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ACTIVATED SLUDGE PROCESS SIMULATOR ASP-SIM, PART-2: BOD REMOVAL, NITRIFICATION, DO, AND SEQUENCING BATCH REACTOR.

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ABSTRACT

This paper develops a computer simulator using Visual Basic 6.0 for activated sludge process. Steady state kinetic model with default kinetic parameters taken as arithmetic average of their possible ranges was adopted. The adoption of graphic user interface (GUI) makes this simulation software user friendly and provides easy way for the user to change input parameters and determine the effect of such changes. The software was validated by comparing its output with design problems in literature. The memory space requirement for the simulator is 392kb with an average execution time per option of about 1.0s. Results obtained proves Visual Basic 6.0 program (ASP-SIM) a useful tool for wastewater treatment plant design and simulation that can serve as substitute for the expensive ones in the market.

KEYWORDS: Activated Sludge Process, Simulator, Nitrification, DO, Sequencing Batch Reactor.

INTRODUCTION

BOD removal and nitrification became necessary in wastewater treatment as a result of stringent laws on effluent discharge imposed by regulatory agencies. Nitrification is the biological oxidation of ammonia to nitrite and nitrite to nitrate. The most important environmental factors of significant concern are highlighted by Tchobanoglous and others (2003), these include: 1. the effect of ammonia on receiving water with respect to dissolved oxygen concentration and fish toxicity; 2. The need to remove nitrogen to control eutrophication and; 3. The need to provides nitrogen control for water re-use and applications including ground water recharge.

Nitrification can be achieved in the same single process with BOD removal consisting of an aerator, clarifier and sludge recycle system or in a two-sludge system consisting of two aeration tanks, and two clarifiers in series, with the first aerator/clarifier operated at short Solid Retention Time, SRT for BOD removal. The SRT is made short for the BOD removal if there is potential for toxic and inhibitory substances in the wastewater. The BOD and toxic substances are removed in the first unit, so that nitrification can be accomplished in the second (Tchobanoglous and others, 2003). The growth rate for nitrifying bacteria is slow compared to bacteria for carbonaceous BOD removal hence systems for nitrification are characterized with much longer hydraulic and solid retention times than those for BOD removal only. Completely mixed reactor or sequencing batch reactor configurations are common in BOD removal and nitrification plants. The microbiology, the stoichiometry of biological nitrification and the growth kinetics are described in the literature (Tchobanoglous and others, 2003; Enger and Smith, 2004).

The evolution of computer modeling and simulation for wastewater treatment using activated sludge process was described in part 1 paper of this work (Adamu & Nwaogazie, 2010). However, part 2 of the same work as presented herein deals with five aspects of computer-aided modeling in form of: i) completely mixed activated sludge, CMAS for

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BOD removal only; ii) CMAS for BOD removal and nitrification; iii) Dissolved oxygen model (wastewater self-purification modeling in rivers); iv) CMAS process using sequencing batch reactor, SBR; and v) Effects of temperature and activated sludge kinetics parameters on i) and ii) models. All the five models are unified in one code, ASP-SIM which can be run with different options. Details on the code are presented later on the structure of the software and use.

In many countries, computer software for simulation of major elements of the water quality system have become an inherent tool for experts involved in design, operation and control of that system, unfortunately most experts cannot afford the commercial softwares available in the market. This paper therefore attempts to develop a simulator (ASP-SIM) for activated sludge process for BOD removal and nitrification, using Visual Basic programming (available on request).

MODEL DEVELOPMENT FOR BOD REMOVAL AND NIRIFICATION

A kinetic model based on completely-mixed flow reactor with sludge recycles and a sequencing batch reactor was adopted. The detail of the development of this model is available in literature (Benefield and others, 1980; Tchobanoglous and others, 2003). Dissolved oxygen model was adopted for the disposal of effluent into rivers or streams and the development of this model is presented by Peavy and others (1985).

Design Parameters for BOD removal, Nitrification, DO model and Sequencing Batch Reactor, SBR

Many factors have to be considered in the design and operation of completely mixed activated sludge process for BOD removal and nitrification. Additional kinetics coefficients are required for the design, and because the kinetic coefficients are temperature dependent, the effects of temperature may be more pronounced than in BOD removal. Design parameters affecting BOD removal and nitrification include: solid retention time (SRT), hydraulic retention time τ, mixed liquor suspended solid (MLSS) concentration, sludge production rate, sludge recycle ratio, BOD loading, and oxygen required for aeration. Nitrification is also affected by a number of environmental factors of which the most important are: pH, toxicity, metals and un-ionised ammonia (Tchobanoglous and Others, 2003).

The major characteristics required for this model include: flow rate, BOD, dissolved oxygen, temperature, and velocity of the wastewater treatment plant effluent as well as that of the receiving stream. Also, aeration and re-aeration coefficients for the receiving stream are required.

Activated Sludge process using Sequencing Batch Reactor, SBR

The major design parameters for SBR system are: BOD loading, F/M ratio, Oxygen transfer rate, total SRT, cycle time, sludge production rate, decant pumping rate, aeration tank volume and fill volume per cycle. The design of SBR, requires selecting key design conditions and evaluating the results to determine if the design is appropriate. The design procedure involved iterative approach to determine the reactor parameters based on some assumed conditions. Ordinarily, SBR system is made up of five processes carried out in sequences: (1). fill, (2). react (aeration), (3) settle (sedimentation/clarification), (4) draw (effluent decantation), and (5) idle. Sludge wasting occurs during the settling process.

