Computer Driven Training Simulator of Wastewater Treatment Operations

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COMPUTER DRIVEN TRAINING SIMULATOR
OF WASTEWATER TREATMENT OPERATIONS

BY

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B.S., Carson-Newman College, 1975

RESEARCH REPORT

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COMPUTER DRIVEN WASTE WATER TREATMENT PLANT OPERATIONS TRAINING SIMULATOR

BY
GLENN R. SILKENSEN

ABSTRACT

This research involves design and implementation of computer program for simulation of a wastewater treatment plant. The program has the capability to be interfaced with an existing analog wastewater plant process flow training board which is equipped with meter readouts of key process variables and adjustable control valves. It is planned that the total system simulator could be used to train wastewater treatment plant operators to afford them hands-on dynamic experience in plant operations.

The wastewater treatment process modeled is the activated sludge process. Beginning with the known plant design steady-state equations for this particular process an algorithm was developed to simulate the treatment process through probable system dynamics. All assumptions are presented in a logical manner and used to develop the necessary transient equations.

The success of this project demonstrates that a simulation program which emulates a waste treatment process is possible; however, it is suggested that further research is needed to provide deeper insight into variable changes during system transients.
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CHAPTER I
INTRODUCTION

The Training Simulator

Well-trained wastewater treatment plant operators have been in short supply for quite some time. ¹ The increasing number of wastewater treatment plants in the U.S. along with the strict environmental legislation on effluent quality have each contributed to the present shortage of well trained operators.

Training these plant operators takes time, both in class and on site. Not much can be done about decreasing the classroom time without sacrificing the quality of the trained operator. But, if the schools and colleges had access to a training simulator, the student could gain an appreciable amount of "experience" before going on site. The value of this experience would be directly related to how well the simulator emulated an actual treatment plant.

Taking into account the elapsed times involved with the treatment process cycle, a scaled-down working model would still take hours to simulate a given condition. The ideal situation would exist where the instructor could control the circumstances and the time involved with implementing a solution.

A microcomputer with a simulation program seems ideally fitted to this task. System response and delay times can be set by the program and a given situation can be run repeatedly in a relatively short time.

To improve the useability of a microcomputer-based simulation program, it should be interfaced to a display/control training board. The use of a training board for display and control would allow the student to receive a more physical interpretation of the computed data instead of just looking at a group of numbers on a computer display screen. This would also aid in the reduction of training time and should increase value of the simulation experience.

The implementation of a "Training Simulator" is the problem addressed in this research paper. The research problem can be simply stated as:

To design and implement a computer program that simulates a wastewater treatment plant and to be able to utilize that program interactively with an analog training board for display and control.

Main Research Objectives

(1) Through literary research, find, derive, or develop reactor sewage kinetic equations. Using these equations design a working model/algorithm that simulates a wastewater treatment process not only at steady state but also through probable system transients.

(2) Implement these equations with proportional system time delays to make the model more nearly resemble the actions and reactions of an actual system.
(3) Combine equations and time delays into a simulator computer program which will allow interactive communications with a previously constructed simulator training board which describes the operations of a selected wastewater plant.

These objectives required a working program first be developed which used the display and control capabilities of the computer. This was augmented with necessary information to facilitate the altering of the display and control sections of the simulator program in order that the program could operate in conjunction with the simulator training board.
CHAPTER II
THE WASTEWATER TREATMENT PROCESS

Background

A frequently used biological process in wastewater treatment in recent years is the "activated sludge" system.\(^2\)\(^3\) The activated sludge system is reputed to be the "most versatile and efficient of the available processes."\(^3\) The simulator developed in this research was based upon this process since it would be most generally applicable. As described by Harry S. Harbold, a chemical engineer, the activated sludge process is one in which

... microorganisms present in the activated sludge remove organic matter from the liquid waste by synthesis into new protoplasm. The degradable organic matter is used for food by the microorganisms to synthesize new cell mass and obtain energy for metabolic functions by oxidation of the organic substrate to carbon dioxide and water.\(^4\)

This may be expressed by the following bio-chemical reaction:

\[
\text{wastewater} + \text{microorganism} + \text{oxygen} \rightarrow \text{waste sludge} + \text{end products}
\]


\(^4\)Harbold, pp. 157-158.
Basic Theory

The biological waste treatment process is essentially the same regardless of the specific system used. Therefore, a discussion of the basic theory of biological waste treatment has been included in this research.

Bacteria, the microorganisms of primary importance in biological treatment, have a definite growth pattern. For a given sample, if there is initially an excess of food for the bacteria, the microorganisms begin to rapidly increase in number because of the binary-fission reproductive process. This is called the "log-growth" phase of metabolism. At some point the food becomes a limiting factor and the death of old bacteria begins to offset the growth of new cells. Soon the bacterial death rate exceeds the reproduction rate and the total number decreases, this is called the "log-death" phase.

The last phase, also called the endogenous phase, "is where the cell mass goes through auto-oxidation by endogenous respiration to remain alive. By doing this, using up its stored food supply, the cell mass is depleted of residual organic content, becomes inactive, and forms a heavy floc that may be separated by sedimentation. This settled floc of activated sludge is subsequently re-circulated to be mixed with the treatment plant influent so that cell metabolism and organic removal may continue." 5

---

5Ibid.
A typical activated sludge treatment process is shown in Figure 1. The influent, after some initial screening and sedimentation, enters the aeration tank, or tanks. Here the organic substrate mixes with the present population of microorganisms. Air is continually injected into the tank to provide the necessary oxygen to the microorganisms. After a sufficient length of contact time, usually several hours, the suspended solids are pumped to a settling tank. From the bottom of the settling tank the majority of the solids are returned to the aeration tank to start the process again. A portion of the solids removed from the settling tank are removed from the system as waste sludge. The nearly organic free water is transferred from the upper part of the settling tank to a chlorine tank for final chemical processing. Chlorine contact is a chemical process and is not actually a part of the activated sludge process, but it is included here for completeness of the wastewater treatment cycle.

Figure 1. Typical Activated Sludge Treatment Process
CHAPTER III
NECESSARY STEADY STATE EQUATIONS

Fundamental Relationships

To ensure that the microorganisms will grow, they must be allowed to remain in the system long enough to reproduce. This period is dependent on their growth rate which is in turn related to the rate at which they utilize the waste.

The term solids retention time (SRT) represents the average residence time of the activated microorganisms in the system and is defined as follows:

\[ \text{SRT} = \frac{\text{avg mass of active biological solids in the system}}{\text{mass of biological solids removed from the system per day}} \]

An empirically developed relationship between biological growth and substrate utilization which is commonly used for the biological system is \(^6\)

\[
\frac{dX}{dt} = Y \frac{dF}{dt} - k_d X \quad \text{(I)}
\]

where

\( X \) = concentration of biological solids, (mass/volume)

\( Y \) = growth coefficient as the mass of organisms produced per mass of waste consumed, (mass/volume)

\( F \) = concentration of organic food substrate utilized by microorganism (mass/volume)

\( \frac{dX}{dt} \) = net change in biological solids with respect to time as a result of synthesis and endogenous respiration, [mass/(volume-time)]

\(^6\)Metcalf and Eddy, p. 391.
\[ k_d = \text{microorganism decay coefficient, } \left( \frac{1}{\text{time}} \right) \]

\[ t = \text{time} \]

These two equations are related by the fact that the first equation can be stated in the variables of Equation I as follows:

\[ \text{SRT} = \frac{X}{dX/dt} \quad (\text{II}) \]

now rearranging Equation II,\(^7\)

\[ \frac{1}{\text{SRT}} = \frac{dX/dt}{X} = \frac{dF/dt}{X} - k_d \quad (\text{III}) \]

Referring to the system in Figure 2, the definition of SRT can be stated in terms of system parameters in the following manner. The average mass of active biological solids in the system can be referred to as the system volume \((V)\) multiplied by the concentration of biological solids \((X)\). The mass of biological solids removed from the system per day is the sum of the solids removed through wasting, waste flow rate \((Q_w)\) times the return solids concentration \((X_r)\), and the solids removed through the effluent lines, effluent flow rate \((Q - Q_w)\) times effluent solids concentration \((X_e)\).

In an equation this would be

\[ \text{SRT} = \frac{VX}{Q_wX_r + (Q - Q_w)X_e} \quad (\text{IV}) \]

where

\[ V = \text{volume of system} \]

\[ Q = \text{influent flow rate (millions of gallons/day) or (Mgal/D)} \]

\[ Q_w = \text{waste sludge flow rate (millions of gallons/day) or (Mgal/D)} \]

\[ X = \text{concentration of biological solids in tank(s) (mass/vol.)} \]

\(^7\)Ibid., p. 404.
Figure 2. Flowsheet for the Complete-Mix Activated-Sludge Process Used on the Simulator Control Board
Xr = concentration of biological solids in return line (mass/vol.)
Xe = concentration of biological solids in effluent line (mass/vol.)

