A DIGITAL COMPUTER SIMULATION OF AN AUTOMATICALLY CONTROLLED COMPLETE MIX ACTIVATED SLUDGE WASTEWATER TREATMENT PLANT USING FOOD:MASS RATIO CONTROL

A Thesis

Presented to

the Faculty of the Department of Civil Engineering

The University of Houston

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science Undifferentiated in Civil Engineering

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by

Ronald W. Simpson

May, 1975

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ABSTRACT

With the activated sludge wastewater treatment process being as complicated as it is, a concerted effort is needed to develop an automatic control system which will respond effectively to variations in influent flow and concentration. Such a control system has been devised and evaluated in the research study reported herein.

The primary control objective established for this study was to maintain a near constant food:mass ratio using return sludge flow as the control variable. Hydraulic retention time was allowed to vary from three to fifteen hours while the solids retention time was held constant at a value of eight days. A quasi food:mass ratio set point of 0.35 Kg/day/Kg was intended for steady state operation.

Results of the study indicate that the previously mentioned control strategy allowed the food:mass ratio to vary from 0.1 to 0.7 Kg/day/Kg when the influent flow and concentration were varied sinusoidally from plus to minus fifty percent of the steady state values. Effluent quality remained essentially constant; however, the final settling tank model indicated that the limiting solids flux was exceeded for periods up to eight hours. This would contribute to a degraded effluent should the condition last long enough for the sludge blanket to reach the effluent weir.

A tighter control of the food:mass ratio was attempted by varying the reactor volume so as to maintain a constant hydraulic retention time of six hours. This control system modification reduced the food:mass ratio excursions significantly; however, no improvement was obtained in effluent quality.

Finally, the performance of food:mass ratio control was compared with that of a more conventional control strategy--portional return sludge flow

control. For the influent variations applied, the conventional control strategy gave as good a performance as food:mass ratio control.

Future studies should incorporate a much more detailed settler model which describes the effects of food:mass ratio changes on settling characteristics of the biological floc.

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NOMENCLATURE

Symbol	Description	Unit
A	Settler surface area	m^2
BO	Sludge constant	liters/mg
DS(N)	Delta change in substrate concentration	mg/l/hr
DSNB(N)	Delta change in non-bio substrate concentration	mg/l/hr
DT	Delta time	hrs
DXS(N)	Delta change in stored mass concentration	mg/l/hr
DXA(N)	Delta change in active mass concentration	mg/l/hr
DXI(N)	Delta change in inert mass concentration	mg/l/hr
F(N)	Flow into tank (N)	gal/hr
FEFF	Effluent flow	gal/hr
FM(N)	Food/mass ratio in tank (N)	mg/day/mg
FR(N)	Return flow into tank (N)	gal/hr
FRACV	Volatile fraction of TSS	--
FSM	Max fraction - storage products	--
FW	Waste sludge flow	gal/hr
GTA	Actual total SS flux	$Kg/m^2/hr$
GTL	Limiting total SS flux	$Kg/m^2/hr$
KS	Sorption coefficient	mg/l
KXS	Saturation constant	mg/l
MLSS(N)	Mixed liquor SS in tank (N)	mg/l
OXYGEN(N)	Oxygen requirement in tank (N)	mg/l/hr
RT	Substrate transfer rate coefficient	hr^{-1}
RXA	Maximum growth rate coefficient	hr^{-1}

Symbol	Description	Unit
RXI	Decay rate coefficient	hr^{-1}
S(N)	Substrate concentration into tank (N)	mg/l
SLGERT	Delta change in stroed sludge	Kg/hr
SLUDGE	Stored sludge	Kg
SNB(N)	Non-bio substrate concentration into tank(n)	mg/l
SNBR	Return non-bio substrate concentration	mg/l
SR	Return substrate concentration	mg/l
T	Time	hrs
THETA(N)	Hydraulic retention time-tank(N)	hrs
THETAC	Solids retention time - system	days
THETAD	Desired hydraulic retention time	hrs
THTACM	Washout solids retention time	hrs
TODEFF	Effluent total oxygen demand	mg/l
TSSEFF	Effluent total suspended solids	mg/l
V(N)	Volume of reactor tank(N)	gal
VSS02	TOD of MLVSS	mg/mg
XCA	Actual underflow concentration	mg/l
XCL	Limiting underflow concentration	mg/l
XA(N)	Active mass concentration into tank (N)	mg/l
XAR	Return active mass concentration	mg/l
XI(N)	Inert mass concentration into tank (N)	mg/l
XIR	Return inert mass concentration	mg/l
XM(N)	Total mass in tank (N)	Kg
XS(N)	Stored mass concentration into tank (N)	mg/l

Symbol	Description	Unit
XSR	Return stored mass concentration	mg/l
Y1	Mass XA/mass XS converted	--
Y2	Mass XI/mass XA decayed	--
YTOD	TOD of volatile substrate fraction	mg/mg
ZA	Depth of sludge in clarifier	m

Chapter 1

INTRODUCTION

The activated sludge wastewater treatment process has been around for some time, having been developed during the early 1900's. Since that time, many variations of the original process have been developed. Two variations of the flow regime are plug flow and complete mixing. Some of the process variations which have been developed are conventional activated sludge, high rate, contact stabilization, step aeration, and extended aeration. In all of these process variations, however, the primary requirement still exists for the bringing together of wastewater and a mixed culture of microorganisms under aerobic conditions. Moreover, each of these process variations requires some sort of control in order to obtain stable operation and a high quality effluent.

Efforts have been made in the past to reduce man's workload in the control of activated sludge plants by bringing the computer into the picture. The computer systems being installed or specified for wastewater treatment plants are designed to perform a variety of functions. Included among these are data logging, data processing, equipment monitoring and alarm, maintenance scheduling, inventory control, and report preparation. While these are useful tasks for the computer to perform, a desirable addition is to have the computer maintain closed-loop control of the process itself. The provision of information storage and computing power will also permit the calculation of important variables which cannot be measured.

Many benefits can be gained by developing and putting into operation an effective closed-loop control system. Included among these are the improvement of plant performance, increases in productivity and reliability, evaluation of process stability, decreases in operating personnel, decreased operational costs, and shorter start-up times.

Purpose of Investigation

The purpose of this investigation is to determine the plant performance benefits which can be obtained through closed-loop control of the activated sludge wastewater treatment plant. Plant performance is primarily measured in terms of effluent quality. However, an additional indication of plant performance is given by the final settling tank performance. In the real world, settler performance is reflected in effluent quality; however, in this study, a simplified final settling tank model was used where the solids flux, settler capacitance and effluent quality were not interrelated as in the real world. Thus, in this investigation, both settler performance and effluent quality had to be evaluated to determine the overall system performance.

Scope of Investigation

In this investigation, it is assumed that the activated sludge plant influent has undergone primary clarification. No differentiation is made between the soluble and suspended solids portions of the remaining BOD. Domestic waste is assumed with its characteristic diurnal variations and a mean BOD level of 250 mg/l. A complete mix activated sludge (CMAS) system is modeled with perfect mixing assumed. This study does not address the problem of reliable on-line sensor requirements but assumes that the required sensed data are available for utilization in the control system. It was also assumed that sufficient oxygen was available to supply the oxygen demand in the reactor.

Method and Procedures

An all digital simulation was conducted using a Raytheon 440 digital computer. The treatment process model was developed using models already existing in the literature. The model was tuned to typical CMAS steady state operating conditions by varying the maximum growth rate and decay rate coefficients. Stensel and Shell (1) indicate that when a plant is operating properly, the food:mass ratio approaches a value of 0.35 Kg/day/Kg and the return sludge flow rate is approximately thirty percent of the influent flow rate. A control algorithm was developed with the objective of maintaining these process conditions for all realistic influent conditions. Typical domestic wastewater inputs were then applied to the system to determine the performance of the control algorithm and its effect on plant performance.

Chapter 2

BACKGROUND

Good process control is needed in the activated sludge treatment plant because of the wide variations which can occur in the influent conditions. Daily variations in flow can range from 50 to 150 percent of the mean and substrate concentrations may vary from 10 to 300 percent. When proper control is not maintained, process failures can occur, such as sludge breakdown or bulking. It is also possible for the final settling tank to be overloaded, thus exceeding the limiting flux. When this happens over a period of time, floc particles may be lost in the effluent stream.

Control Variables

For the conventional activated sludge process, Chasick (2) indicates that the operator has a rather limited choice of control variables, these being: (1) return sludge flow rate, (2) waste sludge flow rate, and (3) oxygen or air flow rate. These variables are defined in table I along with other parameters which could feasibly be used as control variables. Sludge recycle and sludge wasting are important parameters in controlling such things as mixed liquor suspended solids (MLSS), food:mass ratio (F/M), solids retention time (SRT), and sludge blanket height. These are control strategies and will be discussed in the next section. Aeration rate is varied so as to maintain a desired dissolved oxygen level at the reactor exit point. Influent rate and reactor volume (in some cases) could feasibly be used to control the hydraulic retention time (HRT). In order to control the influent rate, a holding tank would have to be incorporated upstream from the activated sludge plant to damp variations in the influent flow rate. Reactor volume could feasibly be controlled using movable gates at the tank exit. Hydraulic mixing can be varied to control floc particle size and peak oxygen requirements of the system. Matson, Characklis, and Rios (3) indicate that floc particle size is important in determining the available reaction potential.

Control Strategies

Control strategies which are used in the activated sludge process are defined in table II. Table III gives the advantages, disadvantages, and implementation techniques of each strategy.

Food:Mass (F/M) Ratio Control:

Depending upon what activated sludge process configuration is used, Goodman (4) indicates the optimum F/M ratio may vary from 0.03 to 4.0. Stensel (5) and others indicate that the F/M ratio should be about 0.35 for a CMAS system. Significant deviations from this optimum value can cause process failure due to sludge breakdown or bulking. It should be noted that F/M ratio is defined using BOD applied per day per active mass under aeration as defined by Sherrard (6) rather than BOD utilized per day per active mass under aeration which is the more popular definition. The advantages and disadvantages of using F/M control are summarized in table III. The primary advantage of this control strategy is that the F/M ratio is directly related to substrate removal rate and microorganism growth rate.

Solids Retention Time (SRT) Control:

SRT can be defined as sludge age using either the sludge mass in the reactor or sludge mass in the total system [Deaner (7)]. It appears that the correct calculation of sludge age should take account of the sludge mass in the total system (reactor plus clarifier) because the total sludge mass is cycled throughout the system. The SRT can vary from 3 to 18 days [Goodman (4)]. If the SRT is allowed to go below 5 days, nitrifying bacteria will wash out and nitrification will not take place in the treatment plant [Jenkins and Garrison (8)], but will occur somewhere downstream, putting a NOD load on the stream. Carbonaceous reactions can occur in the plant at SRT values of 3 days or lower. There is, however, a washout point even for carbonaceous bacteria. This occurs at a SRT of approximately 6 hours (θ_c^M) in this study. Sherrard (6) has also indicated that sludge settling properties are best at higher values of SRT where the sludge volume index (SVI) is minimal. SRT is also directly related to substrate removal rate; however, influent concentration changes are usually not accounted for (Table III). SRT is normally controlled by wasting at a constant rate [Burchett (9)].