Algorithms and flow chart

The algorithms for activated sludge process using CMAS and SBR, that are based on kinetic model for microbial growth rate using Monod's equation, biomass and substrate mass balances (Tchobanoglous and Others, 2003; Peavy and Others, 1985; Agunwamba, 2007). The algorithm for BOD removal and nitrification is as follows:

1. Obtain influent wastewater characterization data.
2. Calculate bCOD, nbCOD, and $sCOD_e$.

$$\mathrm{bCOD} = 1.6 * \mathrm{BOD}\,, \quad \mathrm{nbCOD} = \mathrm{COD} - \mathrm{bCOD}$$

$$\mathrm{sCOD_e} = \mathrm{sCOD} - 1.6 * \mathrm{sbBOD}$$

3. Calculate nbVSS and iTSS, that is:

$$nbVSS = \left[1 - \frac{(bCOD/BOD)*(BOD - sBOD)}{(COD - sCOD)}\right] * VSS$$

4. Determine k_d and μ_m at the operating temperature:

$$k_{dn}(T) = k_{dn\,20}\theta_{kdn}^{(T-20)} \quad , \quad \mu_{nm}(T) = \mu_{nm\,20}\theta_{nm}^{(T-20)}$$

$$k_d(T) = k_{d\,20}\theta_{kd}^{(T-20)} \quad , \quad \mu_n(T) = \mu_{n\,20}\theta_{\mu n}^{(T-20)}$$

5. Calculate μ_n, that is:

$$\mu_n = \left(\frac{\mu_{nm} * N}{K_n + N}\right) * \left(\frac{DO}{K_o + DO}\right)$$

6. Determine the theoretical and design SRT :

$$SRT = \frac{1}{\mu_n} \quad , \text{ design } \quad SRT = SRT * F$$

7. Substrate reactor effluent concentration, S:

$$S = \frac{K_s[1 + (k_d)SRT]}{SRT(\mu_m - k_d) - 1}$$

8. Calculate rate of production of volatile suspended solid $P_{X,VSS}$ and total suspended solids, $P_{X,TSS}$ in the reactor:

$$P_{XVSS} = \frac{QY(S_o - S)}{1 + (k_d)SRT} + \frac{(f_d)(k_d)(S_o - S)SRT}{1 + (k_d)SRT} + \frac{Q * Y_n(NO_x)}{1 + k_{dn}SRT} + Q * nbVSS$$

$$P_{XVSS} = \frac{QY(S_o - S)}{1 + (k_d)SRT} + \frac{(f_d)(k_d)(S_o - S)SRT}{1 + (k_d)SRT} + \frac{Q * Y_n(NO_x)}{1 + k_{dn}SRT} + Q * nbVSS + Q(TSS_o - VSS_o)$$

$$NO_x = 0.8 * TKN$$

9. Determine the amount of nitrogen oxidized to nitrate :

$$NO_{xcal} = TKN - N_e - 0.12 * P_{Xbio} / Q$$

$$P_{Xbio} = \frac{QY(S_o - S)}{1 + (k_d)SRT} + \frac{(f_d)(k_d)(S_o - S)SRT}{1 + (k_d)SRT} + \frac{Q * Y_n(NO_x)}{1 + k_{dn}SRT}$$

10. Calculate mass of VSS and TSS in the reactor :

$$\text{mass of } VSS = P_{XVSS} * SRT \, , \quad \text{mass of } TSS = P_{XTSS} * SRT$$

11. Select a design MLSS concentration.
12. Calculate Aeration tank volume, V and hydraulic detention time, τ :

$$V = \frac{P_{XTSS} * SRT}{MLSS} \quad , \quad \tau = \frac{V}{Q}$$

13. Determine MLVSS and observed yield :

$$MLVSS = \frac{\text{mass VSS}}{\text{mass TSS}} * MLSS$$

$$Y_{obsTSS} = 1.6 * \frac{P_{XTSS}}{Q * (S_o - S)} \, , \quad Y_{obsVSS} = 1.6 * Y_{obsTSS} * \frac{\text{mass VSS}}{\text{mass TSS}}$$

14. Determine food to micro-organism ratio F/M :

$$F/M = \frac{Q * S_o}{X * V}$$

15. Determine volumetric BOD loading :

$$\text{BOD loading} = \frac{Q*S_o}{V}$$

16. Calculate the oxygen required :

$$R_o = Q*(S_o - S) - 1.4P_{Xbio}$$

$$P_{Xbio} = \frac{QY(S_o - S)}{1+(k_d)SRT} + \frac{(f_d)(k_d)(S_o - S)SRT}{1+(k_d)SRT}, \; R_o = SOTR$$

17. Determine air required :

$$(AOTR) = (SOTR)(\alpha)(F)(1.024^{T-20})\frac{\beta C_{STHav} - C_L}{C_{S,20}}$$

$$\beta = \frac{\text{saturation concentration in wastewater}}{\text{saturation concentration in clean water}}$$

$$C_{STHav} = (C_{STH})\frac{1}{2}\left(\frac{P_d}{P_{atm,H}} + \frac{O_t}{21}\right), \quad C_{STHav} = (C_{STH})\left(\frac{P_{atm,H} + P_{w,mid\ depth}}{P_{atm,H}}\right)$$

$$(C_{ST})_{760} = \frac{475 - 2.65*S}{33.5+T}, \quad C_{ST,H} = (C_{ST})_{760}\frac{P - P^{sat}}{760 - P^{sat}}$$

18. Calculate the Alkalinity to be added :

$$\text{Alkalinity to be added} = \text{Residual Alk} - \text{Influent Alk} + \text{Alkalinity used}$$

$$\text{Alkalinity used} = 7.14*NO_x, \quad \text{Residual Alkalinity} = 70 \text{ to } 80 g/cm^3$$

19. Determine secondary clarifier design parameters :

$$\text{Solid loading} = \frac{(Q+Q_R)*MLSS}{A}, \quad Q_R = R*Q \text{ and } R = \frac{X}{X_R - X}$$

$$A = \frac{Q}{\text{Hydraulic application rate}}$$

20. Prepare record of design summary.
21. Stop

The graphical representation of the algorithm for the design of Activated sludge process for BOD removal and Nitrification in form of flow chart is shown in Figure 1.The algorithm for sequencing batch reactor is based on kinetic model presented by Tchobanoglous and Others (2003) and that of Dissolved Oxygen model is based on kinetic model presented by Peavy (1985).