Now using Equations III and IV, a relationship can be made between the actual system values and the known constants for this type of system. But, before that relationship would be useful, a few more system equations should be developed.

Looking at the system in Figure 2, a mass balance steady state equation for the aeration tanks can be developed. The mass of biological solids entering the tanks must be equal to the mass of solids leaving the tanks. The mass of solids at the inlet would be the sum of the solids entering from the return line, return flow rate (Qr) times return solids concentration (Xr), and the solids entering from the influent line, influent flow rate (Q) times influent solid concentrates (Xi). That sum would be the same as the mass of the solids leaving the tanks, flow from the tanks (influent flow plus return flow, Q+Qr) multiplied by the solids concentration in the tank (X). Putting all this into an equation, it can be written as

QrXr + QXi = X(Q + Qr)

or

X = \frac{QrXr + QXi}{Q + Qr}

(V)

where
Qr = return sludge flow rate (millions of gallons/day) or (Mgal/D)
Xi = concentration of biological solids in influent (mass/vol.)
Normally influent and effluent solids (Xi and Xe) are small enough to be neglected.\textsuperscript{8,9} But it was found that Xi or Xe could not be neglected and still derive a usable set of equations for a program where, after repeated evaluations of a specific statement, a very small error could manifest itself into a very large error.

A simple example will prove this point. Taking some system parameter values from Example 12-1 in Wastewater Engineering by Metcalf and Eddy and using an entire system mass balance, developed just like the previous mass balance equation only this time the mass of biological solids entering the system from the influent line (QXi) is equated to the mass of solids leaving the system both through the effluent line (Xe (Q-Qw)) and the mass of solids being wasted (QwXr), leads to the following:

\[ Q_{Xi} = Xe (Q-Qw) + QwXr \]

using

\[ Q = 5 \text{ Mgal/D} \]
\[ Qw = 0.0396 \text{ Mgal/D} \]
\[ Xr = 10000 \text{ mg/l volatile suspended solids} \]

then

\[ 5 \times \frac{396}{5} = 79.2 \quad \text{(assuming } Xe = 0). \]

If we assume no suspended solids in effluent (ideal case) then Xi must be 79.2 mg/l. As can be seen if Xi or Xe is neglected, problems

\textsuperscript{8}Ibid., p. 493.
\textsuperscript{9}Ibid., p. 403.
could arise with possible negative values of flow rates or concentration of suspended solids. Therefore, it was arbitrarily selected that $X_i$ be set to 80 mg/l which in turn makes $X_e 0.8$ mg/l. These are small enough to be neglected in a steady state situation, but play an important role in evaluating a transition.

Another parameter of utmost importance is the hydraulic retention time (HRT) or simply the time it takes a unit volume of liquid to traverse the entire system. In equation form this would be

$$HRT = \frac{V_r + V_s}{Q^{10}}$$

where

- $Q = $ influent flow rate (Mgal/D)
- $V_r = $ volume of reactor [millions of gallons (Mgal)]
- $V_s = $ volume of settling tank & piping (Mgal).

This research uses HRT as a measure of transition time. This is based upon the assumption that a change in some parameter in a steady state system will not completely affect every other parameter instantaneously. The assumption is made that an HRT fraction of a parameter will be affected each time period. To keep the equations as simple as possible a time period of one hour was selected, but to keep the simulation time controllable by the operator the computer can equivalence a simulated hour to nearly any real time value. In other words, if the HRT is 6 hours, 1/6 of the ultimate total change in the value of a parameter will occur each hour.
So far quite a number of equations and system parameters have been introduced. To see where all this leads, the next step should be a look at what variables need to be evaluated and displayed on the training board.

The basic function of a wastewater treatment plant is to reduce the biological waste in the water, i.e., the concentration of waste \( S \), also called the substrate concentration. This substrate is the food for the microorganisms, and so far, the only equations introduced that have terms related to microorganism food are Equations I and II. The rate of food utilization \( (dF/dt) \), for programming purposes, needs to be expressed and evaluated on a finite time basis, or

\[
\frac{\Delta F}{\Delta t} = \frac{Q}{V} (S_o - S),
\]

(VII)

\( S_o \) = concentration of influent waste

\( S \) = concentration of influent waste not biologically degraded appearing in the effluent.

\( V \) = volume of the system

Now by simply equating the SRT values of Equations III and IV it can be seen that;

\[
y \frac{dF/dt}{X} - k_d = \frac{1}{SRT} = \frac{QwXr + (Q-Qw)Xe}{VX}
\]

Substituting in Equation VI and solve for effluent waste concentration \( S \);

\[
y \frac{Q/V \left( S_o - S \right)}{X} - k_d = \frac{QwXr + (Q - Qw)Xe}{VX}
\]

\[
yQ \left( S_o - S \right) - VXk_d = QwXr + (Q - Qw)Xe
\]

\[11\text{Ibid., p. 399.}\]
Equations IV, V, VI, and VIII are the fundamental relationships on which the computer simulation was based. One very important reason these equations were used is because the effluent waste concentration \( S \) can now be found by knowing the system constants \((Y \text{ and } k_d)\), the nearly constant operational values \((Q, S_o, X_i, X_e, \text{ and } V)\) and the operational control values. As an illustration of this an example will now be presented.

**Steady State Example**

Find the effluent waste concentration escaping treatment for the complete-mix activated-sludge process shown in Figure 2 if:

1. Influent flow rate \((Q)\) of 5 Mgal/day of settled sewage having waste concentration of 250 mg/liter
2. Influent volatile suspended solids \((X_i)\) is 80 mg/liter
3. Effluent suspended solids \((X_e)\) is 0.8 mg/l
4. Return-sludge volatile suspended solids concentration \((X)\) of 9850 mg/liter
5. Return-sludge flow rate \((Q_r)\) of 2.7 Mgal/day
6. Sludge wasting rate \((Q_w)\) of .0396 Mgal/day
7. System volume of 1.13 million gallons
8. System constants of \( Y = \frac{.65 \text{ lb cells}}{1 \text{ lb waste utilized}} \); \( k_d = .10/\text{day} \)
9. Assume constant adequate temperature, with sufficient oxygen being introduced so as not to become growth limiting, and waste contains adequate nitrogen and phosphorus and the trace nutrients for biological growth.
Starting with Equation V, the concentration of suspended solids in the reactor can be found:

\[
X = \frac{QrXr + QXi}{Q + Qr} = \frac{(2.7 \text{ Mgal/day})(9850 \text{ mg/l}) + (5 \text{ Mgal/day})(80. \text{ mg/l})}{5 \text{ Mgal/day} + 2.7 \text{ Mgal/day}}
\]

\[
X = 3505.8 \text{ mg/l.}
\]

Using this value of reactor suspended solids the average cell residence time (SRT) can be found with Equation IV;

\[
\text{SRT} = \frac{VX}{QwXr + (Q-Qw)Xe}
\]

\[
(1.13 \text{ Mgal}) (3505 \text{ mg/l})
\]

\[
(.0396 \text{ Mgal/D})(9850 \text{ mg/l}) + (5 \text{ Mgal/D}.0396 \text{ Mgal/D})(0.8 \text{ mg/l})
\]

\[
\text{SRT} = 10.05 \text{ days.}
\]

And finally with Equation VIII;

\[
S = S_0 - \frac{QwXr + (Q - Qw)Xe + VXkd}{YQ}
\]

\[
S = 250 - \frac{(.0396)(9850) + (5 -.0396)(0.8) + (1.13)(3505.8)(0.1)}{(.65)(5)}
\]

\[
S = 6.89 \text{ mg/l waste escaping treatment.}
\]

It is noticed that these values are very close in magnitude to Example 12-1, page 494 of Wastewater Engineering by Metcalf and Eddy.

These equations would be all that is necessary if a single steady state condition was the only item under study. But since transients must be allowed for, further equations must be cited or developed.