Hydraulic Retention Time(HRT) Control:

In practice, HRT times ranging from 1/2 to 24 hours [Goodman (4)] are used depending on the process configuration. For the CMAS configuration, HRT ranges from 4 to 8 hours, with an average of 6 hours based on design flow [Sherrard and Lawrence (10)]. Longer hydraulic detention times are selected to buffer against shock loads or marked variations in flow rate. Conventionally, this parameter is accounted for in the reactor design. A result of this is that the HRT may vary over a wide range with widely varying influent flows. It is feasible that the HRT could be controlled to a constant value by using a holding tank or by making the reactor volume a variable quantity, as mentioned above.

Mixed Liquor Volatile Suspended Solids (MLVSS) Control:

Another method of control is to maintain a constant MLVSS concentration in the reactor. Values of MLVSS range from 450 to 10,000 mg/l [Goodman (4)]. For the CMAS system, MLVSS concentration ranges from 1850 to 3340 mg/l [Toerber, Paulson and Smith (11)]. This control strategy is simple but is only effective when the influent conditions are relatively constant. All this means is that for stable operation with a constant input, a special control system is not needed.

Volumetric Load Control:

Volumetric load control is defined as the weight of BOD applied daily per 1000 cubic feet of aeration tank volume. This parameter can vary from 20 to 135 lb/1000 ft^3-day [Metcalf and Eddy (12)]. Volumetric load control is used more in the initial plant design (reactor volume sizing) than it is in process control, and is mainly of historical importance.

Sludge Blanket Height Control:

Sludge blanket height control is incorporated primarily to prevent suspended solids overflow into the secondary clarifier effluent. No specific value exists for the desired sludge blanket height as this depends upon the clarifier depth.

Dissolved Oxygen Control:

In the activated sludge process, oxygen is required for substrate oxidation and for endogenous respiration. D. O. control is aimed at maintaining a level of dissolved oxygen sufficient to satisfy the oxygen requirement. The D. O. should be maintained within the range of 1.5 to 2.0 mg/l at the reactor exit. At values below this range, sludge bulking can occur [Metcalf and Eddy (12)]. If the D. O. level goes above this range, energy is wasted by pumping excess air.

Chapter 3

CONTROL SYSTEM DEVELOPMENT

The objective of any control system should be to provide a stable system for every bounded input. A standard approach in designing a stable closed-loop control system is to conduct a Bode analysis of the system in open-loop configuration. First, the differential equation representing the system is linearized and then transformed to the complex plane (S-plane). This transformation provides the transfer function of the system. The transfer function for the control system is then combined with the system transfer function and this open-loop transfer function is plotted on Bode plots to analyze the phase and gain margins. In order to obtain a stable system, the control system is modified until the gain margin is greater than 1.7 and the phase margin is greater than 30 degrees. It was not the intent of this investigation to go to these depths of design for the control system, but rather, the control algorithm used was derived from the literature search conducted. An account was made of the operating characteristics of a stable system in the control system design.

Control System Objectives

The ultimate objective of the CMAS control system must be to provide a high quality effluent. Current standards of "quality" are measured by suspended solids and BOD_5 concentration. Additional objectives, however, must enter into the control system design because a feedback control system based on effluent conditions would be too slow in responding. A faster loop is required such as designing the control system around F/M ratio control. Therefore, the primary control objective was to maintain a near constant F/M ratio for all inputs into the system. It is usually assumed that if this objective can be satisfied, then the ultimate objective of a high quality effluent will also be satisfied. Inherent in this ultimate objective is the objective of proper final settling tank operation. Thus, settler operation and effluent quality are used in this investigation to judge control system performance.

Food:Mass Ratio Control

To maintain a constant F/M ratio with variable influent characteristics, the MLSS concentration must be varied in accordance with the influent loading rate. Most investigators indicate that when a CMAS plant is operating properly, the F/M ratio is approximately 0.35 [Stensel and Shell(1)]. F/M is maintained at this value by recycling sludge mass from the secondary clarifier to the reactor. At this stable operating point, the return activated sludge (RAS) flow is approximately 30 percent of the influent flow rate. Using this knowledge, a variable-proportional control algorithm was developed to control the RAS flow. The control equation is as follows:

$$F_{RAS} = (F/M) * (F_{INFL})$$

It will be shown in the discussion of the results that this algorithm established the desired steady state operating conditions, but under dynamic conditions a tighter control of F/M ratio is needed.

Solids Retention Control

As indicated above, Jenkins and Garrison (8) have found that the SRT must be above five days for nitrification to occur within the treatment plant. It was also indicated that clarifier performance is better at higher SRTs. Therefore, in this investigation, the SRT was maintained at a constant value of eight days by varying the waste activated sludge (WAS) flow rate. The equation used to compute WAS flow rate is as follows:

$$F_{WAS_2} = 0.125 * (F_{WAS_1}) * (\theta_{c_1})$$

This equation utilizes the SRT (θ_{c_1}) previously calculated for the current WAS flow rate (F_{WAS_1}) to calculate a new WAS flow rate (F_{WAS_2}).

Hydraulic Retention Control

It was desired for the HRT to be six hours at steady state operation and to remain above two hours for dynamic inputs. This was achieved by sizing the reactor volume to provide a six-hour HRT at steady state flow.

Chapter 4

PROCESS MODELS

Most conventional activated sludge wastewater treatment plants can be represented by reactors in series as shown in figure 1. The system model and digital computer program used in this investigation were developed for the system shown in figure 1 to provide for a more universal program which will be used in future investigations. In this specific investigation, it was desired to model a complete mix activated sludge (CMAS) system. This type of system can be represented using only one reactor. This was accomplished by bypassing reactors 2, 3, and 4 in the digital program. Thus, the effluent at station (2) became the influent to final settling tank No. 1. It should be noted that sludge was wasted from the reactor effluent rather than from the settler (No. 1). This method of sludge wasting was first derived by Garrett [Burchett (9)]. Settler No. 2 is not included in the system model but is shown in figure 1 for completeness.

Biological Reactor Model

The reactor model used in this investigation is one that was developed by Busby and Andrews (13). This model accounts for conservation of mass for substrate, stored mass, active mass, inert mass, and nonbiodegradeable mass as shown in figure 2. It is important in investigations of dynamic activated sludge plant operations to account for each of these components of the MLSS. Past investigations [Goodman(4)] have shown that the substrate can be transformed into stored mass within an hour while the complete oxidation process takes much longer. It was found in this investigation that the reactor model performance is very sensitive to the values used for the maximum growth rate coefficient (RXA) and the decay rate coefficient (RXI). Most investigators indicate that there are two orders of magnitude difference between the growth and decay coefficients. It was found that the maximum growth rate and decay rate coefficients ranged from the low values of 0.1 and 0.002, respectively, [Ott and Bogen(14)] to the high values of 0.8 and 0.007 [Reynolds(15)]. These two parameters were varied in unison (i.e., two magnitudes difference) to achieve the steady state conditions expected for a CMAS system. This analysis is discussed in the results section.

Final Settling Tank Model

The clarifier model used in this investigation is one that accounts for suspended solids flux due to (1)gravity and (2)sludge withdrawal from the bottom of the clarifier tank. This model was developed by Dick (16). The model has also been described by Roper and Grady (17) in equation form. This equation describes a total flux curve such as the one shown in figure 3 and is of the form

$$G_t = C_i*(K_1*\theta_c - K_2)*C^{-Bo*Ci} + C_i*(\frac{FRAS}{A}).$$

The first term accounts for gravitational flux and the second term accounts for bulk transport flux. The constants K_1, K_2, and Bo account for mixed units and empirical relationships. Ci represents the suspended solids concentration at the minima, which is the limiting flux. The underflow concentration is determined, then, by projecting the limiting flux onto the bulk flux line. This underflow concentration is the maximum that can be obtained for an operating condition. The actual flux is determined by calculating the load being applied to the clarifier in terms of $Kg/m^2/hr$. This equation is

$$G_a = (MLSS) * (F_2 - F_{WAS})/A.$$

The actual underflow concentration is calculated as follows:

$$X_a = G_a * A/F_{RAS}.$$

If the actual flux exceeds the limiting flux for an extended period of time such that the settler capacitance is also exceeded and the sludge blanket reaches the effluent weir, then floc will be lost to the effluent stream in a real world situation. In this investigation, equations were not developed to add floc to the effluent when the limiting flux was exceeded. The complete settler model is shown in figure 4.

Digital Computer Program

A flow chart of the digital computer program developed for this investigation is shown in figure 5. The influent parameters are read every five minutes and incremental changes in the reactor mass components are computed. The incremental changes are computed using rectangular integration. An analysis of the effects of this type of integration was conducted by evaluating the steady state operation of the system. The delta time increments of 5 minutes were small compared to the system time constant. Therefore, truncation errors were not a problem. Some drift occurred in the steady state operation, but it was not serious over a 48 hour period, thus indicating that roundoff errors were also not a problem. The bisection method was used to calculate the suspended solids concentration at the limiting flux. A complete listing of the digital program is given in the appendix. A sample data sheet is also given.

Chapter 5

RESULTS AND DISCUSSION

Steady State Operation - F/M Control Algorithm

Digital computer runs were made for three sets of values for the maximum growth rate coefficient (R_{XA}) and the decay rate coefficient (F_{XI}). Results of these runs are shown in figures 6(a) through (d). The runs were made for a simulated time period of 20 days. In figure 6(a), it can be seen that the steady state active mass varied as the reaction coefficients were varied. For R_{XA} and R_{XI} values of 0.3 and 0.003, respectively, the active mass stabilized at 2269 mg/l which is near what was expected for a CMAS system. The inert mass profile remained the same for all values of the reaction coefficients. In figure 6(b), the limiting and actual flux curves are plotted. The smallest margin of difference between limiting and actual flux exists for an R_{XA} of 0.3. In figure 6(c), the oxygen demand is plotted, with the lowest steady state oxygen demand of 6.3 mg/l-hr occurring when R_{XA} is 0.3. The effluent TOD, shown in figure 6(d), is acceptable for all cases, with the lowest value corresponding to an R_{XA} of 0.3. Values of 0.3 and 0.003 were selected for R_{XA} and R_{XI}, respectively, for the remainder of the study as these values appear to best represent the CMAS system. Values of all the constants are given in table IV. The influent conditions used for these runs were a flow of 1 mgd (41,666 gal per hr), a substrate concentration of 250 mg/l, an inert mass concentration of 50 mg/l and a nonbiodegradeable mass concentration of 50 mg/l. These values were considered as steady state influent conditions for the remainder of the runs made. Sinusoidal and step variations of the influent parameters were programmed as variations from these steady state values. All the initial conditions for subsequent runs are given in table V.