DEVELOPMENT OF THE SOFTWARE: ASP-SIM.

The computer code ASP-SIM stands for Activated Sludge Process Simulator. The algorithms were developed into computer codes written in Microsoft Visual Basic. Visual Basic is an interpreted programming language that can be implemented in an interactive environment called form or window (Jonnes, 2001; Holzner, 2004). It is currently among the most popular computer languages in the world because of the ease with which it can be learned and applied particularly for development of short- to medium-sized programs. Visual Basic shares many computational advantages of FORTRAN such as long variable names, double precision and adequate libraries of mathematical functions. The computer code development is based on kinetic model for completely mixed activated sludge process.

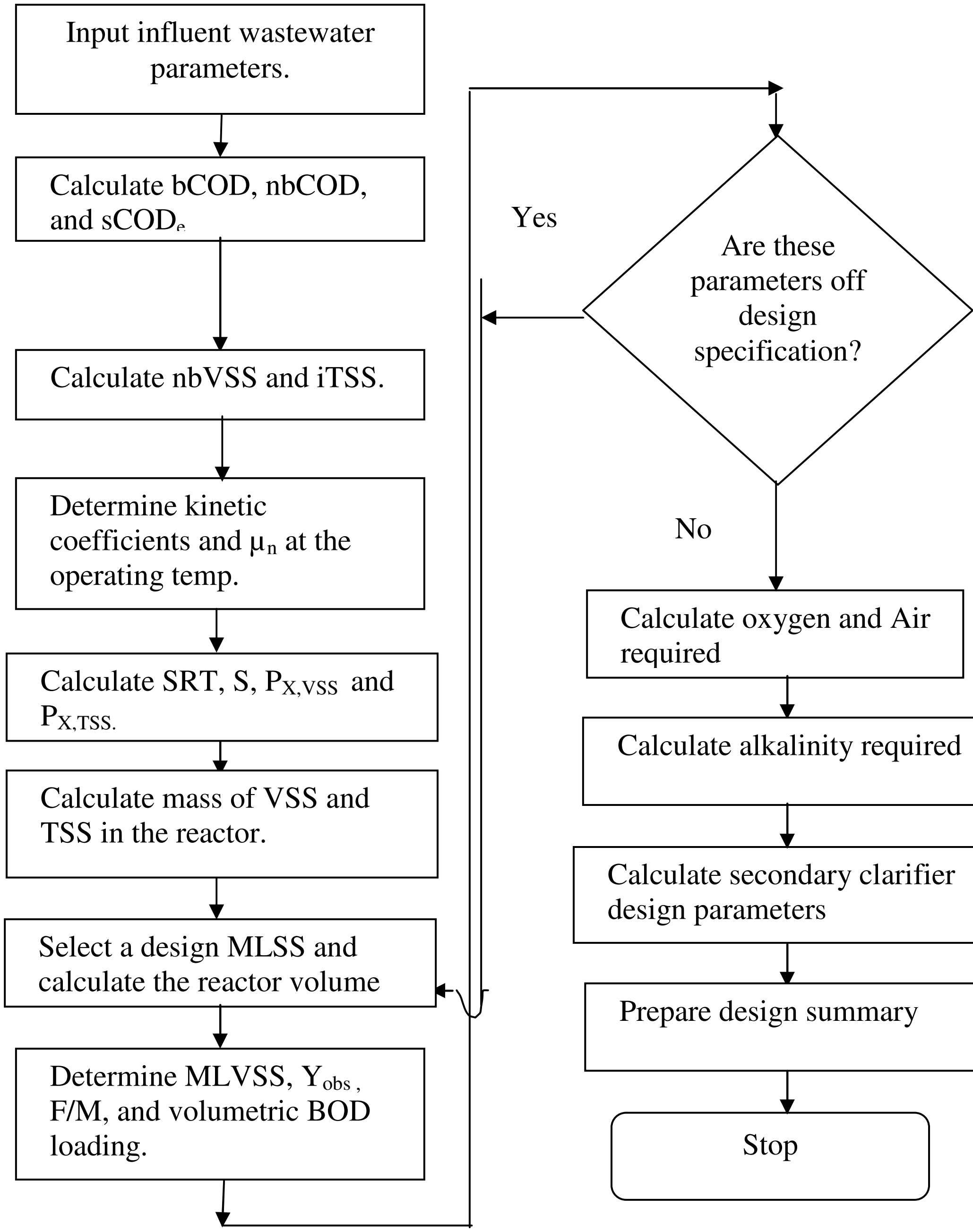

Figure 1: Flow chart for design of completely-mixed activated sludge process for BOD removal and nitrification.