**Oxygen Requirement and Transfer**

One basic process that has been practically ignored up until now is oxygen requirements and transfer. Since this is a chemical process it can best be described by referring to Metcalf and Eddy.
The theoretical oxygen requirements can be computed by knowing the Biological Oxygen Demand (BOD) of the waste and the amount of organisms wasted from the system per day. The reasoning is as follows. If all the BOD were converted to end products, the total oxygen demand would be computed by converting BOD₅ to BOD₇ using an appropriate conversion factor. It is known that a portion of the waste is converted to new cells that are subsequently wasted from the system; therefore, if the BOD₇ of the wasted cells were subtracted from the total, the remaining amount would represent the amount of oxygen that must be supplied to the system; therefore, if the BOD₇ of the wasted cells were subtracted form the total, the remaining amount would represent the amount of oxygen that must be supplied to the system.¹²

Therefore, the theoretical oxygen requirements for an activated-sludge system can be computed from the following equation,

\[
O_2 \left( \frac{1 \text{ lb}}{\text{day}} \right) = \left[ \text{food utilized per day} \right] - C \left[ \text{organisms wasted per day} \right]
\]

where C is the ratio of the mass of oxygen used by the wasted cell to the mass of cells wasted. This constant can be evaluated by calculating biological oxygen demand (BOD₇) of a mole of cells. The biochemical reaction¹² can be written as

\[
C_2H_7NO_2 + 5O_2 \rightarrow 5CO_2 + 2H_2O + NH
\]

This shows that it takes 160 lb \( O_2 \) [(5)(32) lb] for each 113 lbs of cells. Therefore, the ratio of mass of oxygen used to mass of cells wasted is;

\[
\frac{1 \text{ lb } O_2}{1 \text{ lb cells}} = \frac{160}{113} \approx 1.416
\]

Then in terms of previously defined symbols

\[
O_2 \left( \frac{1 \text{ lb}}{\text{day}} \right) = \frac{dF}{dt} - (1.416) \frac{dX}{dt}
\]

Again, on a finite time basis Equation VII can be used for \( dF/dt \).

¹²Ibid., p. 490.
\[
\frac{dF}{dt} \sim \frac{\Delta F}{\Delta t} = \frac{Q(S_0 - S)}{V}.
\]

But to convert this to the system oxygen requirement based on ultimate biological demand, it must first be multiplied by the system volume and then by the conversion factor 1/0.68 to convert from \(\text{BOD}_5\) to \(\text{BOD}_L\).\(^{13}\)

\[
\left( \frac{\Delta F}{\Delta t} \right)_{\text{overall}} = \frac{Q(S_0 - S)}{V} \left( \frac{V}{0.68} \right)
\]

Then from Equation II
\[
\frac{dX}{dt} = \frac{X}{\text{SRT}}
\]

but here again this is per unit volume so it must be multiplied by the system volume to get overall organisms wasted per day, or
\[
\left( \frac{dX}{dt} \right)_{\text{overall}} = \frac{XV}{\text{SRT}}
\]

now substituting into equation IX
\[
O_2 = \frac{Q(S_0 - S)}{0.68} - \frac{XV}{\text{SRT}}
\]

Oxygen requirement is normally expressed in pounds/day so the inclusion of a conversion factor is all that is needed.

(to convert mg/liter to lb/Mgals, multiply by 8.34 \(\frac{\text{liter lb}}{\text{mg Mgals}}\))

\[
O_2 (\text{lb/day}) = \left[ \frac{Q(S_0 - S)}{0.68} - \frac{XV}{\text{SRT}} \right] 8.34 \quad (X)
\]

\(^{13}\text{Ibid.}, \ p.494.\)
Using this equation one can calculate how much oxygen is required to reduce influent substrate concentration to a specific effluent concentration knowing a few other system parameters. Also note that all these other system parameters are either known or can be calculated by previously stated equations.

In the computer program that was written, Equation X is used simply to find if there is enough oxygen present so as not to inhibit cellular growth of the biological solids. If this equation shows that the systems oxygen requirements are greater than the oxygen being introduced, it is obvious that something has to change. These changes, due to oxygen mismatch, and the magnitude of these changes is addressed in the next chapter along with other transient dependent parameters.
CHAPTER IV
EQUATIONS FOR TRANSIENTS

Time Dependent Input Variables

Until now the equations that have been presented are directly applicable only to a steady state situation. In the literature that was found on waste treatment systems, the previous equations were used for examples and plant design only. It must now be decided how each parameter changes with respect to time along with how the changes in one parameter affect other parameters and develop equations for these changes.

As mentioned before, it seems reasonable to assume that a change impressed on a given system parameter will not affect every other parameter throughout the system at the same time. For instance, if influent flow rate \((Q)\) should suddenly increase by 25\%, that does not mean that the system volume suddenly increases by 25\% or that the effluent flow rate suddenly increases. What should occur is that the full effect of that change is not transmitted through the entire system any faster than the liquid traversing the system; which is to say that the full effect of a change cannot occur until the passage of at least one hydraulic retention time (HRT), also called the liquids retention time.

Therefore, the following type of equation is used for all system input parameters:
\[ P_{eq} = P_o + \frac{(P_n - P_o)}{\text{HRT}} \Delta t \]  

where

- \( P_n \) is the value the parameter will ultimately be changed to
- \( P_o \) is the value of parameter during the previous \( \Delta t \)
- \( P_{eq} \) is the value of the parameter to be used at present \( \Delta t \).

It can be seen that after but a few iterations of this type equation that \( P_{eq} \) becomes increasingly close to \( P_n \). This equation seemed to work well for all the input parameters, but evaluating how the other internal system parameters behave with respect to these inputs was a little more difficult.

**Indirect Time Dependent Variables**

An important parameter which can now be developed is called the volumetric recycle ratio \((Qr/Q)\).\(^{14}\) The recycle ratio can be used to gain some understanding of the internal working of the system. Starting with Equation V, 

\[ X = \frac{QrXr + QXi}{Q + Qr} \]

then solving for \( Qr/Q \) yields,

\[ \frac{Qr}{Q} = \frac{X - Xi}{Xr - X} \quad \text{or} \quad \frac{Qr}{Q} = \frac{1 - Xi/X}{Xr/X - 1} . \]

It was mentioned before that the term \( Xi \) (influent solids) would not be neglected, but since it is a small value and in this instance it is divided by a relatively large value, the ratio \( Xi/X \) will be assumed

\(^{14}\)Harbold, p. 160.
negligible. Another reason it can be neglected now is that this equation will not be used to solve directly for other system values, but only to get a feeling for the internal changes.

Now defining $R$ as the recycle ratio this reduces to

$$ R = \frac{Q_r}{Q} = \frac{1}{X_r - 1} $$

(XII)

For a properly operating activated sludge complete-mix process, the value for $Q_r/Q$ should range from 0.25 to 1.0. That implies that $X_r$, from Equation XIII, should be three to five times larger than $X$. Here again, this equation is precise only at a steady state condition, but it can be used to gain some insight of how the return sludge solids ($X_r$) and reactor tank solids ($X$) might change. Suppose, at steady state, that $Q$ was 5 Mgal/D and $Q_r$ was 3.0 Mgal/D, then the recycle ratio would be .6 and there would be some specific values for $X$ and $X_r$ according to Equation XIII. Now if $Q_r$, for some reason, dropped to 2.5 Mgal/D, this means that the recycle ratio decreases and Equation XIII is no longer exact, but it can be seen that the ratio $X_r/X$ must also increase or at least begin to increase.

This is the point at which a lot of man hours were expended trying different approaches. It is known how much the ratio must increase, but a description of any processes which would give more information could not be located. It was not known which or how the parameters $X$ and $X_r$ change. The following reasoning was finally utilized. Two possible extremes exist: first suppose $X$ remained constant and the total

15Metcalf and Eddy, p.498.
change was a product of a changing Xr only, the other extreme would be just the opposite - keep Xr constant and allow X to change. Mathematically either case would suffice and be a correct solution to Equation XIII, but common sense says that the correct answer would fall somewhere between these two extremes.

Plotting these extremes on a graph of Xr vs. X would yield the following, assuming an increase in the recycle ratio (if Qr/Q increases then Xr/X decreases).

\[
\text{RECYCLE RATION} = \frac{Q_r}{Q} = \frac{1}{\frac{X_r}{X} - 1}
\]

Figure 3. Possible Change in Solids Due to Change in the Recycle Ratio
Where $X_r$ and $X_o$ indicated the initial values at some steady state condition. $X_{r_m}$ is the minimum value $X_r$ could have if $X$ remained constant and $X_m$ is the maximum value $X$ could have if $X_r$ remained constant.

The points $(X_m, X_{r_o})$ and $(X_o, X_{r_m})$ indicate the mathematically possible extremes. It now seems logical to assume that the final steady state condition would lie on the line connecting these two points. If both parameters change at the same rate, then the final $X_r$ would be exactly half way between $X_{r_o}$ and $X_{r_m}$ and the same could be said for $X$. This at least provides a set values with which to proceed.