Response to Sinusoidal Flow Variations - F/M Control Algorithm

A run was made next applying a sinusoidal flow into the system while holding the substrate concentration constant at 250 mg/l. The flow variations were plus and minus 50 percent of the steady state value with a period of 24 hours. The return flow was controlled using the algorithm developed previously. The results of this run are shown in figure 7. It can be seen that the F/M ratio varied from 0.15 to 0.5. The effluent TOD, however, leveled off at 9.7 mg/l and remained constant. The limiting flux was exceeded at periodic intervals as shown. Return flow reached a value of 31,000 gph at each influent flow peak.

Response to Sinusoidal BOD_u Variations - F/M Control Algorithm

In this case, the influent flow rate was held constant while the substrate concentration was varied sinusoidally from 125 to 375 mg/l. The results (figure 8) were almost identical with the previous run with the exception of the return flow and actual flux peaks being lower in this case. This is, of course, due to the fact that return flow and the actual flux are both proportional to the influent flow rate which was held constant. The limiting flux was again exceeded at periodic intervals.

Response to Simultaneous Flow and BOD_u Variations - F/M Control Algorithm

Next, a run was made with both the flow and concentration varying sinusoidally from plus to minus 50 percent of steady state values with a period of 24 hours. These results are shown in figures 9(a) through (e). It can be seen that the active and inert mass oscillations were out of phase with the influent oscillations which indicates that a proportional/derivative control of the return flow would probably have provided a tighter control of the active mass and, thus, the F/M ratio. Oxygen demand varied from 15 to 65 mg/l-hr and was in phase with the input. Again, the limiting flux was exceeded at periodic intervals lasting eight hours. Figure 9(e) shows that the untreated, dissolved solids in the effluent went to zero at 10 hours time leaving suspended solids as the only contributing factor to an effluent TOD. As shown, the effluent TOD was well below the current requirement of 20 mg/l. The F/M ratio varied from 0.1 to 0.7 for this case.

Response to Simultaneous Flow and Substrate Variations - Modified Control Algorithms

Two different runs were made where the control algorithms were modified. In one case, the original return flow algorithm was maintained and calculations were added to maintain a constant reactor volume. This was done to determine if a tighter control of F/M ratio would improve the system performance. In the second case, a fixed reactor volume was used but the return flow algorithm was modified as follows:

$$F_{RAS} = 0.25\ I\ (F_{INFL}).$$

This type of return flow control has been used in the past and requires much less instrumentation than F/M control of the return flow. The results of these runs are shown in figure 10. Where a variable reactor volume was calculated, a tighter control of F/M ratio was experienced; however, the effluent TOD did not improve along with it. In fact, the constant proportional control of return flow yielded a slightly better effluent with a lower "tax" on the return sludge system. In the second case, F/M varied from 0.15 to 0.72. The limiting flux was exceeded in both cases.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this investigation, the following conclusions are given:

1. For the influent variations applied, the soluble effluent quality is insensitive to F/M ratio variations from 0.1 to 0.7. This does not necessarily mean that F/M control is ineffective in controlling effluent quality, but could simply mean that as long as the F/M ratio is maintained within certain bounds, the effluent will be of good quality.

2. For the influent variations applied, a simple constant proportional control of return flow performs as well as F/M control. This fact would probably remain true in any situation where the substrate concentration increases are accompanied by proportionate increases in flow. In cases where the concentration increases significantly without a proportionate increase in flow, it is believed that the simpler control algorithm would break down.

3. For the influent variations applied, no performance gain was realized using a variable reactor volume. This fact is primarily significant with regard to new plant construction. With most existing plants, this would be impractical.

4. In every data run made where the influent was varied sinusoidally, the limiting flux was exceeded at periodic intervals. This may or may not be a problem depending upon the capacitance of the settling tank and whether or not the sludge blanket reaches the effluent weir. An increase in return sludge flow could solve temporary limiting flux violations.

Four recommendations are made for future analysis:

1. A more detailed investigation of reaction rate coefficients should be conducted.

2. A Bode analysis should be made of the system to improve the performance of the control system.

3. A more detailed final settling tank model should be incorporated which describes the interaction between solids flux, settler capacitance, and effluent quality.

4. More severe influent variations should be applied to the system to determine where each control strategy breaks down.

TABLES

TABLE I. - ACTIVATED SLUDGE CONTROL VARIABLES

Parameter	Definition
1. Sludge Recycle Rate	Rate at which sludge is returned to the aeration basin from the secondary clarifier (RAS).
2. Sludge Wasting Rate	Rate at which excess sludge is wasted from the activated sludge system (WAS).
3. Aeration Rate	Rate at which oxygen is transferred to the water as dissolved oxygen (D.O.).
4. Influent Rate	Rate at which the domestic wastewater flows into the activated sludge system.
5. Reactor Volume	Total volume of MLSS under aeration.
6. Hydraulic Mixing	Method of combining the influent with activated sludge to enhance the biological reaction.

TABLE II. - ACTIVATED SLUDGE CONTROL STRATEGIES

Strategy	Definition
1. F:M Control (U-lb BOD_5/day/lb VSS)	Mass of substrate (BOD_5) applied per day divided by the active mass under aeration (range - 0.03 to 4.0).
2. SRT Control (θ_c - days)	Average age of the activated sludge before it is wasted from the system (range - 3 to 18 days).
3. HRT Control (θ - hrs)	Aeration period of the substrate in the aeration basin (range - 1/2 to 24 hrs).
4. MLVSS Control (X - mg/l)	Concentration of active mass in the aeration basin (range - 450 to 10,000 mg/l).
5. Volumetric Load Control (lb BOD_5/1000 ft^3)	Weight of BOD_5 applied daily per 1000 cubic feet of aeration tank volume (range - 20 to 135 lb/1000 ft^3).
6. Sludge Blanket Height (meters)	Height of accumulated sludge in bottom of secondary clarifier.
7. Dissolved Oxygen (mg/l)	Level of dissolved oxygen existing in the reactor effluent (range - 1.5 to 2.0 mg/l).

TABLE III. - CONTROL STRATEGIES/ADVANTAGES, DISADVANTAGES AND CONTROL TECHNIQUES

Strategy	Advantage	Disadvantage	Implementation
1. F:M Control	Directly related to substrate removal rate and microorganism growth rate.	Difficult to measure food and active mass on-line	Monitor: Infl & Effl. BOD_5 and MLVSS Control: RAS & WAS
2. SRT Control	Directly related to substrate removal rate and microorganism growth rate	No account made for changes in influent substrate concentration	Monitor: Infl. Flow Rt & SVI Control: Operate at a constant WAS rate or a constant WAS/F_{Infl} ratio
3. MLVSS Control	Simple method of control (Maintain constant MLVSS)	Good only for constant influent flow rate and substrate concentration	Monitor: Infl Flow Rate Control: Maintain constant ratio of RAS/F_{Infl}
4. Volumetric Load Control	Accounted for in initial plant design to keep the BOD loading of the reactor below a maximum value	Fixed reactor volume can result in a very high F/M ratio	Monitor: Infl BOD_5 Control: Bypass
5. HRT Control	Accounted for in initial plant design to allow time for microorganism growth in reactor	Fixed reactor volume causes microorganism washout when influent flow rate is high (Portion of influent is usually bypassed)	Monitor: Infl Flow Rate Control: Bypass
6. Sludge Blanket Height Control	Prevents high S.S. concentration in effluent assuming a good settling reactor effluent	No relation to substrate removal rate or microorganism growth rate	Monitor: Sludge Blanket Height Control: RAS
7. Dissolved Oxygen Control	Controls oxygen required for substrate oxidation	--	Monitor: D.O. in reactor effluent Control: Oxygen transfer

TABLE IV. - CMAS Constants

Constant	Value
RT	3.000 hr^{-1}
RXA	0.300 hr^{-1}
RXI	0.003 hr^{-1}
KS	150.000 mg/l
KXS	80.000 mg/l
FSM	0.450
Y1	0.660
Y2	0.250
THETAD	6.000 hrs
DT	0.083 hrs
VSS02	1.420 mg/mg
FRACV	0.800
YTOD	1.500 mg/mg
BO	0.00045 l/mg

TABLE V. - INITIAL CONDITIONS

Parameter	IC
F(1)	41,666.00 gal/hr
S(1)	250.00 mg/l
XS(1)	0.00 mg/l
XA(1)	0.00 mg/l
XI(1)	50.00 mg/l
SNB(1)	50.00 mg/l
S(2)	1.36 mg/l
XS(2)	3.83 mg/l
XA(2)	2269.08 mg/l
XI(2)	1241.21 mg/l
SNB(2)	50.00 mg/l
FR(1)	13,815.00 gal/hr
SR	1.36 mg/l
XSR	14.83 mg/l
XAR	8785.48 mg/l
XIR	4805.76 mg/l
SNBR	50.00 mg/l
FW	1991.00 gal/hr
V(1)	333,000.00 gal
A	232.00 m^2