RESULTS

Structure of the Software

The ASP-SIM is user friendly software consisting of 20 windows (forms) displayed in form of Graphic User Interface, GUI. The main menu which is the start-up window enables the user to select a process, view ranges of parameters used in the model, or view default values used in the models. Four main CMAS processes were considered, CMAS for BOD removal only, CMAS for BOD removal and Nitrification, Dissolved oxygen model and Sequencing batch reactor. Effects of some major parameters on the CMAS process were also considered as part of the simulation process.

Each of the CMAS process was based on Kinetic model for biological wastewater treatment which is more superior to the traditional semi-empirical models used in the past. The use of COD rather than BOD as the measure of the organic matter in the kinetic model help to reduced the effect of non-biodegradable or slowly-biodegradable organic matter in the influent wastewater. This software requires detailed characterization of wastewater, thus more inputs when compared to the semi-empirical models (Adamu, 2007). Figure 2 shows the structure of the software.

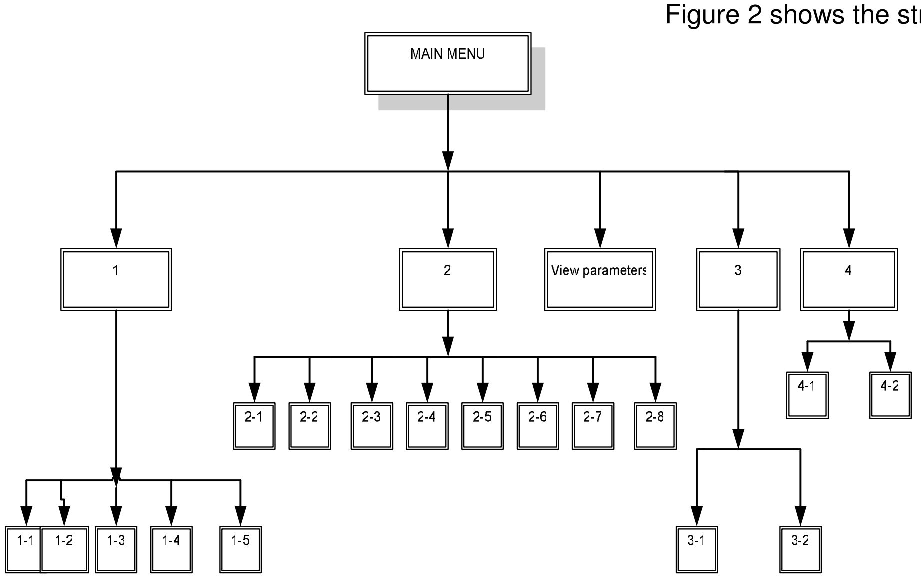

Figure 2: Structure of the software.

Key:

1-CMAS process for BOD removal only.

1-1- Effect of temperature on CMAS process.
1-2- Effect of K_s on CMAS process.
1-3- Effect of k_d on CMAS process.
1-4- Effect of μ_m on CMAS process.
1-5- Secondary clarifier parameters.

2- CMAS for BOD removal and nitrification.

2-1- Effect of temperature on CMAS process.
2-2- Effect of K_s on CMAS process.
2-3- Effect of k_d on CMAS process.
2-4- Effect of μ_m on CMAS process.
2-5- Effect of μ_{mn} on CMAS rocess.
2-6- Effect of K_n on CMAS process.
2-7- Effect of k_{dn} on CMAS process.
2-8- Secondary clarifier parameters.

3 – Dissolved oxygen model

3-1- Wastewater self-purification (dissolved oxygen model)
3-2-Variation of dissolved oxygen with distance downstream from point of discharge.

4 – Sequencing batch reactor model.

4-1- Design and simulation of SBR for process.
4-2- SBR help.

How to Use the Software

The software requires wastewater characteristics as input data through the key board using visual basic textbox or input-box. The kinetic coefficients used as input data are presented in the Appendix. The software consists of about 20 windows linked through the main menu (startup windows) which enables the user to select a task to be performed. The main menu has four options as shown in Figure 3: BOD removal only, BOD removal and Nitrification, Sequencing batch reactor and Dissolved oxygen models.

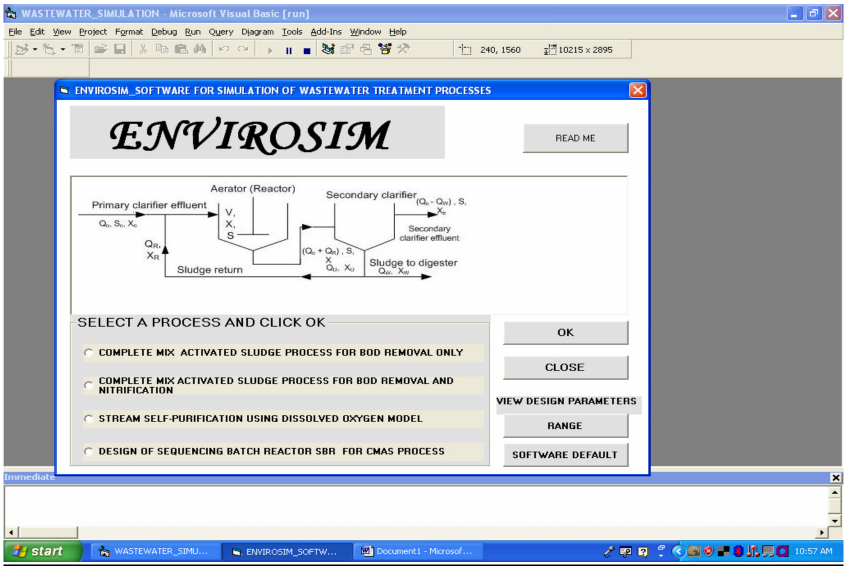

Figure 3: The main menu of the software.

