower than the proposed scheme for all the simulations. This means that the MOC is more dissipative than the proposed scheme [6]. They can be verified numerically or logically in Figures 4 and 5. However, the MOC agrees with the experiments slightly better than the proposed scheme, when the physical dissipation is estimated using only a steady friction formulation (as used in present work).The important aim in this research was to decrease of BOD5 to amount of 80-90 percent. This work was a part of long term project at Rasht city in the north of Iran, which aims at developing a hydraulic model for real-time. Comparison between laboratory observations on fluid streamlines in pipes for three cases including: laminar flow-transient flow and turbulent flow showed the little error in the prediction of fluid flow software analysis results [6-7].

## IV. CONCLUSIONS

As it was mentioned in the introduction, a robust and efficient numerical model able to reproduce unsteady gravity flows, unsteady pressurized flows and the simultaneous occurrence of gravity and pressurized flows in sewers was developed by the authors. The method of characteristics "MOC" approach transforms the water hammer partial differential equations into the ordinary differential equations along the characteristic lines defined as the continuity equation and the momentum equation are needed to determine $V$ and $P$ in a one-dimensional flow system. Solving these two equations produces a theoretical result that usually corresponds quite closely to actual system measurements if the data and assumptions used to build the numerical model are valid. The test procedure was as follows: A steady state flow of an $O_2$ wastewater mixture was established in the wastewater pipe by controlling the exit valves and the pressure of the injected $O_2$ at the inlet. The flow velocity of the $O_2$ wastewater mixture was maintained at a high enough rate so that slug flow could be avoided by limiting the rate of $O_2$ injection. Transient flow was created by a rapid control valve closure at the downstream end of the wastewater pipe. Transient-state pressures were monitored by high-frequency-response pressure detectors at two locations. By comparing the simulated results using the MOC and the proposed scheme, it can be seen that the pressure traces computed using the MOC are lower than the proposed scheme for all the simulations. This means that the MOC is more dissipative than the proposed scheme. However, the MOC agrees with the experiments slightly better than the proposed scheme, when the physical dissipation is estimated using only a steady friction formulation (as used in present work).The important aim in this research was to decrease of BOD5 to amount of 80-90 percent.

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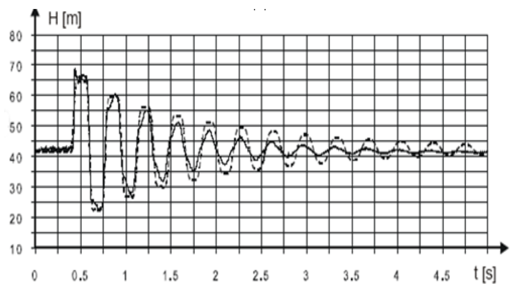
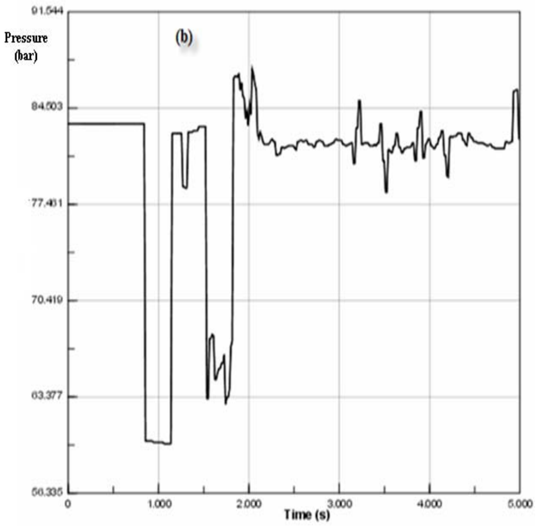
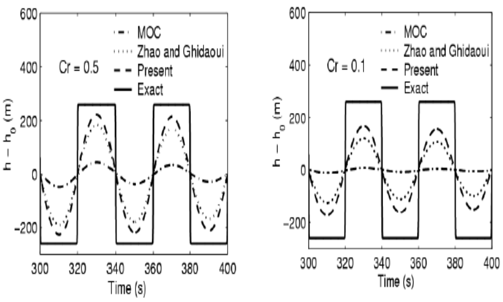



(a)




(b)




(c)

Figure 4. Work comparison with other experts (a) Kodura and Weinerowska research [8], (b) present research (K.H. Asli, et al.) [1], (c) (M.S. Ghidaoui, et al.) [9]

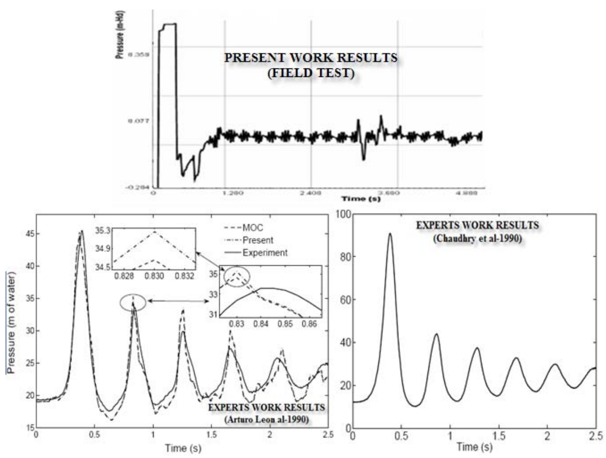



Figure 5. Wastewater depth versus time for comparison of present work with other experts works (K.H. Asli, et al.) [4], (S.L. Arturo, et al.) [6], (S.L. Arturo, et al.) [7]

## APPENDICES

Table 1 shows the dissolved salts in water and Table 2 shows wastewater treatment method comparison.