FIGURES

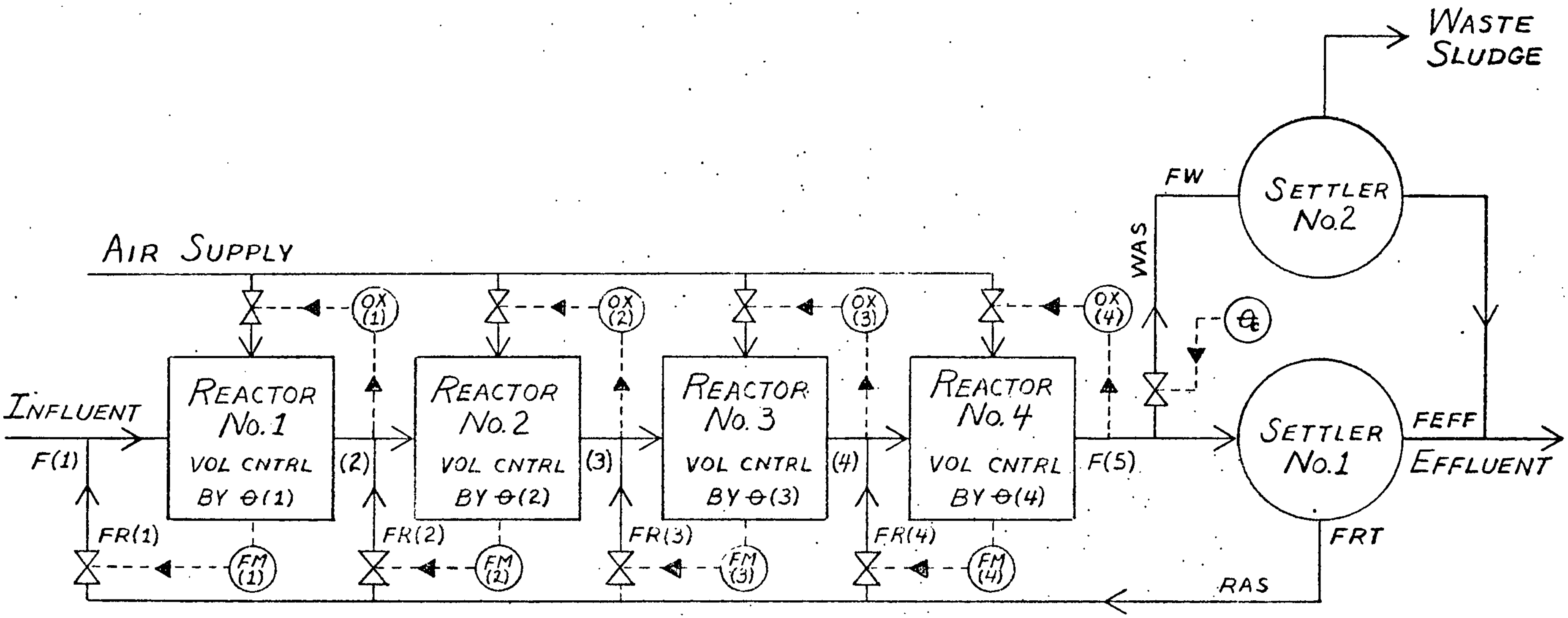


Figure 1. - Activated Sludge System Schematic

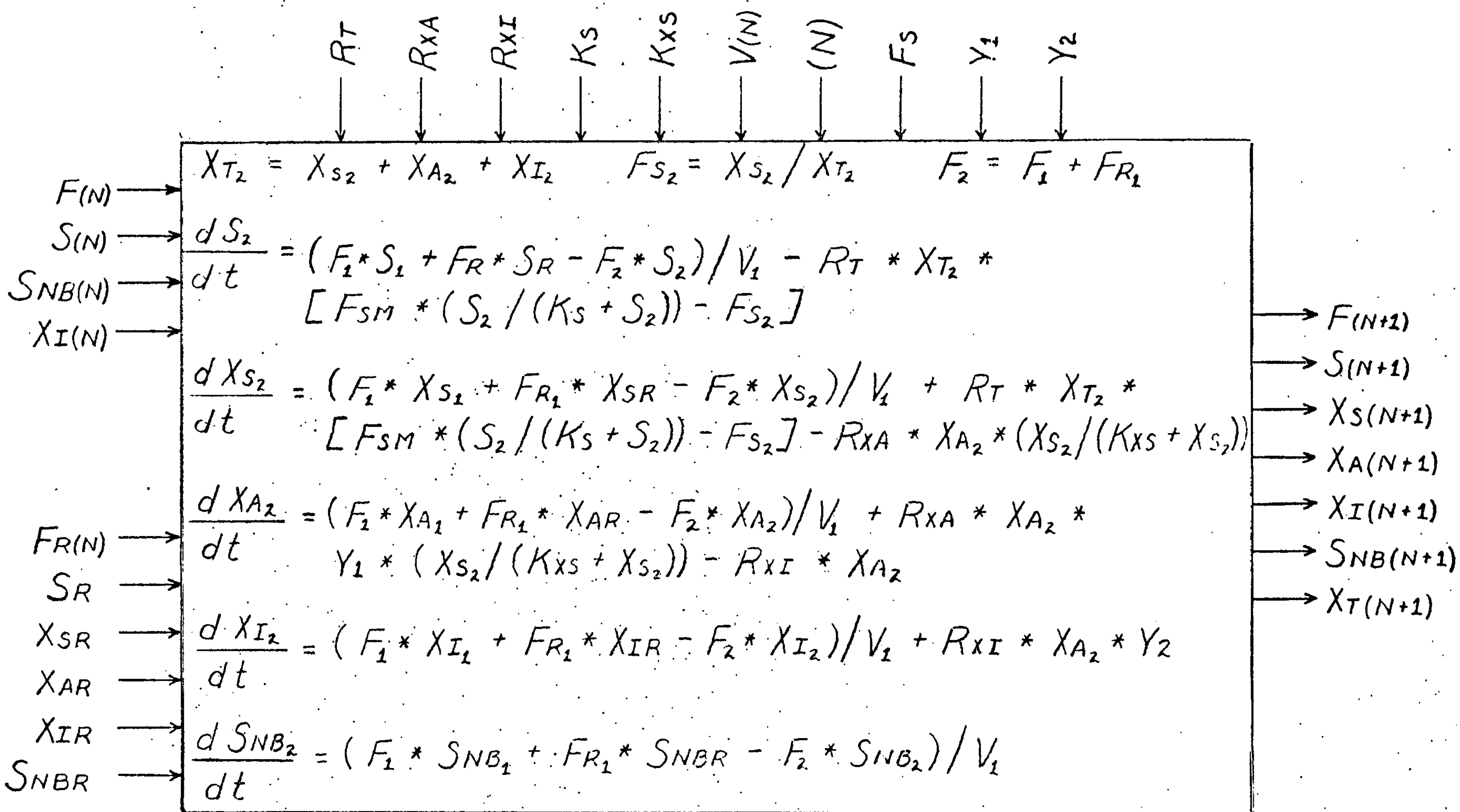


Figure 2. - Reactor Model

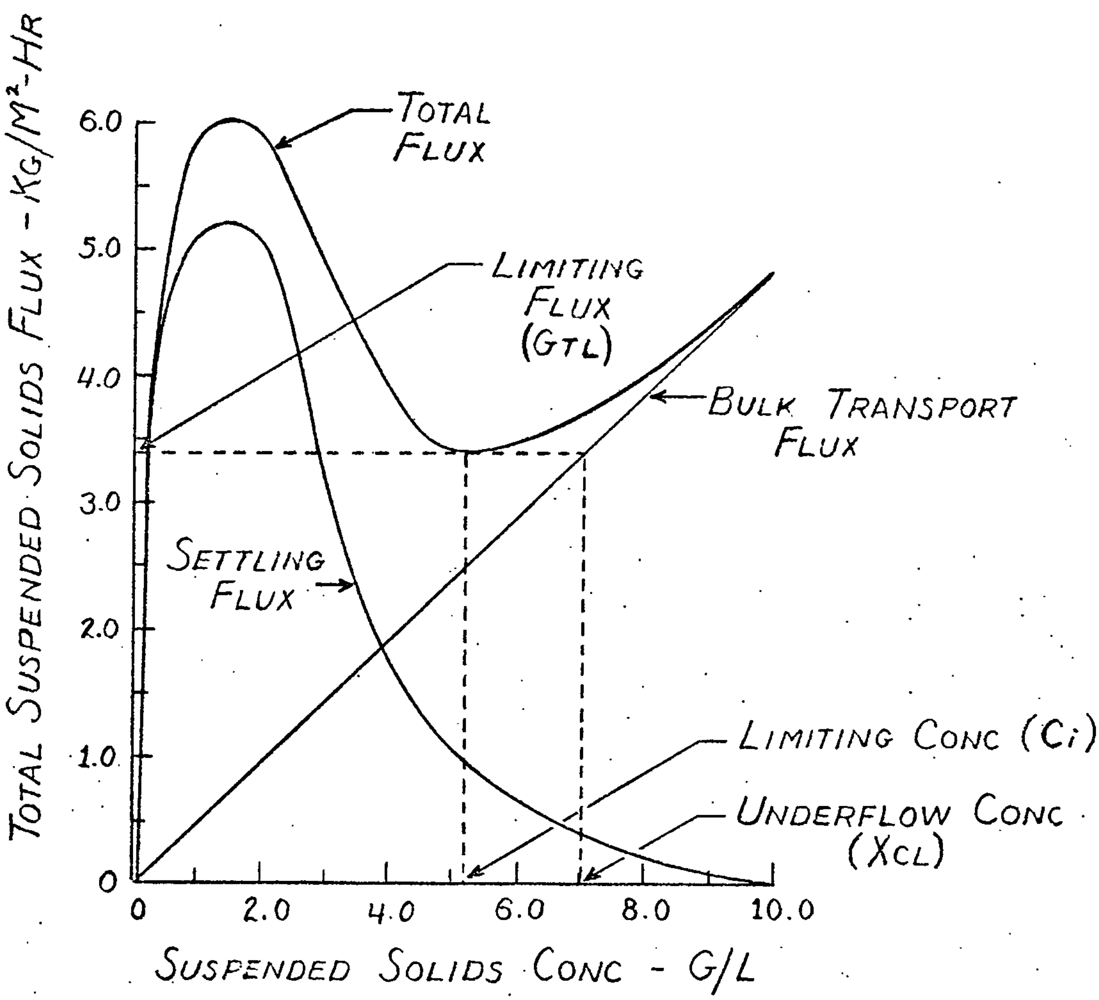


Figure 3. - Settler Dynamics

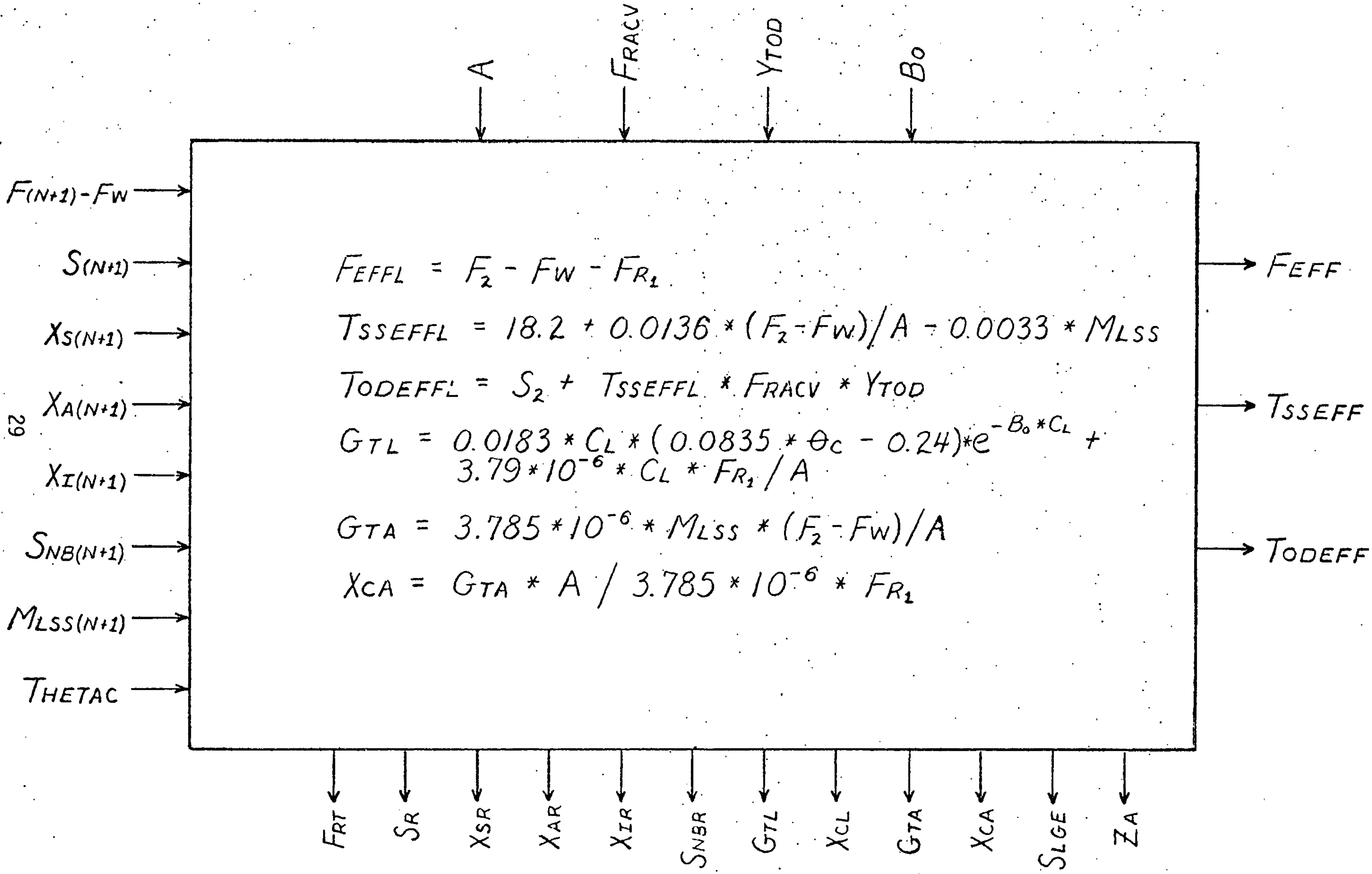