Looking at Equation V, it is obvious that if $X_r$ is held constant then,

$$X_m = \frac{Q_r X_r + Q X_o}{Q + Q_r}$$

also Equation V can then be solved for $X_r$ to yield

$$X_{r_m} = \frac{X_o (Q + Q_r) - Q X_i}{Q} = X_o \left(\frac{Q}{Q_r} + 1\right) - \frac{Q X_i}{Q_r}$$

It should be noted that this method of reasoning is valid if the recycle ratio increases or decreases. It would then be possible to use the following equations if $X$ and $X_r$ changed at the same ratio,

$$X_{r_F} = \frac{X_{r_m} + X_{r_o}}{2} \quad \text{and} \quad X_F = \frac{X_m + X}{2}$$

(XIII)

where

$X_{r_F}$ & $X_F$ are the final values after a long time interval
$X_{r_o}$ & $X_o$ are the initial values before any change
$X_{r_m}$ & $X_m$ are the extreme values (maximums or minimums)
Then again relating this to the hydraulic retention time,

\[ X_r = X_{r0} - \frac{(X_r - X_{rF})}{HRT (k_1)} \Delta t \] and 
\[ X = X_0 - \frac{(X - X_F)}{HRT(k_2)} \Delta t \] (XIV)

where

\[ k_1 \text{ and } k_2 \text{ are data manipulating factors} \]

Now this set of equations, V, XIV and XV, at least yield slowly changing parameters with the proper selection of the values of \( k_1 \) and \( k_2 \). It should be noted again that \( \Delta t = 1 \text{ hour} \) was used.

The factors \( k_1 \) and \( k_2 \) have at least two uses. First, it can be reasoned that a change in return sludge flow rate (Qr) will probably have a greater immediate effect on \( X_r \) than on \( X \), therefore \( k_2 \) would be slightly greater than \( k_1 \). The best way to describe the alternate use for \( k_1 \) and \( k_2 \) is to call them "process factors." By slightly varying these amounts, the rate at which \( X_r \) and \( X \) mathematically respond to changes can be altered.

Utilizing all the equations referenced up to this point, a partial understanding of how the system varies through a change in either influent flow rate (Q) or return sludge flow rate (Qr) can be gained. Still needed is the system kinetic equations to describe the effects of a changing influent substrate (S), waste sludge flow rate (Qw), and air flow (AF) into the reactor tank.

The waste sludge flow rate (Qw) was first mentioned in Equation IV, where it was substituted into the derivation of the equation for effluent substrate (S). This makes Qw a parameter in the so called "fundamental" equations (IV, V, VI,VIII).
To a plant operator the waste sludge flow is one of the most important controls to insure proper operation and sufficiently reduce substrate in the effluent.\(^{16}\) Equation IV shows that if the operator wastes too much, the SRT will decrease. This implies that if the waste rate increases, the program must alter the internal variables X and Xr to reflect a decreasing SRT. Also a decreasing, SRT should imply substrate increase in the effluent. In analysing the recycle ratio, it was decided that both X and Xr should be decreased for an increase in Qw by the same or nearly the same percentage. This would show an increase of effluent substrate and not change the effect of previously explained changes. The following equations were selected for this situation:

\[
X = X \left[ 1 - \frac{(Q_w - Q_{w_0})}{Q_w} \right] \left[ \frac{\Delta t}{\text{HRT} (k_3)} \right]
\]

\[
X_r = X_r \left[ 1 - \frac{(Q_w - Q_{w_0})}{Q_w} \right] \left[ \frac{\Delta t}{\text{HRT} (k_4)} \right]
\]

where

- \(Q_w\) = waste sludge flow rate to be obtained at steady state
- \(Q_{w_0}\) = waste sludge flow rate felt by system during this \(\Delta t\)
- \(\Delta t = 1\) hour
- \(k_3\) and \(k_4\) = process manipulators

After $X$ and $X_r$ have been altered by a changing recycle ratio and/or a change in waste flow rate a look at Equations VIII and X shows that each of these changing parameters will affect the oxygen requirement of the system. This fact in itself is not overly important to the program. What is of great importance to the program, and to an actual system, is if the oxygen requirement tries to increase to the extent that it might mathematically grow larger than the oxygen being supplied.

If the oxygen being supplied is not sufficient to sustain the present bacterial population, the death rate will exceed the growth rate. This implies that both $X$ and $X_r$ should start decreasing which then will have the effect of reducing the oxygen requirement.

There are at least two factors that should affect the rate of change of $X$ and $X_r$. First is the magnitude of this oxygen mismatch, and second is how much of this mismatch was caused by a decrease in input air flow, if any. Here again the approach of using a fractional change equation was taken. Through trial and error it was found that the following equation would yield reasonable results.

\[
X = X - X \left[ \frac{O_{req} - O_{supp}}{O_{req} (k_5)} \right] + X \left[ \frac{O_{supp} - O_{supp_0}}{O_{supp} (k_6)} \right] \tag{XVII}
\]

where

$O_{req}$ = oxygen requirement of system at present time

$O_{supp}$ = oxygen supplied to system at present time

$O_{supp_0}$ = oxygen being supplied one $\Delta t$ previously

$k_5$ & $k_6$ = data manipulating factors
Both of these fractional change terms were included because it seems that the oxygen mismatch condition, described above, would be more severe if the mismatch were caused by a sudden loss of air flow, such as loss of an air pump, rather than a mismatch occurring because of some slowly changing internal growth factors.

Before all these tests and comparisons using the amount of supplied oxygen can be implemented the oxygen supplied must be in the same units as oxygen requirement. Equation X gives oxygen requirement in pounds of \(O_2\) per day but airflow is in cubic feet per minute. Cubic feet per minute can be converted to pounds per day using the following facts and assumptions.\(^{17}\)

(1) The specific weight of air at standard temperature and pressure (STP) is .075 pounds/ft\(^3\),

(2) air contains 23.2\% oxygen by weight,

(3) and an 8\% oxygen transfer rate exists at STP.

Then,

\[
O_{\text{supp}} = \text{airflow} \left( \frac{\text{ft}^3}{\text{min}} \right) \frac{1440 \text{ min}}{\text{day}} (0.08) (0.75 \text{ lb/ft}^3) (0.232)
\]

or,

\[
O_{\text{supp}} \left( \frac{\text{lb}}{\text{day}} \right) = \text{AF} \left( \frac{\text{ft}^3}{\text{min}} \right) 2.00448 \left( \frac{\text{min lb}}{\text{day ft}^3} \right) \tag{XVIII}
\]

where AF is the air being pumped into the aeration tanks.

The last parameter to be examined is the influent substrate \((S_o)\).

Influent substrate could change and should thereby bring about subsequent changes in the system. By simply using equation VIII it would seem that increasing influent substrate would have the effect of only

---

\(^{17}\)Metcalf and Eddy, p. 400.
increasing the effluent substrate; but it is recalled that equation VIII is directly applicable only to a steady state situation. If there is an increase in the food supply, it seems logical to assume there would follow a corresponding increase in the microorganism population followed by an increase in oxygen requirement and so on through the system.

Devising equations that would react to a change in influent substrate was a most difficult task. The following reasoning was used to develop a set of equations to handle this problem.

It is known that process efficiency and the average solids retention time (SRT) are related.\textsuperscript{18,19} It was decided, therefore, to test the value of process efficiency, evaluate if the present SRT was too high or too low, within bounds, and adjust the values of $X$ and $X_r$ to reflect what the SRT should be for the present process efficiency.

\[
E = 1 - e^{-\lambda t}
\]

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure4.png}
\caption{Relationship Between Efficiency and Solids Retention Time}
\end{figure}

\textsuperscript{18} Metcalf and Eddy, p. 400.
\textsuperscript{19} Harbold, p. 160.
By looking at the graph of process efficiency vs. SRT, Figure 4,\(^{19}\) it seems that the relation between the two parameters is of the following form:

\[
E = 1 - e^{-\lambda t}
\]  

(XIX)

\(E\) would be the process efficiency, \(t\) would be SRT, in days, and \(\lambda\) in some time constant, in \((\text{days})^{-1}\).

Here again, if the system were in a perfect steady state, a single value for this \(\lambda\) could be found for a given system. But since something useful for transients is needed, a certain degree of variance must be allowed for in this time constant.