Entering Input Data

The user can enter the data in the text boxes or input boxes as the case may be. Wrong entry can be erased by using delete or backspace key. Entry in one text box can be cut or copied to another textbox. The software has an error control capability in which error messages are displayed for; “no entry”, “negative entry” or “zero entry for some parameters” as shown in Figures 4, 5 and 6.

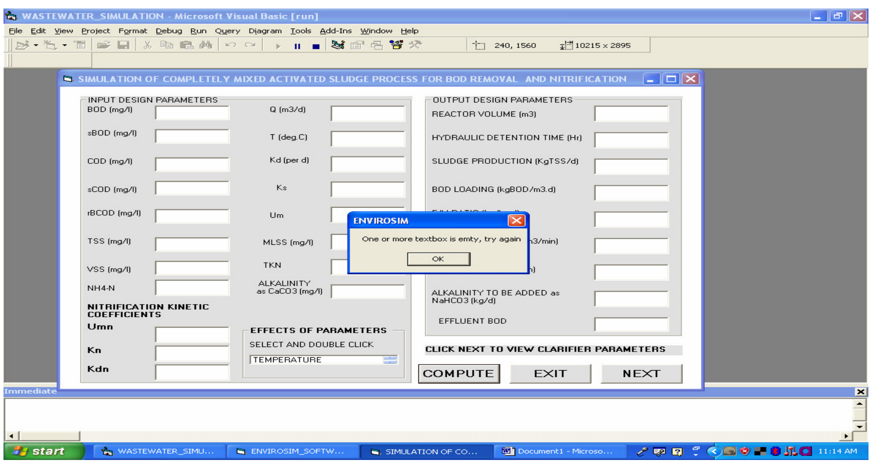

Figure 4: Graphic user interface for error control (no entry).

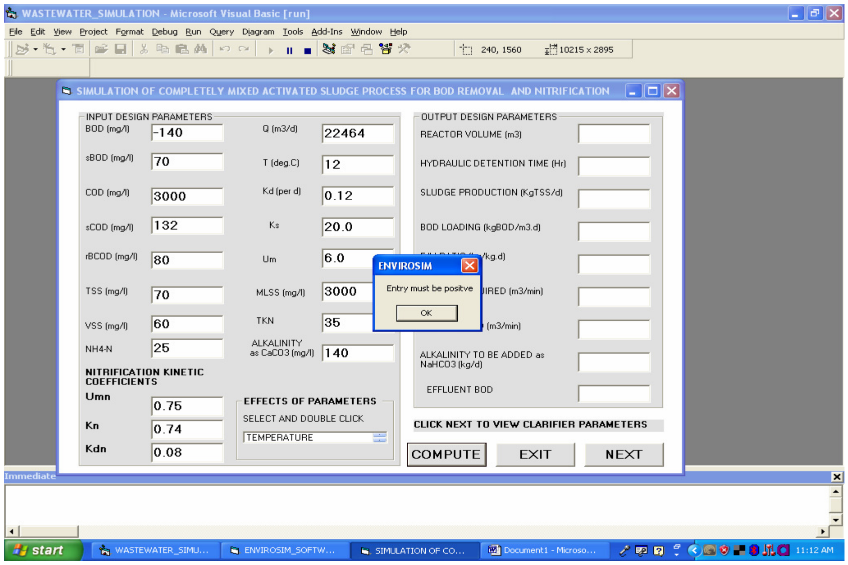

Figure 5: Graphic user interface for error control (negative entry).

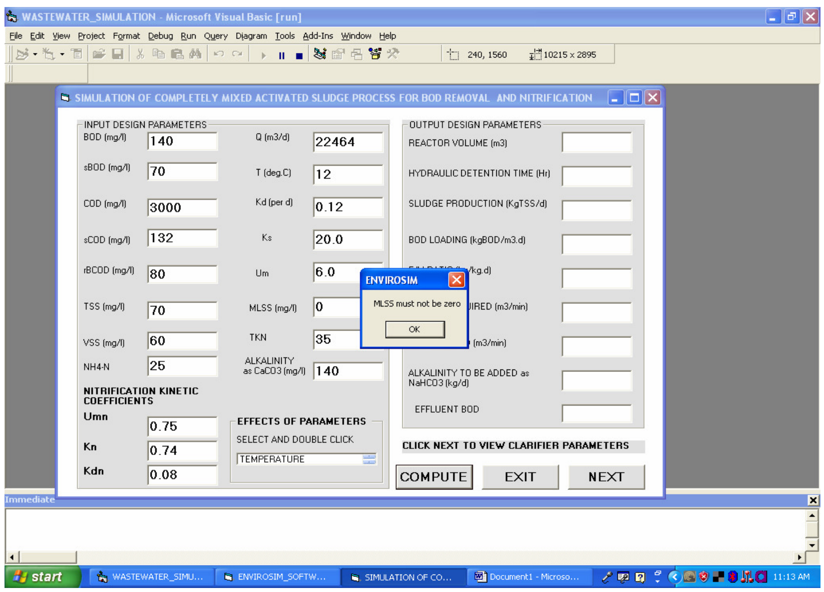

Figure 6: Graphic user interface for error control (zero entry for certain parameters).

MODEL VALIDATION

The last steps in developing software is debugging and testing (Nwaogazie, 2008). The statement that “If a program runs and prints out results then it is correct” is a misconception. There is a danger that the results appear to be “reasonable” but in fact wrong. To avoid the occurrence of such problem, the program must be subjected to a series of tests for which the correct answers are known before hand. The software, ASP-SIM was tested using design problems from literature (Tchobanoglous and others, 2003 ; Peavy & others, 1985).