Figure 4. - Settler Model

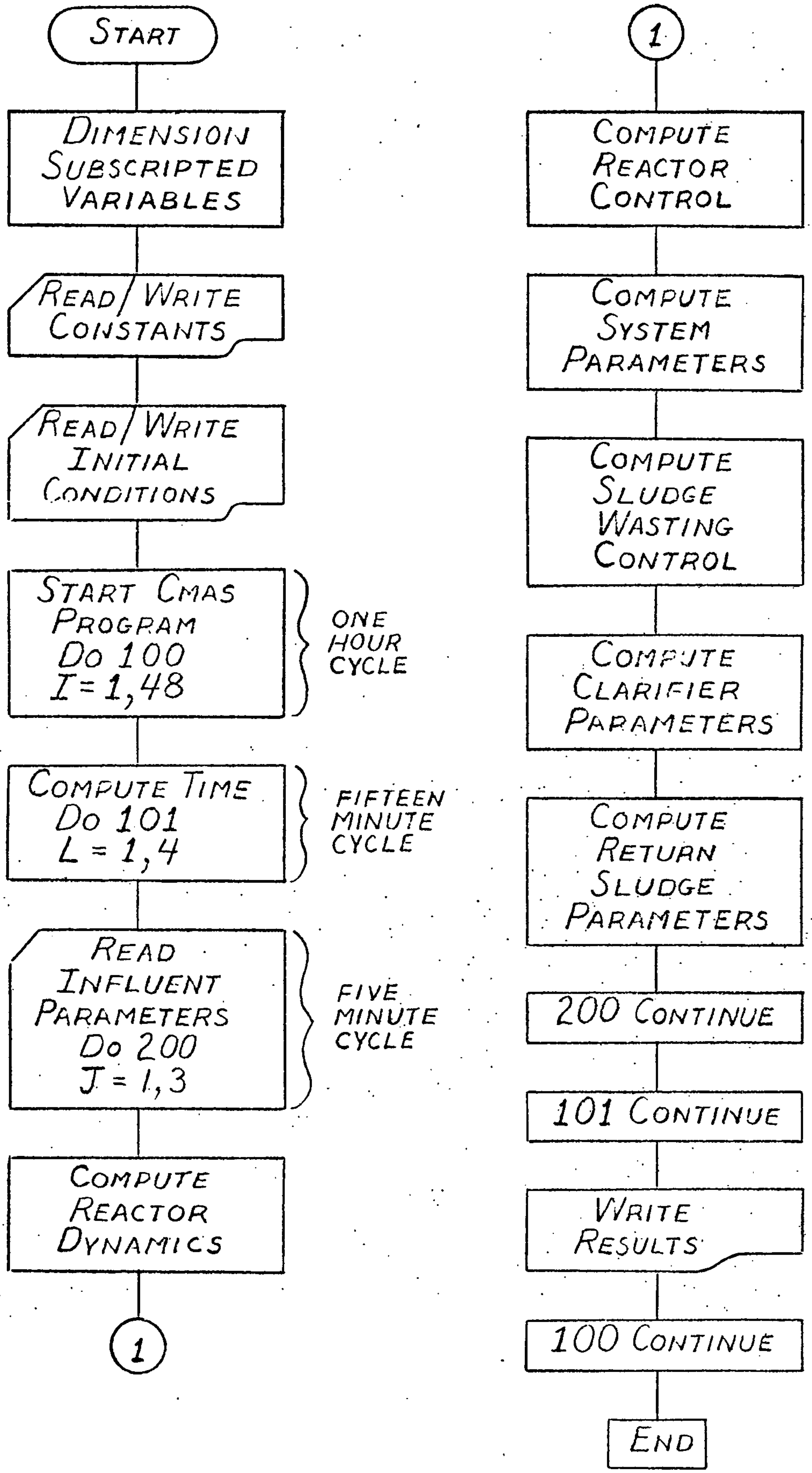


Figure 5. - Digital Program Flow Diagram

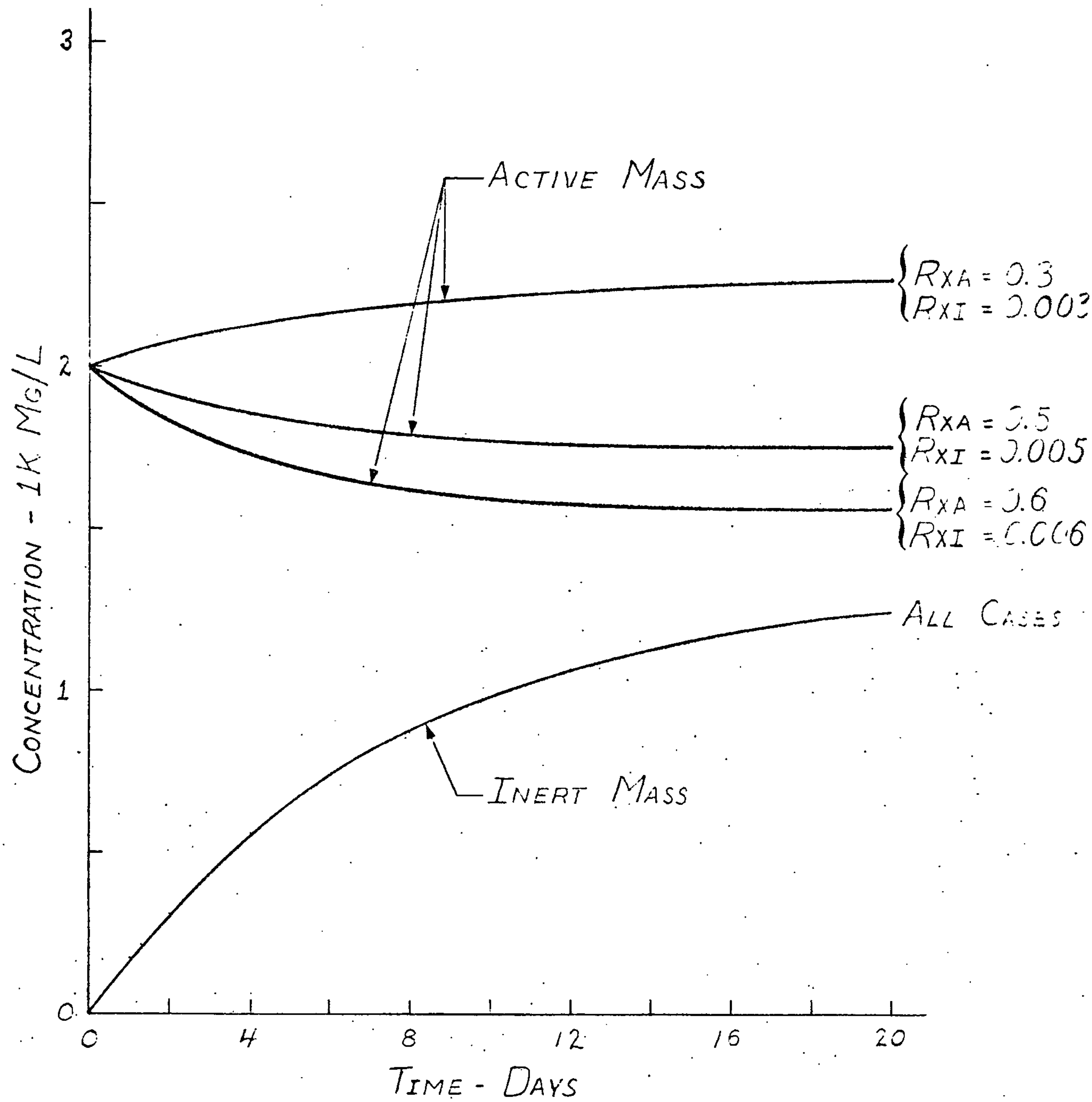


Figure 6. - Steady State Variations Due to Reaction Rate Coefficient Chances