In the example in Chapter III of this report, the SRT of 10.05 days produced an effluent waste concentration of 6.89 mg/l from an influent waste concentration of 250 mg/l. From these values the treatment efficiency is

\[
E = \frac{250 - 6.89}{250} = .97244
\]

and then solving for \(\lambda\) yields;

\[
\lambda = \frac{-\ln (1-E)}{\text{SRT}} = .35735 \text{ days}^{-1}
\]

Therefore it is concluded that the boundary values should fall on either side of this value. After much of experimentation it was found that time constants of .38 days\(^{-1}\) can be used for a low bound on SRT and .28 days\(^{-1}\) for an upper bound on SRT. These would yield reasonable

\(^{19}\) Harbold, p. 160.
result when used in conjunction with the following equations which alter \( X \) and/or \( X_r \).

In terms of logic flow, one of three possible condition can exist: 1) the present SRT is less than calculated lowest SRT, 2) the present SRT is greater than the highest calculated SRT, or 3) the present SRT is within the specified boundary. Each possible condition needs examination:

(1) If SRT is too low for present process efficiency, then \( X \) and/or \( X_r \) must change to increase the SRT; however, "What should change and how much?" Equation IV shows that if the SRT is to increase then \( X \) must increase, or \( X_r \) must decrease, or both, or \( X \) and \( X_r \) can both increase if \( X \) increases such that the numerator of Equation IV increases more than the denominator. Since it is not within the scope of this research to take all possibilities into account, the following two possibilities were selected: a) If the present situation is the result of, or the cause of, the process oxygen requirement being greater than the oxygen supplied, then the SRT will increase by a decreasing \( X_r \); b) Otherwise, \( X \) and \( X_r \) will both increase with \( X \) increasing the greatest percentage. The equations used are

\[
T_{LO} = \frac{-\ln (1-E)}{(.38 \text{ days})} \\
T = \frac{(T_{LO} - \text{SRT})}{T_{LO}} \quad (XX)
\]

where \( T \) is the fractional amount that the SRT is beyond the set boundary \( (T_{LO}) \), then if the process is low on oxygen being supplied;

\[
X_r = X_r - (X_r)(T/HRT) \quad (XXI)
\]
or if there is sufficient oxygen being supplied;
\[ X = X + (X) \frac{(T)}{(HRT)} \]  
\[ X_r = X_r + (X_r) \frac{(T)}{(2 \cdot HRT)} \].  

(XXII)  

(XXIII)

(2) If the present SRT is too great for present process efficiency then \( X \) and/or \( X_r \) must change to decrease the SRT. Here again there are many possible combination of changes to achieve the desired effect. The following was chosen:

\[ T_{HI} = -\ln \left(1 - \frac{1}{E} \right)^{-1} \]  
\[ \frac{T}{T_{HI}} = \frac{(SRT-T_{HI})}{T_{HI}} \]  

(XXIV)

where \( T \) is the fractional amount that the SRT is beyond the set boundary \( (T_{HI}) \), then if the process is low on oxygen being supplied;

\[ X = X - (X) \frac{(T)}{(HRT)} \]  

(XXV)

or if there is sufficient oxygen being supplied;

\[ X = X + (X) \frac{(T)}{(2 \cdot HRT)} \]  
\[ X_r = X_r + (X_r) \frac{(T)}{HRT} \].  

(XXVI)  

(XXVII)

(3) If the present SRT is within the previously set boundaries, it must then be decided if any further changes are necessary. It was decided to test if the SRT calculated with system parameters for the present \( \Delta t \) is any different from what the SRT would be calculated from end-of-transient system parameters. Simply using Equation IV and substituting in the values, the flow rates should approach if they were undergoing a change; i.e. the \( P_n \), or end of transient values of Equation XI. This was done assuming it would yield at least a reasonable
value for the SRT and then X and Xr were adjusted based on the fractional amount this estimated SRT differs from the present SRT. The equations used are

\[ SRT_F = \frac{VX}{QwXr + (Q-Qw)Xe} \]

where V, X, X, and Xe are present system values with Q and Qw being end of transient values, which implies that \( SRT_F \) is estimated SRT after the transient, then

\[ T = \frac{SRT - SRT_F}{SRT_F} \]  (XXVIII)

\( T \) is the fractional amount that the SRT is different from the estimated final SRT, then if the SRT needs to be decreased;

\[ X = X - \left( X \frac{T}{2 \text{HRT}} \right) \]  (XXIX)

\[ Xr = Xr + \left( Xr \frac{T}{2 \text{HRT}} \right) \]  (XXX)

which will decrease X and increase Xr, or if the SRT increased;

\[ X = X + \left( X \frac{T}{2 \text{HRT}} \right) \]  (XXXI)

\[ Xr = Xr - \left( Xr \frac{T}{2 \text{HRT}} \right) \]  (XXXII)

which will increase X and decrease Xr.

It should be noted that this last test is not necessarily an accurate reflection of what the final SRT will be, simply because present values of X and Xr are all that is known and that the end of transient values will be different.

After all these tests, equations, and time dependent changes, another problem that manifested itself was that for a given change of system parameters the calculation of effluent waste concentration by
Equation VIII would sometimes yield a result less than zero, which is obviously invalid. Here a rather drastic step was taken; a completely new X and a new Xr were calculated. This calculation would be based on assumed process limits such as 98% efficiency with an SRT of approximately 10 days.

It was decided to set the effluent waste concentration \( S \) to 2% of the influent waste concentration \( S_0 \) and reduce the present system solids concentration \( X \) by 2%. The reduction of the solids concentration seemed the logical step because when the waste concentration drops very low it implies a larger microorganism population than there is food to support. Substituting this reduced value of \( X \) and the other necessary present system parameters into Equation V, a corresponding reduced value for return solids concentration \( Xr \) can be found.

The situation of effluent waste concentration being very, very small and the solution proposed, presents a slightly non-realistic change in the effluent waste concentration. When the effluent waste concentration takes on very small values, i.e. less than 2% of influent waste concentration, it will sometimes make slight jumps back up to a full 2% of the influent concentration. While this may be somewhat annoying, it is the only method tried that provides realistic values.
CHAPTER V
HARDWARE DESCRIPTION AND INTERFACE

The Computer

Two different computers were used during this research. At the University of Central Florida (UCF) a Radio Shack, TRS-80, Model I, with an expansion interface, 32K memory and dual five inch floppy disk drives as mass storage devices was used. Later, a TRS-80, Model I, 16K, with a cassette recorder was used for the majority of the programming. On both computers the only language used was Level II Basic.

The TRS-80 at UCF has the S-100 bus interface for communication to the analog to digital (A/D) and digital to analog (D/A) converters and therefore communication to the simulator training board.

The Control Board

As mentioned in the introduction, most of this work was completed without access to the analog control simulation training board at UCF. In the following sections a brief description of the hardware and software necessary for the communication interface between the analog training board and the digital computer is presented.

The physical appearance of the board is very similar to Figure 5, which shows the approximate location of the read-out meters and the parameter control devices (potentiometers). The only real difference between Figure 1 and Figure 5 is that the board also displays a chlorine contact tank and related meters and controls. The chlorine contact
Figure 5. Analog Control Simulator Training Board
process is not directly a part of the activated sludge process; therefore it was not included in this research.

The training board was designed, built, and wired by William Selph, a UCF student in 1977, as a research project. Shown in Figure 6 is a wiring schematic of the board along with the necessary connection points for the A/D and D/A converters. This schematic shows meters to monitor the system influent parameters. These meters were not present on the board, but they are shown in the schematic where they will be installed at some future time. Until then the influent parameter values can be displayed on the computers CRT for monitoring during program operation.

**A/D Description and Suggested Use**

The TECMAR analog to digital (A/D) converter used is capable of 16 single-ended inputs with 12 bit accuracy. As the simulation program now stands only 6 of these need be used. The computer I/O ports used were:

- **I/O Port 1**: Sludge Waste Rate (Qw)
- **2**: Sludge Return Rate (Qr)
- **3**: Air Flow (Af)
- **4**: Influent Suspended Solids (Xi)
- **6**: Influent Substrate (So)
- **7**: Influent Flow Rate (Q)

**NOTE**: Other ports are not used.
Figure 6. Training Board Schematic
The appropriate input voltages are mapped into the digital end with the smallest voltage corresponding to 111110000000, mid voltage corresponding to 0000000000000000, and the highest voltage corresponding to 0000011111111111.20 This input value must then be converted to a decimal equivalent for use in the program. The following are the subroutines to receive data from the I/O ports and perform the necessary conversions.