Test Problem 1: BOD removal and Nitrification

This is a case of completely mixed activated sludge process design for a) BOD removal only, and b) BOD with nitrification. The simulation herein is for part (b) as part (a) has been presented in Adamu & Nwaogazie (2010). Design a complete-mix activated sludge (CMAS) process to treat 22,464 m^3/d of primary effluent to; (a) meet a BOD effluent concentration less than 30 g/m^3 , and (b) to accomplish BOD removal and nitrification with an effluent NH_4-N concentration of 0.5 g/m^3 and

BOD effluent and TSS effluent less than 15 g/m^3. The aeration basin mixed-liquor temperature is 12 ^oC. The following wastewater characteristics and design conditions apply: BOD=140 g/m^3, sBOD=70 g/m^3, COD=300 g/m^3, sCOD=132 g/m^3, rbCOD=80 g/m^3, TSS=70 g/m^3, VSS=60 g/m^3, TKN=35 g/m^3, NH_4-N=25 g/m^3, TP=6 g/m^3, Alkalinity=140 g/m^3 as $CaCO_3$ and bCOD/BOD ratio=1.6.

Design conditions and assumptions:

(i). Fine bubble ceramic diffuses with an aeration clean water O_2 transfer efficiency = 35%

(ii). Liquid depth for the aeration basin = 4.9 m

(iii). The point of air release for the ceramic diffusers is 0.5m above the tank bottom.

(iv). Dissolved oxygen in aeration basin = 2.0 g/m^3

(v). Site elevation is 500m (pressure = 95.6 kPa)

(vi). Aeration factor, α = 0.5 for BOD removal only and α = 0.65 for nitrification; β = 0.95 for both conditions and diffuser fouling factor, F = 0.90

(vii). SRT for BOD removal = 5d

(viii). Design MLSS concentration = 3000g/m^3; values of 2000 to 3000 g/m^3 can be considered.

(ix). TKN peak/average factor of safety FS = 1.5

(x). Use kinetics coefficients given in Tables A-1 and A-2 in the Appendix.

(Source: Tchobanoglous and others, 2003)

Solution to Test Problem 1, Part-b: BOD removal and Nitrification

The input data for this test problem consists of the wastewater flow rate, the mix liquor suspended solids, the wastewater characteristics and the kinetic coefficients presented in Tables A-1 and A-2 in the Appendix. The input and output design parameters are shown in Figure 7. The software output is compared with that in the Literature and presented in Table 1. The effect of temperature on BOD removal and Nitrification is also shown in Figure 8.

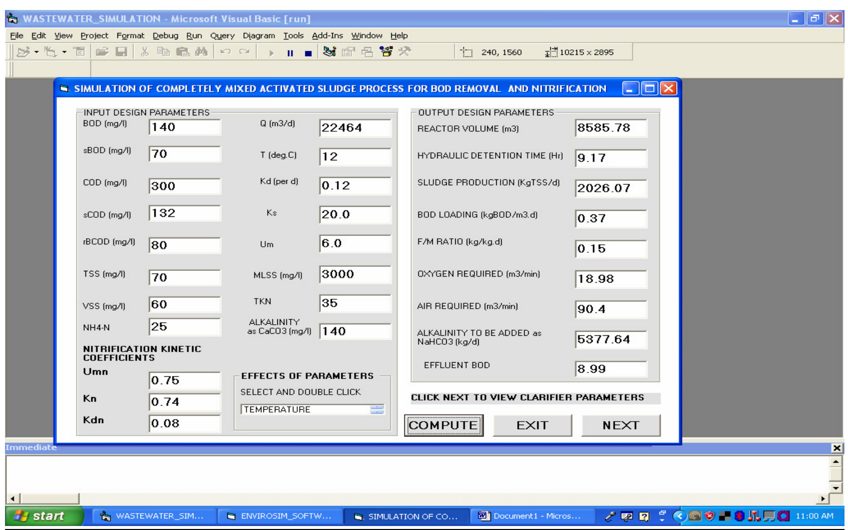

Figure 7: Graphic user interface for BOD removal and nitrification.

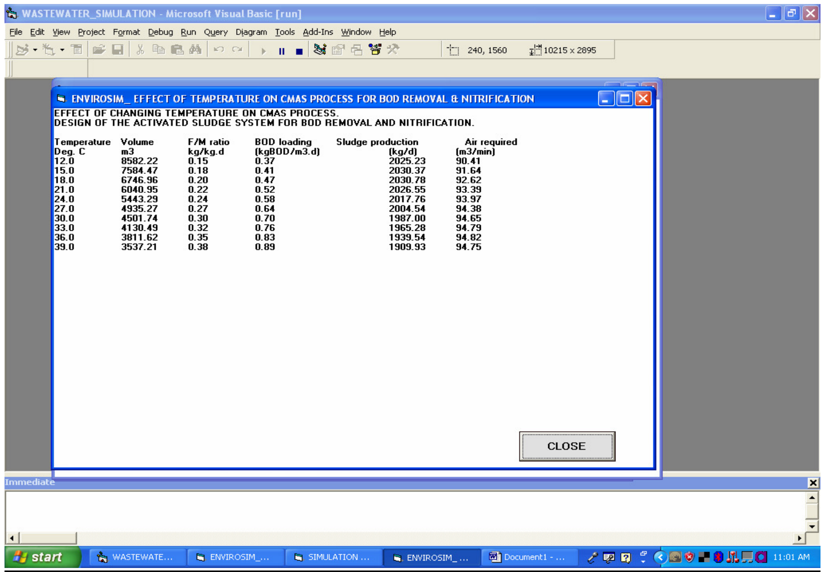

Figure 8: Effect of temperature on BOD removal and Nitrification.