(a) Active and Inert Mass - vs - Time

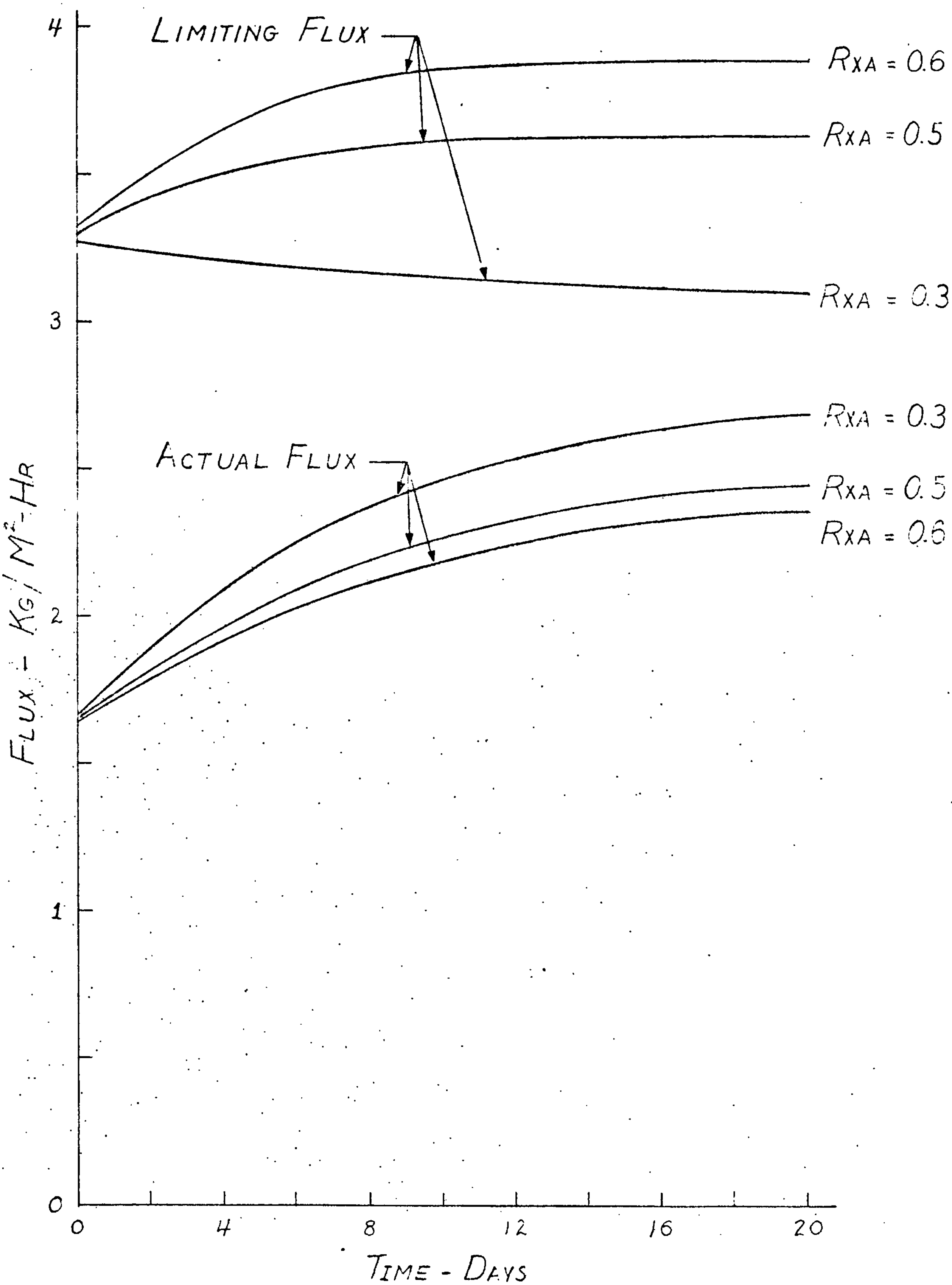


Figure 6 (b). - Limiting and Actual Flux - vs - Time

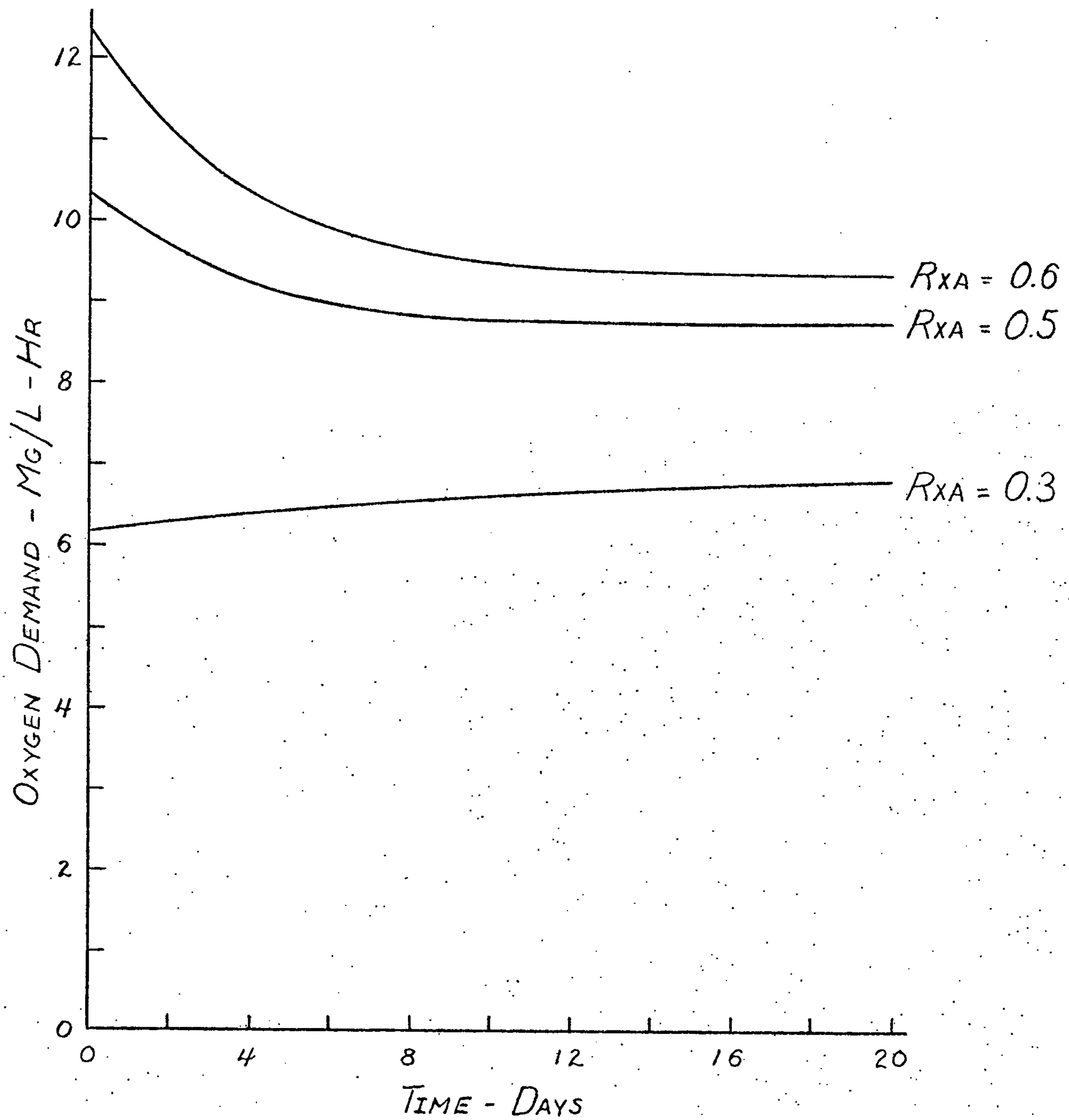


Figure 6 (c). - Oxygen Demand - vs - Time

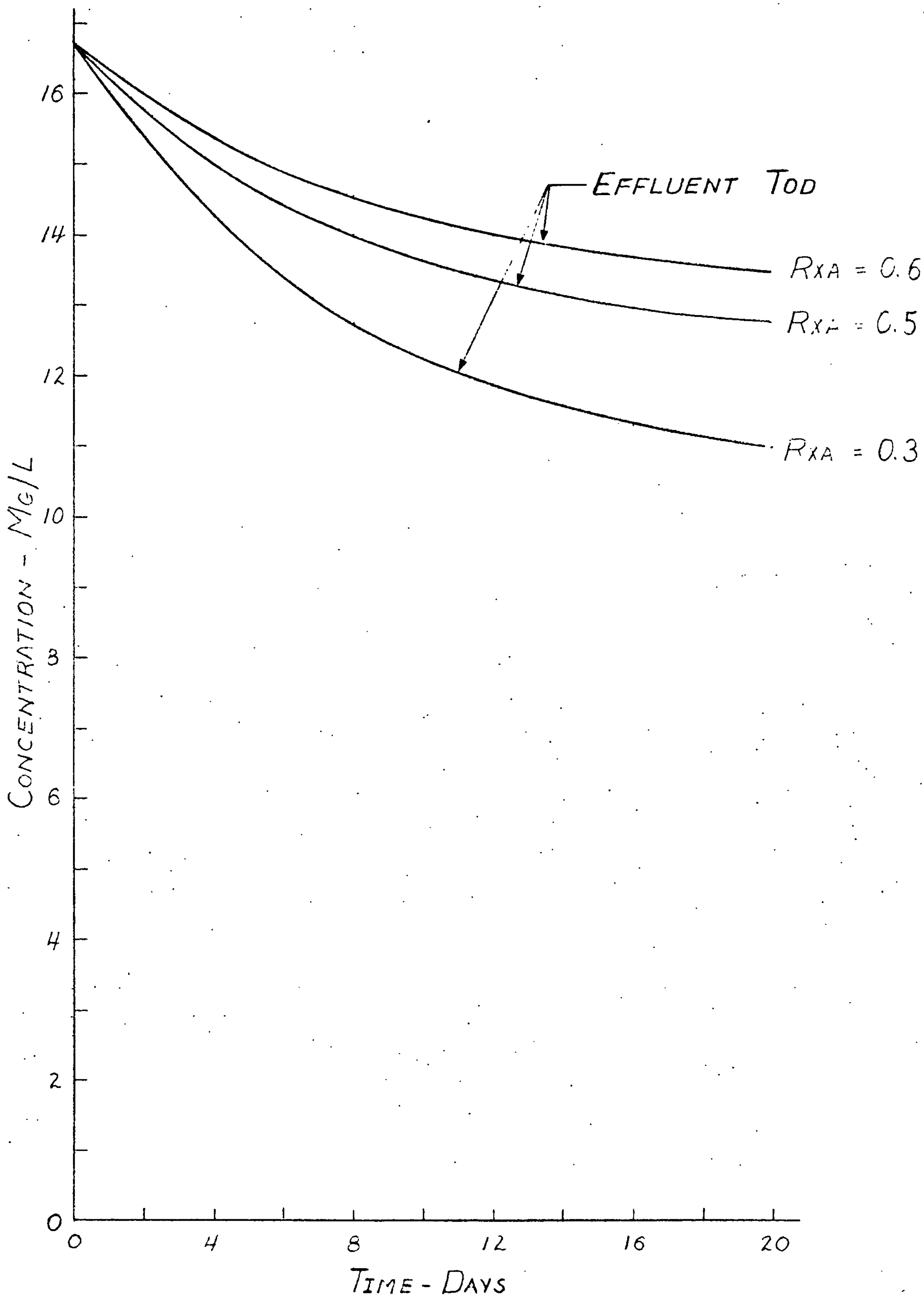