The loop at statements 3010 to 3060 will read in the values at each input port and store those values in V1 and V2. Then there is a section of code for each system parameter that is input. In each section the full scale (FS) or maximum allowable value for that parameter is set and the index, I, is set to reference a specific parameter to a specific input port. Statements 3400 to 3490 convert the quantity that was stored in variables V1 and V2 to its decimal equivalent and stores that value in the temporary variable, XT.

Subroutine to receive data from input ports

3000 REM SUBROUTINE RECEIVE DATA
3010 FOR I = 1 TO 7
3020 OUT 0, I
3030 OUT 1, 2

3040 IF INP(1) <> 1 THEN 2040
3050 VA(I) = INP(2) : VB(I) = INP(3)
3060 NEXT I
3070 REM INPUT SLUDGE WASTE RATE (MGD)
3080 FS = .22 : I = 1
3090 GOSUB 3400
3100 QW = XT
3110 REM INPUT SLUDGE RETURN RATE (MGD)
3120 FS = 4 : I = 2
3130 GOSUB 3400
3140 QR = XT
3150 REM INPUT AIR FLOW RATE (CFM)
3160 FS = 19000 : I = 3
3170 GOSUB 3400
3180 A = XT
3190 REM INPUT SUSPENDED SOLIDS (MG/L)
3200 FS = 150 : I = 4
3210 GOSUB 3400
3220 XI = XT
3230 REM I = 5 Not Connected
3240 REM INPUT INFLUENT SUBSTRATE (SI)
3250 FS = 500 : I = 6
3260 GOSUB 3400
3270 SI = XT
3280 REM INFLUENT FLOW RATE (Q)
3290     FS = 10 : I = 7
3300     GOSUB 3400
3310     Q = XT
3320     RETURN
3400 REM CONVERT A/D
3410 REM FS = FULL SCALE
3420 IF VB(I) > 247 THEN 3460
3430     VV = VB(I) * 16^2 + VA(I)
3440     XT = (VV/2047 + 1) * FS/2
3450     GO TO 3500
3460     V2 = ABS (VB(I) - 255)
3470     V1 = ABS (VA(I) - 255)
3480     VV = V2 * 16^2 + V1
3490     XT = (1 - VV/2047) * FS/2
3500     RETURN

D/A Description and Suggested Use

The TECMAR digital to analog (D/A) converter board is capable of four independent D/A conversions with 12 bit accuracy. Each of these D/A units are accessed through addressing two out of eight possible I/O ports. The highest of the two I/O ports receives a byte in which the lowest four bits are the highest four bits of the 12 bit output. The lower I/O port receives a second byte which contains the the lower 8 bits of the 12 bit output. What this means is that by accessing the
two I/O ports an output digital number must be mapped into; 1111100000-000000 corresponding to the smallest output possible, 0000000000000000 corresponding to the middle value of the output, and 0000011111111111 corresponding to the maximum output value possible. The following is a subroutine which will accomplish this task.

Let YT be the decimal value which is to be converted to an analog signal and FS (full scale) be the maximum allowed value of YT.

```
12600 REM CONVERT D/A
12610 IF YT < (FS/2) THEN 12660
12620 VV = (YT/(FS/2) - 1) * 2047
12630 V2 = FIX (VV/16^2)
12640 V1 = INT((VV/16^2 - V2) * 16^2)
12650 GO TO 12700
12660 VV = (1 - YT/(FS/2)) * 2047
12670 V2 = 255 - FIX (VV/16^2)
12680 V1 = 255 - INT ((VV/16^2) - FIX (VV/16^2)) * 16^2
12700 RETURN
```

Now with V2 being the equivalent of the high order bits it is sent to the lower of the I/O port pair and V1 is sent to the higher I/O port.

---

The D/A units will be set for I/O mapped operation if the switch package is set in the following manner.

<table>
<thead>
<tr>
<th>Switch</th>
<th>Assignments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Closed (1)</td>
</tr>
<tr>
<td>2</td>
<td>Closed (1)</td>
</tr>
<tr>
<td>3</td>
<td>Don't Care</td>
</tr>
<tr>
<td>4</td>
<td>Open (0)</td>
</tr>
<tr>
<td>5</td>
<td>Open (0)</td>
</tr>
<tr>
<td>6</td>
<td>Open (0)</td>
</tr>
<tr>
<td>7</td>
<td>Closed (1)</td>
</tr>
<tr>
<td>8</td>
<td>Open (0)</td>
</tr>
</tbody>
</table>

Then the block of I/O ports which are accessible are 00010000 (16_{10}) through 00010111 (23_{10}).

In TRS-80 BASIC this addressing can be done with the following statements:

```plaintext
XXXX FS = (some full scale value)
XXXX YT = (parameter value to display)
XXXX GOSUB 12600 (see subroutine listed above)
XXXX OUT 22, V2
XXXX OUT 23, V1
```

The training board was wired so that I/O ports 16 and 17 were used for effluent substrate (S), ports 20 and 21 were the reactor tank suspended solids (X), and 22 and 23 I/O ports were for the oxygen required (Oreq). Other I/O ports were not used but they are available.
CHAPTER VI

CONCLUSIONS AND OBSERVATIONS

The computer driven training simulator can be a very useful tool in the training of students in the operation and control of a waste water treatment plant. Due to the variability of the system time delays a full transient, steady state to steady state, can be simulated in a matter of minutes, if desired. The training simulator will also put the training back into the classroom instead of at an on site facility. If an operational error is made with the simulator, it can simply be restarted, but if an error occurs at an actual facility, the seriousness of the mistake might possibly have an impact on the environment. The intended use of training simulators is not to do away with on site training but only to give the student a more realistic impression of what to expect when his on-the-job training does start.

The research that was done here and the computer program developed has shown that the computer driven training simulator idea is, at very least, a plausible and realistic idea. Admittedly, the computer program does not emulate an actual treatment process exactly in all possible situations, but it does react to system deviations in a manner at least similar to the reactions expected in an actual system.
It should be noted that many of the equations presented herein were simply a product of the author's intuition and knowledge gained by reading publications about process plant design and operational criteria. The equations are presented only as possible reactor sewage kinetic equations and not as equations mathematically derived from previously proven relationships, although numerous proven relationships were used throughout.

Suggestions For Further Research

Within the limited scope of the research, the simplification of using a time increment, $\Delta t$, of one hour was utilized. This implies that the full spectrum of equations developed can only be evaluated once each simulation hour, in other words each evaluation of the equations simulates one hour of treatment plant operation even though it may only use a few seconds of elapsed "real" time. This can be a disadvantage if the simulated transient time is to be increased, the computer will still evaluate the necessary equations very rapidly but will then "wait" (in programming a "wait" would simply be a section of the coding that would do nothing useful except waste time) the appropriate amount of time before continuing. This "wait" time can be thought of as spacing out the number of times the computer program updates the inputs and outputs, or the data which is passed to and from the simulator training board.

It would probably be of great value to include a $\Delta t$, time increment, variable in each of the time dependent equations so that each half hour or even each minute of the simulation could be observed on
the training board. This would entail a study of behavioral characteristics of the presented equations through many more evaluation iterations than this research considered.

After careful scrutiny of experts in the waste water treatment field, the equations presented here may prove to be flawed and therefore required revision. Even if this does happen it does not detract from the fact that a computer driven waste water training simulator is a beneficial concept and a concept that should be pursued.
APPENDIX A

SIMULATOR PROGRAM FLOWCHART
SET ALL CONSTANTS.
SET CONTROL PARAMETERS TO THEIR INITIAL STEADY STATE VALUES.
CALCULATE OTHER INITIAL PARAMETERS.

DISPLAY PRESENT CONDITIONS (EITHER ON CRT AND/OR ON TRAINING BOARD).

READ ALL INPUTED PARAMETERS (EITHER FROM CRT OR FROM TRAINING BOARD).

CALL SUBROUTINE TO CALCULATE SYSTEM CHANGES FOR THIS TIME INCREMENT (Δt), BASED ON PRESENT HRT.

EVALUATE PRESENT RECYCLE RATIO (RR) BASED ON PRESENT Δt PARAMETERS.

IS THE RECYCLE RATIO FOR THIS Δt DIFFERENT THAN THE RECYCLE RATIO CALCULATED FOR THE LAST Δt?

CALL SUBROUTINE TO EVALUATE EFFECTS OF A CHANGE IN RECYCLE RATIO.
1

CHANGE IN QW

YES

CALL C SUBROUTINE FOR CHANGE IN QW

NO

WAS CHANGE IN RR SMALL

YES

IF Qw HAS CHANGED EVALUATE EFFECT ON X AND Xr.