Table 1: Comparison of Results for CMAS process for BOD removal and Nitrification.

Design Parameter	Units	Solution		% diff.
		Literature	Software	
Aeration tank volume	m^3	8466 (2822 x 3 tanks)	8585.78 (2861.9 x 3 tanks)	-1.41
Hydraulic detention time	Hr	9.0	9.17	1.89
F/M ratio	kg/kg.d	0.16	0.15	6.25
BOD loading	kg BOD/m^3.d	0.37	0.37	0.00
Sludge production	kg/d	2032	2026.07	0.29
Air required	M^3/min	90.5	90.4	0.11
Alkalinity addition	kg/d	5380	5377.64	0.04
Clarifiers				
Clarifier surface area	m^2	312	314.2	-0.70
Clarifier diameter	M	20	20	0.00
Return activated sludge ratio	-	0.6	0.6	0.00
Solid loading rate	kgMLSS/m^2.d	4.8	4.77	0.63

Test problem 2: Sequencing Batch Reactor Design

Design a sequencing Batch reactor process to treat a domestic wastewater with a flow of 7570 m^3/d. The reactor mixed liquor concentration at full volume is 3,500 mg/m^3 and the temperature is 12^oC. The required effluent NH_4-N concentration is 0.5 g/m^3. Primary treatment is not used.

The following wastewater characteristics and design conditions apply: BOD=220 g/m^3, sBOD=80 g/m^3, COD=485 g/m^3, sCOD=160 g/m^3, rbCOD=80 g/m^3, TSS=240 g/m^3, VSS=220 g/m^3, TKN=35 g/m^3, NH_4-N=25 g/m^3, TP=6 g/m^3, Alkalinity=200 g/m^3 as $CaCO_3$ and bCOD/BOD ratio = 1.6.

Design conditions and assumptions:

(i). Use two tanks.
(ii). Total liquid depth when full = 6m
(iii). Decant depth = 30% of tank depth.
(iv). SVI = 150 mL/g.
(v). NO_x is approximately 80% of TKN.
(vi). Use kinetics coefficients given in Table A-2.1 and A-2.2 in the appendix.

(Source: Tchobanoglous and others, 2003).

Solution to Test Problem 2- - Sequencing Batch reactor

The graphic user interface shown in Figure 9 shows the results when the program is run after entering the required input data. The results were compared with that in the literature as presented in Table 2.

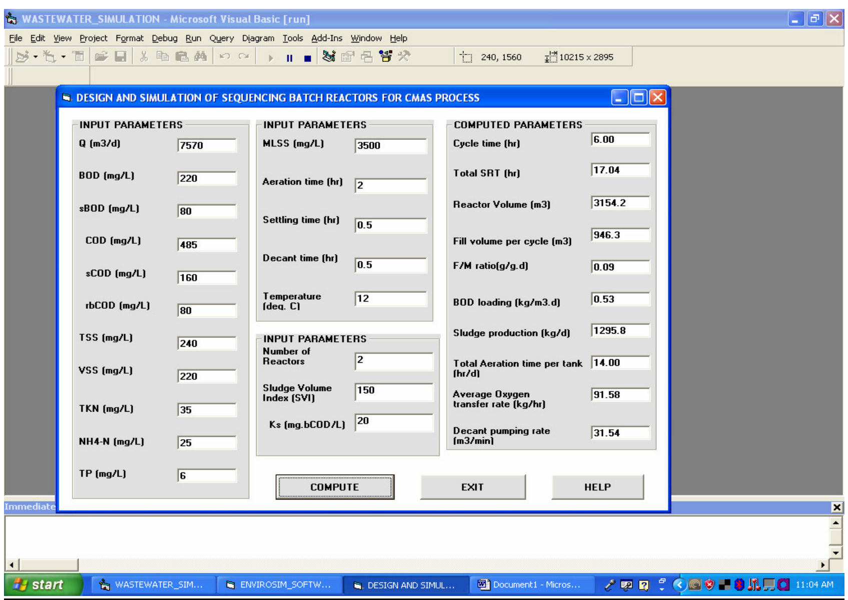

Figure 9: Graphic user interface showing results for sequencing batch reactor.

Table 2: Comparison of results for Sequencing Batch Reactor process.

Design Parameter	Units	SOLUTION		% diff.
		Literature	Software	
Aeration tank volum e	m^3	3154	3154.2	-0.006
Fill volume per cycle	m^3	946.3	946.3	0.000
Total SRT	Hr	17.0	17.04	-0.235
Cycle time	Hr	6.0	6.0	0.000
Total aeration time per day per tank	hr/d	14	14	0.000
F/M ratio	kg/kg.d	0.09	0.09	0.000
BOD loading	kg BOD/m^3.d	0.53	0.53	0.000
Sludge production	kg/d	1299	1295.8	0.246
Average oxygen transfer rate	kg/hr	98.4	91.58	6.931
Decant pumping rate	m^3/min	31.5	31.54	-1.269

Test Problem 3: Dissolved Oxygen Model

A municipal wastewater treatment plant discharges secondary effluents to a surface stream. The worst conditions are known to occur in the summer months when stream flow is low and water temperature is high. Under these conditions, measurements are made in the laboratory and in the field to determine the characteristics of the wastewater and stream flows. The wastewater is found to have maximum flow rate of 15,000 m^3/d, a BOD_5 of 40 mg/L, a dissolved oxygen concentration of 2 mg/l and a temperature of 25 ^oC. The stream (upstream from the point of discharge) is found to have a minimum flow rate of 0.5 m^3/s (43,200 m^3/d), BOD_5 of 3 mg/L, a dissolved oxygen concentration of 8 mg/l and a temperature of 22 ^oC. Complete mixing of the wastewater and stream is almost instantaneous, and the velocity of the mixture is 0.2 m/s. from the flow regime, the reaeration constant is estimated to be 0.4 day^{-1} for 20 ^oC conditions (BOD reaction rate at 20 ^oC = 0.23 day^{-1}). Sketch the dissolved oxygen profile a 100 km reach of the stream below the discharge (Peavy and others, 1985).