Figure 6 (d). - Effluent TOD - vs - Time

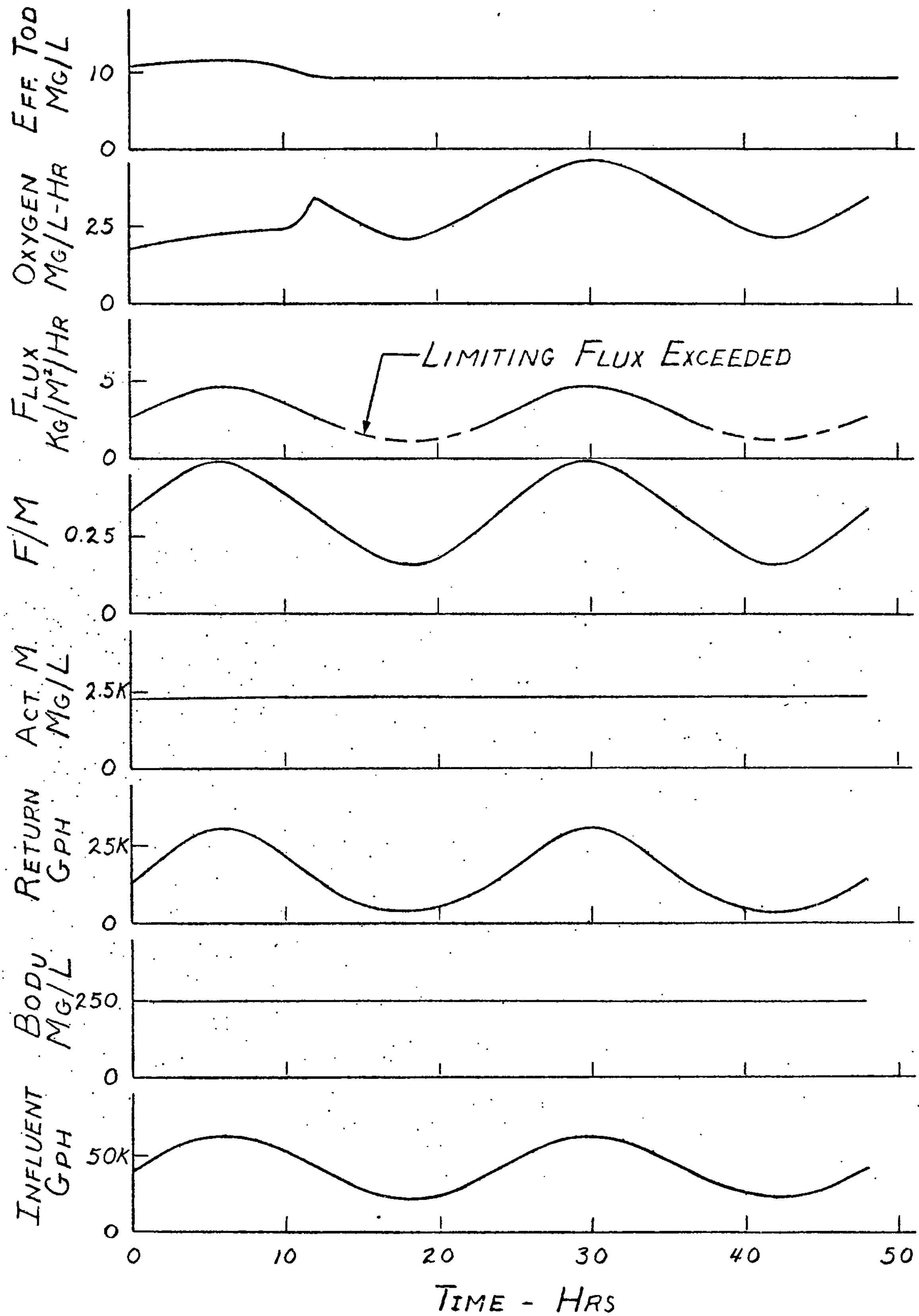


Figure 7. - Response to Sinusoidal Variations in Flow - F/M Control Algorithm

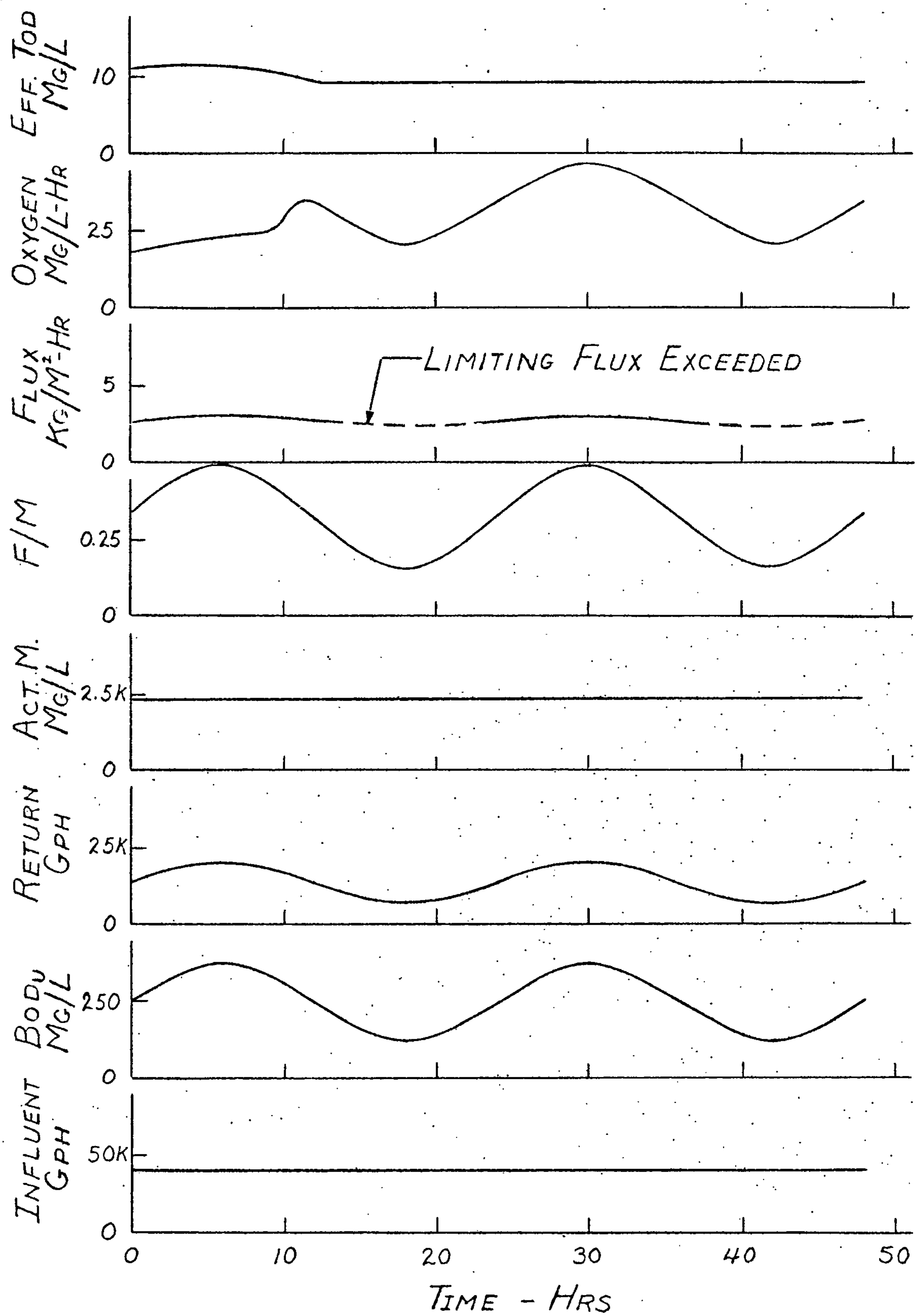
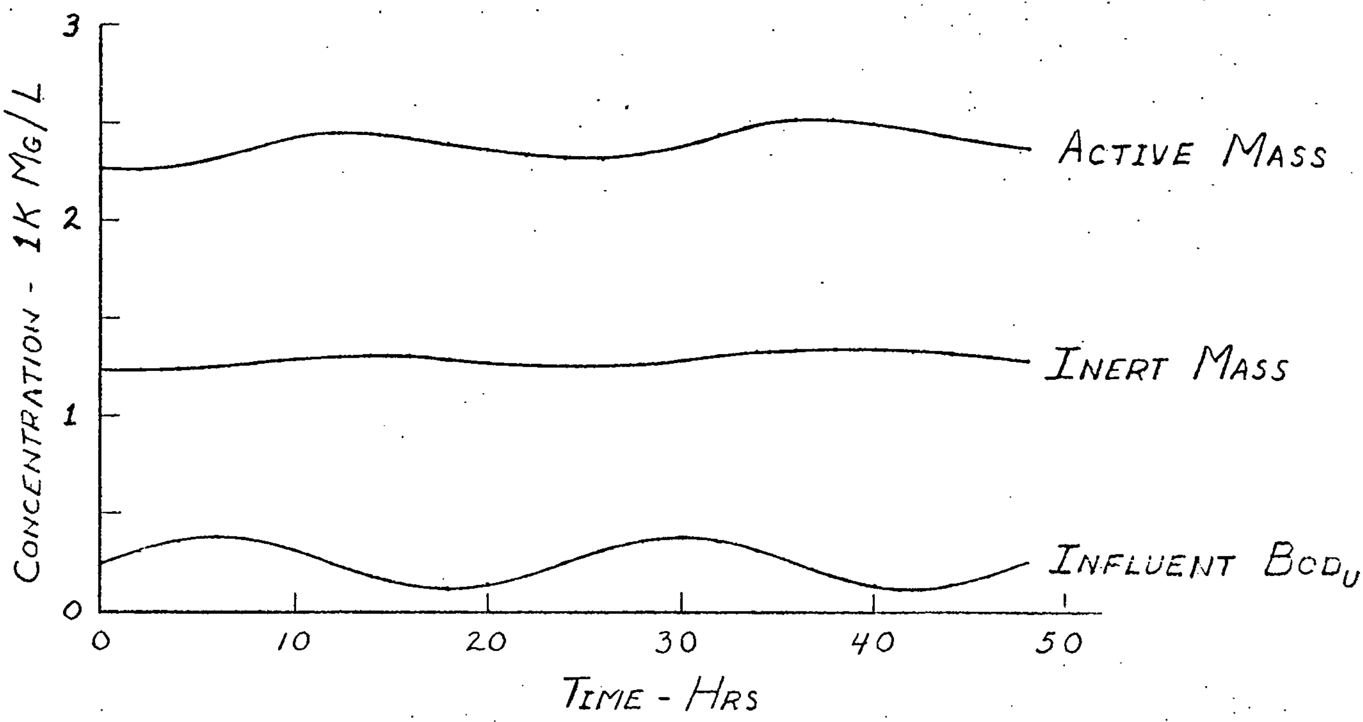
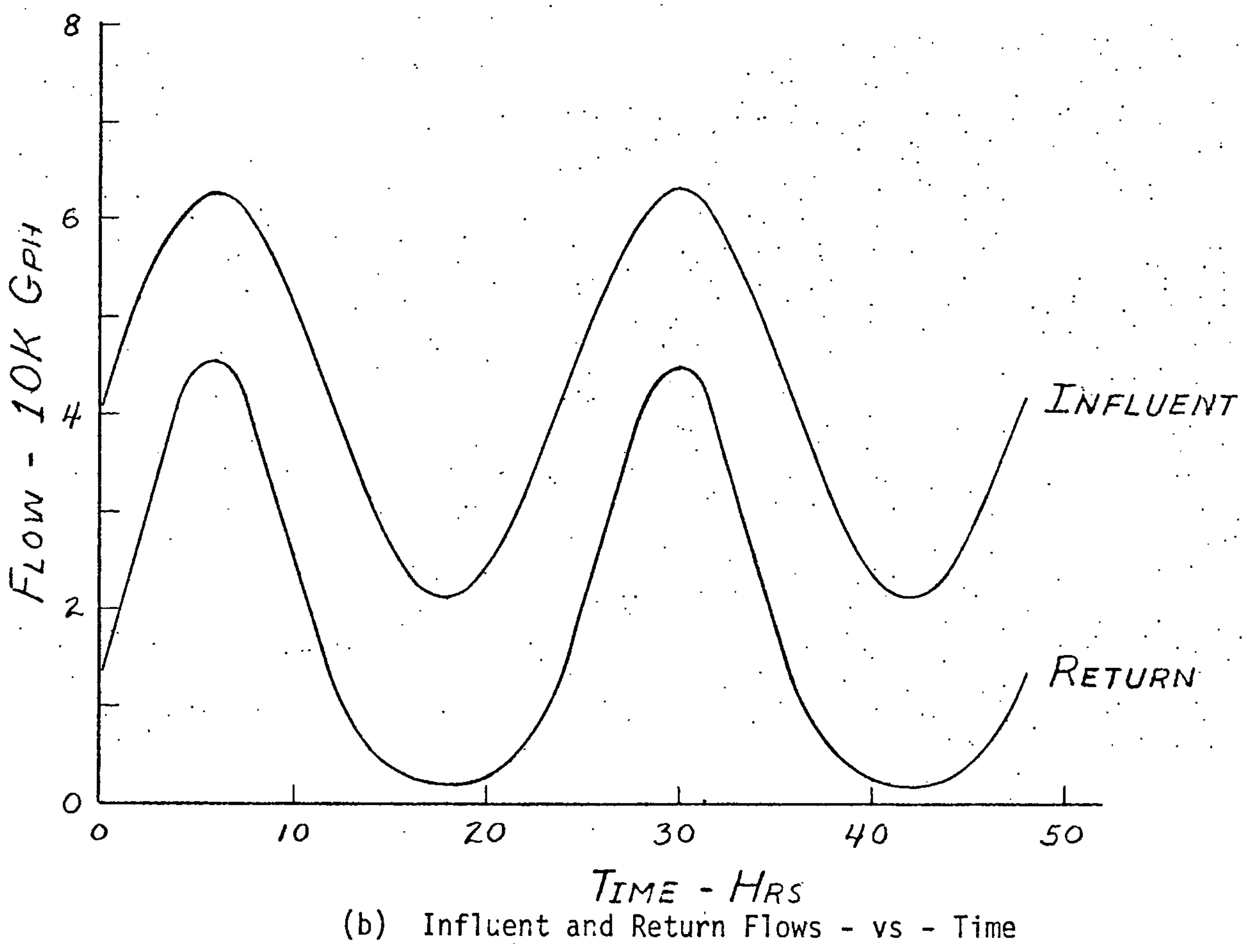