Table 1. Dissolved salts in water

| Sea water | | | Brackish water | Water | Water temp. (°C) |
|---|---|---|---|---|---|
| Dissolved salts in water (mg/lit) | | | | | |
| 20000 | 15000 | 10000 | 5000 | 0 | |
| 11.32 | 12.14 | 12.97 | 13.74 | 14.62 | 0 |
| 10.01 | 10.7 | 11.39 | 12.09 | 12.8 | 5 |
| 8.98 | 9.55 | 10.13 | 10.73 | 11.33 | 10 |
| 8.14 | 8.63 | 9.14 | 9.65 | 10.15 | 15 |
| 7.42 | 7.86 | 8.3 | 8.73 | 9.17 | 20 |
| 6.74 | 7.15 | 7.56 | 7.96 | 8.38 | 25 |
| 6.13 | 6.49 | 6.86 | 7.25 | 7.63 | 30 |

Table 2. Wastewater treatment method comparison

| Method | Pollut. | Sludge | Solid weight | Return Sludge | Air vol. $m^3$ | Effic. (%) |
|---|---|---|---|---|---|---|
| Exten. Aer. | 0.1 - 0.4 | 0.5 - 0.15 | 3 - 6 | 50 - 150 | 90 - 125 | 75 - 95 |
| Conven | 0.3 - 0.6 | 0.2 - 0.4 | 1.5 - 3 | 15 - 50 | 45 - 90 | 85 - 95 |
| Taper. Aer. | 0.3 - 0.6 | 0.2 - 0.4 | 1.5 - 3 | 15 - 50 | 45 - 90 | 85 - 95 |
| Step Aer. | 0.6 - 1 | 0.2 - 0.4 | 2 - 3.5 | 20 - 75 | 45 - 90 | 85 - 95 |
| Contact Stab. A.S. | 0 - 0.2 | 0.2 - 0.4 | 2 - 5 | 25 - 100 | 45 - 90 | 80 - 90 |
| Two stage | 1.6 - 6 | 0.4 - 1.5 | 3 - 6 | 100 - 500 | 25 - 90 | 75 - 90 |

## NOMENCLATURES

*f*: Friction
*F*: Atmospheric pressure coefficient=1(at sea level) & for every 1000 (m) height the "*F*" value decrease 1*C*: Slope (deg.)
*V*: Velocity (m/s)
*V*: Aeration tank volume ($m^3$)
*t*: Time (s)
*H*: Head (m)
*H*: Aeration tank depth (m)
$L_O$: Total influent pollution (kg BOD5)
$B_V$: Tank volume rate (kg BOD5/$m^3$.day)
$B_V$: Volume rate (kg BOD5/$m^3$.day)
*MLSS*: Mixed liquor suspended solids (kg)
*MLVSS*: Mixed liquor volatile suspended solids (kg BOD5/day)
$R_t$: Detention time (h)
*Q*: Influent flow rate ($m^3$/h) ($m^3$ /day)
$V_S$: Sedimentation velocity (m/sec)
*F/M:* Coefficient is the food to micro-organism ratio
*SMLSS*: Sludge mixed liquor suspended solids
*MLSS*: Mixed liquor suspended solids (kg/$m^3$) (kg / $m^3$.day)
*SSE*: Effluent suspended solids density (kg/$m^3$)

*RS*: Return sludge
$Q_{Max}$: Max influent in without rain case
*SLS*: Effluent sludge due to suspended solids (kg)
*A*: Constant (0.35-0.55), average ~ 0.5
*B*: Constant (0.07 -0.15), average ~ 0.1
*Y*: Aeration tank efficiency
*ON*: Need of oxygen for Nitrogen zings
$Q_V$: Amount of oxygen per 24 hours for one cubic meter of aeration lagoon (kg/m$^3$.day)
$C_X$: Dissolved oxygen density (mg/lit)
$C_S$: Amount of water dissolved oxygen in saturation condition (mg/lit)
$Q_C$: Oxygen required per 0.1 (m$^3$) of aeration tank per 24 hours (kgO$^2$/m$^3$.day)

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## BIOGRAPHIES

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**Faik Bahman oglu Nagiyev** was born in Gakh, Azerbaijan on March 16, 1952. He received the Ph.D. in Physical and Mathematical Sciences from Russia. Dr. Nagiyev received the position as a mathematician and mechanical engineer at some universities and colleges. He has 34 years of varied experience in mathematics, mechanical engineer, pedagogy and also business education and management, focusing on design and development of training programs, and commercialization of scientific and technical exploration. He served as professor in several universities. His research interests are in the application of over 100 articles and also, 2 books and more than 200 analytical reports, notes, projects and seminars about fundamental and applied studies in hydro-mechanics and thermal physics of multiphase media, mathematics, computer programming, research studies in oil and gas sphere, power engineering and technological complexes, organize of education and sciences.

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**Hossein Hariri Asli** was born in Rasht, Iran in June 1983. As a civil student in department of civil, at Applied Science and Technology University, Rasht, Iran; he has reports, notes, projects and seminars about fundamental and applied studies in water and wastewater. His research areas are on reengineering of urban system design for water and wastewater resources, networks, transmission pipelines and treatment plant. His publications are more than 20 articles and projects and seminars.