Solution to Test Problem 3: Dissolved Oxygen Model

On entering the required input data and clicking on "compute", the output design parameters appears as shown in Figure 10. These parameters were compared with that in the literature as presented in Table 3.

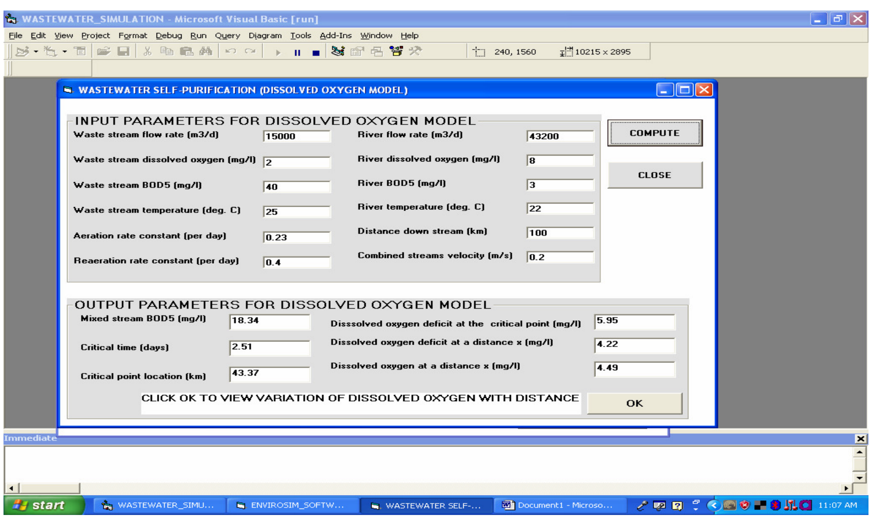

Figure 10: Graphic user interface showing results for dissolved oxygen model.

Table 3: Comparison of Results for Dissolved Oxygen model.

Design Parameter	Units	SOLUTION		% diff.
		Literature	Software	
Mixed streams BOD_5	mg/L	18.2	18.34	-0.77
Critical time	D	2.5	2.51	-0.40
Critical point location	km	43.2	43.37	-0.39
Dissolved O_2 deficit at critical point	mg/L	5.9	5.55	5.93
Dissolved O_2 at distance x	mg/L	4.1	4.22	-2.92
Dissolved O_2 deficit at distance x	mg/L	4.7	4.49	0.95

DISCUSSIONS

Comparison of the results obtained with the software shows that there is essentially no difference between the literature results and that of the software. The slight differences in some values are as a result of some approximations done on the literature solution. In effect, the computer code (ASP-SIM) is error free and much confidence should be exercised in its use for design purposes.

CONCLUSION

The computer code ASP-SIM written in Visual Basic 6.0 is a very handy tool in the design of wastewater treatment plant using activated sludge process. The graphic user interface GUI of ASP-SIM makes it user friendly with ease of changing design parameters to accommodate changes in design conditions. Comparison of the software result and that of literature shows that the software can be used for design and simulation purposes. The software can also predict the fate of wastewater treatment plant effluent discharged into flowing rivers or streams. Effects of changes in most of the major parameters on the CMAS process can also be predicted.

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APPENDIX A-1

Kinetic coefficients for activated sludge process; The kinetic coefficients in Table A-1 are to be used for the design of activated sludge process for removal of carbonaceous material (based on bCOD) by heterotrophic bacteria.

Table A-1: Activated sludge kinetic coefficients for heterotrophic bacteria at 20 ^oC

Coefficient	Unit	Range	Typical value
μ_m	gVSS/gVSS.d	3.0 - 13.2	6.0
K_s	gbCOD/m^3	5.0 - 40.0	20.0
Y	gVSS/gbCOD	0.30 – 0.50	0.40
k_d	gVSS/gVSS.d	0.06 – 0.20	0.12
f_d	unitless	0.08 – 0.20	0.15
θ values			
μ_m	unitless	1.03 – 1.08	1.07
k_d	unitless	1.03 – 1.08	1.04
K_s	unitless	1.0	1.0

The kinetics coefficients in Table A-2 are to be used for design of activated sludge process for nitrification by heterotrophic bacteria.

Table A-2: Activated sludge nitrification kinetic coefficients for heterotrophic bacteria at 20 ^oC

Coefficient	Unit	Range	Typical value
μ_{mn}	gVSS/gVSS.d	0.20 – 0.9	0.75
K_n	gNH$_4$-N/m^3	0.5 - 1.0	0.74
Y_n	gVSS/gNH$_4$-N	0.10 – 0.15	0.12
k_{dn}	gVSS/gVSS.d	0.05 – 0.15	0.08
K_o	g/m^3	0.40 – 0.60	0.50
θ values			
μ_n	unitless	1.03 – 1.08	1.07
K_n	unitless	1.03 – 1.08	1.053
k_{dn}	unitless	1.0	1.04