NO

IS SYSTEM IN STEADY STATE

YES

IF THE CHANGE IN RECYCLE RATIO WAS SMALL NEED TO TEST TO SEE IF SYSTEM IS IN STEADY STATE.

NO

CALL D SUBROUTINE TO EVALUATE SMALL SYSTEM CHANGES

ENOUGH OXYGEN

YES

CALL E SUBROUTINE DUE TO LOW OXYGEN

NO

IF THE SYSTEM IS NOT IN STEADY STATE NEED TO MAKE SMALL CHANGES IN X AND Xr.

ENOUGH OXYGEN

NO

IS OXYGEN BEING SUPPLIED GREATER THAN THE OXYGEN REQUIRED?

YES

IF NOT ENOUGH OXYGEN THEN SYSTEM PARAMETERS NEED TO CHANGE TO REFLECT THIS OXYGEN MISMATCH.
CALL F SUBROUTINE TO CHECK VALUE OF S

CALL G SUBROUTINE TO CALCULATE SYSTEM PARAMETERS

IS S > 0

YES

CHECK PRESENT VALUE OF EFFLUENT SUBSTRATE (S) AGAIN UPPER AND LOWER BOUND OF PROCESS SRT.

EVALUATE ALL OTHER SYSTEM PARAMETERS.

IF EFFLUENT SUBSTRATE (S) IS TOO LOW GO BACK AND RECALCULATE.

NO

CALL F SUBROUTINE TO CHECK VALUE OF S
SUBROUTINE A
CALCULATE SYSTEM CHANGES FOR THIS TIME INCREMENT

EVALUATE
HRT, Q, Qr, Qw,
AIRFLOW, Qsupp,
AND TANK VOLUME

CALCULATE EACH BASED ON GENERAL EQUATION XI
IN CHAPTER IV.

RETURN

SUBROUTINE B
EVALUATE EFFECTS OF A CHANGE IN RECYCLE RATIO

CALCULATE MAX,
MIN, AND MID
VALUES OF X AND
Xr

FIND THE MAXIMUM, MINIMUM, AND MIDPOINT
VALUES OF X AND Xr ACCORDING TO EQUATION
DEVELOPED FOR FIGURE 3.

CALCULATE THE
CHANGES IN X
AND Xr

USING THESE VALUES, JUST CALCULATED, AND THE
PRESENT HRT FIND NEW X AND Xr VALUES TO
REFLECT SYSTEM CHANGES.

RETURN
SUBROUTINE C

Evaluate new X and Xr

Based on magnitude of the change in Qw and HRT
Evaluate new values for X and Xr

RETURN

SUBROUTINE D

Near steady state changes

Evaluate new X and Xr

If system is near steady state need to make sure changes bring system nearer to steady state.

RETURN

SUBROUTINE E

Effects due to low oxygen being supplied

Evaluate new X and Xr

New X and Xr values are based on magnitude of oxygen mismatch (Osupp - Oreq) and the magnitude of the change in Osupp.

Set low oxygen flag

- Set flag to indicate system is low on oxygen during this time increment.

RETURN
SUBROUTINE F
CHECK EFFLUENT SUBSTRATE AGAINST SRT BOUNDS

FIND EFFICIENCY

IS S < 0
YES F3
NO

FINAL BOUNDS
ON SRT

IS PRESENT SRT
BELOW LOWER
BOUND
YES

FIND X AND XR

IS PRESENT SRT
ABOVE UPPER
BOUND
YES

FIND X AND XR

NO

CALL G
SUBROUTINE
FOR SYSTEM
PARAMETERS

F1

F2

CALCULATE PRESENT SYSTEM EFFICIENCY

TEST TO SEE IF EFFLUENT SUBSTRATE IS NOT NEGATIVE.

USING PROCESS EFFICIENCY CALCULATE UPPER AND LOWER BOUNDS ON SRT.

BRANCH TO SEPERATE SECTION DEPENDING ON IF SRT IS TOO LOW OR TOO HIGH AND CALCULATE NEW X AND XR DEPENDING ON HOW FAR FROM THE BOUNDARY SRT IS AND DEPENDING ON IF LOW OXYGEN FLAG IS SET.

EVALUATE THE OTHER SYSTEM PARAMETERS.
SRT is within previously set bounds but the system may not be in steady state. Calculate X and Xr based upon end of transient parameters.

If effluent substrate is too small, the set to 98% efficiency and reduce X by 2% and calculate corresponding Xr.
SUBROUTINE G

FUNDAMENTAL SYSTEM EQUATIONS

FIND S, SRT
Oreq, Osupp

RETURN

USING EQUATION DEVELOPED IN CHAPTER III
CALCULATE EFFLUENT SUBSTRATE, (S), SOLIDS
- RETENTION TIME (SRT). OXYGEN REQUIRED (Oreq)
AND OXYGEN BEING SUPPLIED (Osupp).
APPENDIX B

SIMULATOR PROGRAM LISTING
(This listing utilizes the computers' own CRT for all I/O functions, to communicate with the simulator training board the subroutines mentioned in Chapter V of this report must be incorporated into the program.)

1 REM CONSTANTS
10 Y=.65 : KD=.1 : VM=1.15 :VS=.4
30 REM INITIAL CONSTANTS
40 Q=5 : QR=2.7 : QW=.0396 : XR=9850 : SO=250 : AF=5150
60 RO=QR/Q : XI=80 : XE=.8
70 GOSUB 8500
80 OIS=OS
100 REM
110 PRINT"INITIAL CONDITIONS ARE:" : GOSUB 10000
120 PRINT"DO YOU WISH TO CHANGE ANY PARAMETERS ?"
125 A$=INKEY$ : IF A$="" GOTO 125
130 IF A$="N" GOTO 1000
140 IF A$="Y" GOTO 200
150 PRINT"JUST Y OR N PLEASE" : GOTO 120
200 CLS : PRINT"YOU HAVE CONTROL OVER THE FOLLOWING ;"
210 PRINT" 1) RETURN SLUDGE FLOW RATE"
220 PRINT" 2) WASTE SLUDGE FLOW RATE"
230 PRINT" 3) AIR FLOW INTO TANK"
235 PRINT
240 PRINT"INPUT THE NUMBER OF THE PARAMETER YOU WISH TO CHANGE."
250 PRINT" INPUT 4 IF CHANGES ARE COMPLETE.";
270 A$=INKEY$ : IF A$="" GOTO 270
280 IF A$="Q" GOTO 9000
290 IF A$="S" GOTO 9500
300 N=ASC(A$)-48
310 IF N<1 OR N>4 GOTO 235
320 ON N GOTO 11000,11500,12000,1000
999 REM MAIN
1000 GOSUB 1400
1010 XO=X : RI=XR
1020 RO=QI/QO
1030 RR=QR/Q : RD=RR-RO
1040 IF ABS(RD) > 1E-5 GOSUB 1500
1060 IF QW-WO <> 0 GOSUB 1800
1070 IF ABS(RD) > 1E-3 THEN 1100
1080 XTR = QO/QI * (X-XI) + X
1090 IF ABS( (XTR-XR)/XR ) > .05 GOSUB 1700
1100 REM
1110 FACT = 0
1120 IF OS - 0 < 0 GOSUB 1900
1130 REM CHECK VALUE OF S
1140 GOSUB 2000
1150 GOSUB 8510
1160 IF S > 0 GO TO 1175
1170 GOSUB 2000
1175 PRINT" CONDITIONS NOW ARE ;"
1180 GOSUB 10000
1190 GO TO 120
1400 REM SYSTEM CHANGES FOR THIS DELTA TIME
1410 HRT = (V+VS)/Q * 24
1420 QO = QO + (Q-QO)/HRT
1430 QI = QI + (QR-QI)/HRT
1440 AOF = AOF + (AF-AOF)/HRT
1450 SI = SI + (SO-SI)/HRT
1460 OIS=OIS + (OS-OIS)/HRT
1470 WO = WO + (QW-WO)/HRT
1480 V = V - (QO-Q)/24 + (WO-QW)/24
1490 IF VM < V THEN V = VM
1495 RETURN
1500 REM CHANGE IN RECYCLE RATIO
1510 RM = X*(1+Q/QR)-Q*XI/QR
1520 XM = XR*QR/(Q+QR) +XI*Q/(Q+QR)
1530 XF = (XM+X) /2
1540 RF = (XR+RM)/2
1550 IF Q = QO THEN 1580
1560 H1 = HRT*2 : H2 = HRT*1.8
1570 GO TO 1590
1580 H1 = HRT*1.5: H2 = HRT * 2.0
1590 XR = XR + (RF-XR) /H1
1600 X = X + ( XF -X ) /H2
1690 RETURN
1700 REM XR/X NOT CLOSE TO (Q/QR+1)
1710 XR = XR + (XTR-XR)/HRT
1720 XSS = (QI*XR + QO*XI)/(QO+QI)
1730 X = X + (XSS - X)/HRT
1790 RETURN
1800 REM CHANGE IN QW
1810 X = X *(1-(QW-WO)/QW/(HRT*1.7))
1820 XR = XR + (1-(QW-WO)/WQ/HRT )
1890 RETURN
1900 REM LOW OXYGEN SUPPLIED
1910 FACT = 1
1920 X = X-(X*(O-OS)/0/1.2)+(X*(OS-OIS)/OS/5)
1930 XR = XR-(XR*(O-OS)/0/1.0)+(XR*(OS-OIS)/OS/5)
1990 RETURN
2000 REM S CHECK
2010 EFF = (SI-S)/SI
2020 IF EFF > 1 GOTO 2270
2030 IF EFF = 1 GOTO 2320
2040 TLO = -LOG(1-EFF)/.38
2050 THI = -LOG(1-EFF)/.28
2060 IF SRT < TLO GOTO 2100
2070 IF SRT > THI GO TO 2180
2080 GO TO 2330
2100 REM INCREASE SRT
2110 TO = (TLO-SRT)/TLO
2120 IF FACT = 0 GO TO 2150
2130 XR = XR - (XR*T0/HRT)
2140 GO TO 2170
2150 X = X + (X * T0/HRT)
2160 XR = XR + (XR*T0/(HRT*2) )
2170 GO TO 2250
2180 REM DECREASE SRT
2190 TO = ( SRT-THI)/THI
2200 IF FACT = 0 GOTO 2230
2210 X = X-(X*T0/HRT)
2220 GO TO 2250
2230 XR = XR + (XR*T0/HRT)
2240 X = X + (X*T0/(HRT*2) )
2250 GOSUB 8510
2260 IF S>O GO TO 2320
2270 REM S < 0
2280 S = .02*SI
2300 X = X *.98
2310 XR = (X;QI-QI) /QI
2320 RETURN
2330 REM SRT WITHIN BOUNDS, BUT NOT SS
2340 TM = V * X / (QW*XR + (Q-QW)*XE )
2350 IF SRT<TM GO TO 2410
2360 REM DECREASE SRT X DN, XR UP
2370 TO = (SRT-TM)/TM
2380 X =X -(X*T0/(2*HRT) )
2390 XR = XR +(XR*T0/ (2*HRT) )
2400 GO TO 2320
2410 REM INCREASE SRT X UP, XR ON
2420 TO = (TM-SRT)/TM
2430 X = X +(X*T0/(2*HRT) )
2440 XR = XR - (XR*T0/(HRT*2) )
2450 GO TO 2320
2510 PRINT"CONDITIONS NOW ARE;"
2520 GOSUB 10000
2530 GOTO 120
8499 REM FUNDAMENTAL SUBROUTINE
8500 X=(QR*XR+Q*XI)/(Q+QR)
8510 S=SI-(X*KD*V+WO*WR+(Q0-WO)*XE)/Y/QO
8520 SRT=V*X/(WO*XR+(Q0-WO)*XE)
8530 O=(SI-S)*8.34*Q0/.68-1.4159*8.34*X*V/SRT
8540 OS=AOF*2.00448
8590 RETURN
9000 REM SUBROUTINE TO CHANGE Q
9010 CLS: PRINT"INFLUENT FLOW RATE IS NOW ";Q:" MG/D"
9020 INPUT"WHAT NEW VALUE OF Q DO YOU WISH TO USE";QC
9030 IF QC/QR >1 GOTO 9090
9040 PRINT"THAT IS QUITE SMALL FOR PRESENT CONDITIONS, ARE YOU SURE?"
9050 A$=INKEY$: IF A$="" GOTO 9050
9060 IF A$="N" GOTO 9020
9070 IF A$="Y" GOTO 9150
9080 PRINT"ONLY Y OR N PLEASE": GOTO 9050
9090 IF QC/QR <4 GOTO 9150
9100 PRINT"THAT IS VERY LARGE FOR PRESENT CONDITIONS, ARE YOU SURE?"
9110 A$=INKEY$: IF A$="" GOTO 9110
9120 IF A$="N" GOTO 9020
9130 IF A$="Y" GOTO 9150
9140 PRINT"ONLY Y OR N PLEASE": GOTO 9110
9150 Q=QC
9160 GOSUB 10000
9170 GOTO 120
9500 REM SUBROUTINE TO CHANGE INFLUENT SUBSTRATE CONC.
9510 CLS: INPUT"INPUT NEW SUBSTRATE CONC.";SN
9520 PRINT"ARE YOU SURE?"
9530 A$=INKEY$: IF A$="" GOTO 9530
9540 IF A$="N" GOTO 9510
9550 IF A$="Y" GOTO 9570
9560 PRINT"ONLY Y OR N PLEASE": GOTO 9530
9570 SO=SN
9580 GOSUB 10000
9590 GOTO 120
9999 END
10000 CLS
10010 PRINT" INFLUENT RETURN SLUDGE SLUDGE WASTE"
10020 PRINT" FLOW (MG/D) FLOW (MG/D) FLOW (MG/D)
10030 PRINT" ;Q;" ";QR;" ";QW
10040 PRINT
10050 PRINT" INFLUENT EFFlUENT AIR FLOW"
10060 PRINT" SUBSTRATE (MG/L) SUBSTRATE (MG/L) (CF/M)"
10070 PRINT" ;SO;" ";S;" ";AF
10080 PRINT
10090 PRINT" SUSPENDED OXYGEN OXYGEN"
10100 PRINT" SOLIDS (MG/L) REQ. (LB/D) SUPP (LB/D)
10110 PRINT" ;X;" ";O;" ";OS
10120 PRINT
10190 PRINT"SRT =";SRT;" DAYS"
10130 RETURN
10999 REM SUBROUTINE TO INPUT QR
11000 INPUT"NEW RETURN SLUDGE FLOW RATE";Q1
11020 IF Q/Q1 >1 GOTO 11050
11030 PRINT"THAT IS VERY LARGE, ARE YOU SURE?"
11035 B$=INKEY$: IF B$="" GOTO 11035
11040 IF B$="N" GOTO 11000
11045 IF B$="Y" GOTO 11080
11046 PRINT"ONLY Y OR N PLEASE": GOTO 11035
11050 IFQ/Q1<4 GOTO 11080
11060 PRINT"THAT IS QUITE SMALL, ARE YOU SURE?"
11065 B$=INKEY$: IF B$="" GOTO 11065
11070 IF B$="N" GOTO 11000
11075 IF B$="Y" GOTO 11080
11077 PRINT"ONLY Y OR N PLEASE":GOTO 11070
11080 QR=Q1
11090 GOTO 235
11100 REM SUBROUTINE TO INPUT QW
11110 INPUT"INPUT YOUR NEW SLUDGE FLOW RATE";Q2;
11120 SRT=V*X/(Q2*X+Q0-Q2)*XE)
11130 IF SRT>4.5 GOTO 11600
11140 PRINT"THAT MAKES FOR A SMALL SRT, ARE YOU SURE?"
11150 B$=INKEY$:IF B$="" GOTO 11150
11160 IF B$="N" GOTO 11150
11170 IF B$="Y" GOTO 11170
11180 PRINT"ONLY Y OR N PLEASE":GOTO 11150
11190 IF SRT<15 GOTO 11700
11200 PRINT"THAT MAKES FOR A LARGE SRT, ARE YOU SURE?"
11210 B$=INKEY$:IF B$="" GOTO 11210
11220 IF B$="N" GOTO 11150
11230 IF B$="Y" GOTO 11170
11240 PRINT"ONLY Y OR N PLEASE": GOTO 11150
11250 CLS
11260 QW=Q2
11270 GOTO 235
11280 REM SUBROUTINE TO INPUT AIR FLOW
11290 INPUT"INPUT NEW AIR FLOW IN CFM";A1
11300 O1=A1*2.00448
11310 IF O1>2 GOTO 12100
11320 PRINT"THATS A LITTLE SMALL, ARE YOU SURE?"
11330 C$=INKEY$ : IF C$="" GOTO 12050
11340 IF C$="N" GOTO 12050
11350 IF C$="Y" GOTO 12100
11360 PRINT"ONLY Y OR N PLEASE": GOTO 12050
11370 AF=A1
11380 OS=01
11390 GOTO 235
15000 END
SELECTED BIBLIOGRAPHY