Figure 8. - Response to Sinusoidal Variations in Substate Concentration - F/M Control Algorithm



(a) Active Mass, Inert Mass and Influent BOD - vs - Time



(b) Influent and Return Flows - vs - Time

Figure 9. - Response to Simultaneous Variations in Flow and Concentration - F/M Control Algorithm

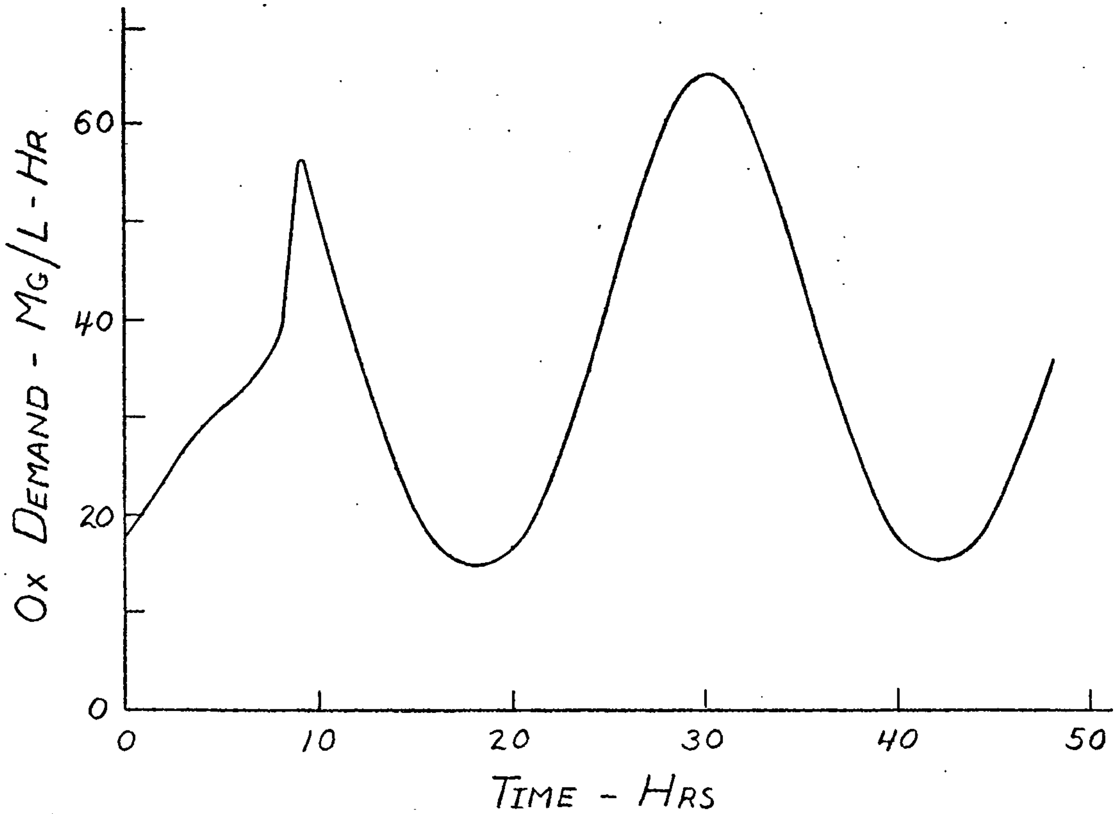


Figure 9 (c). - Oxygen Demand - vs - Time

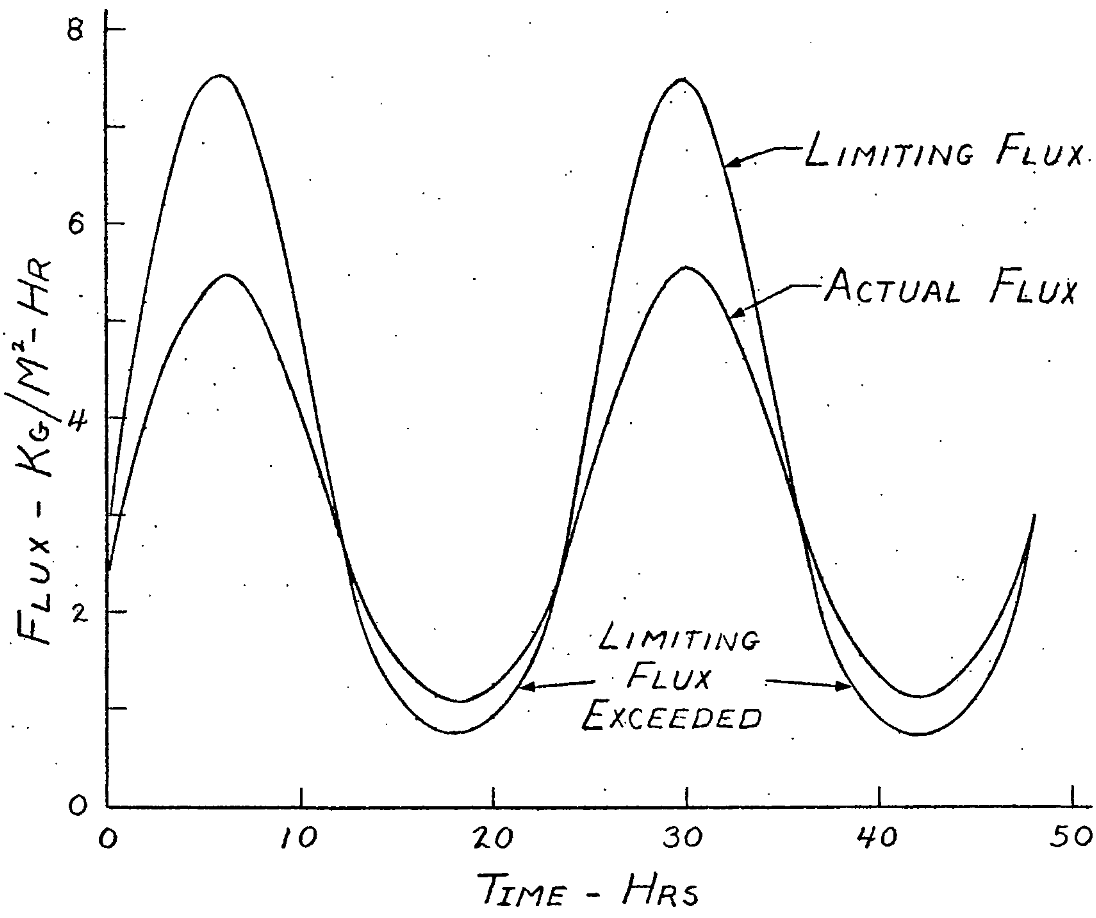


Figure 9(d). - Limiting and Actual Flux - vs - Time

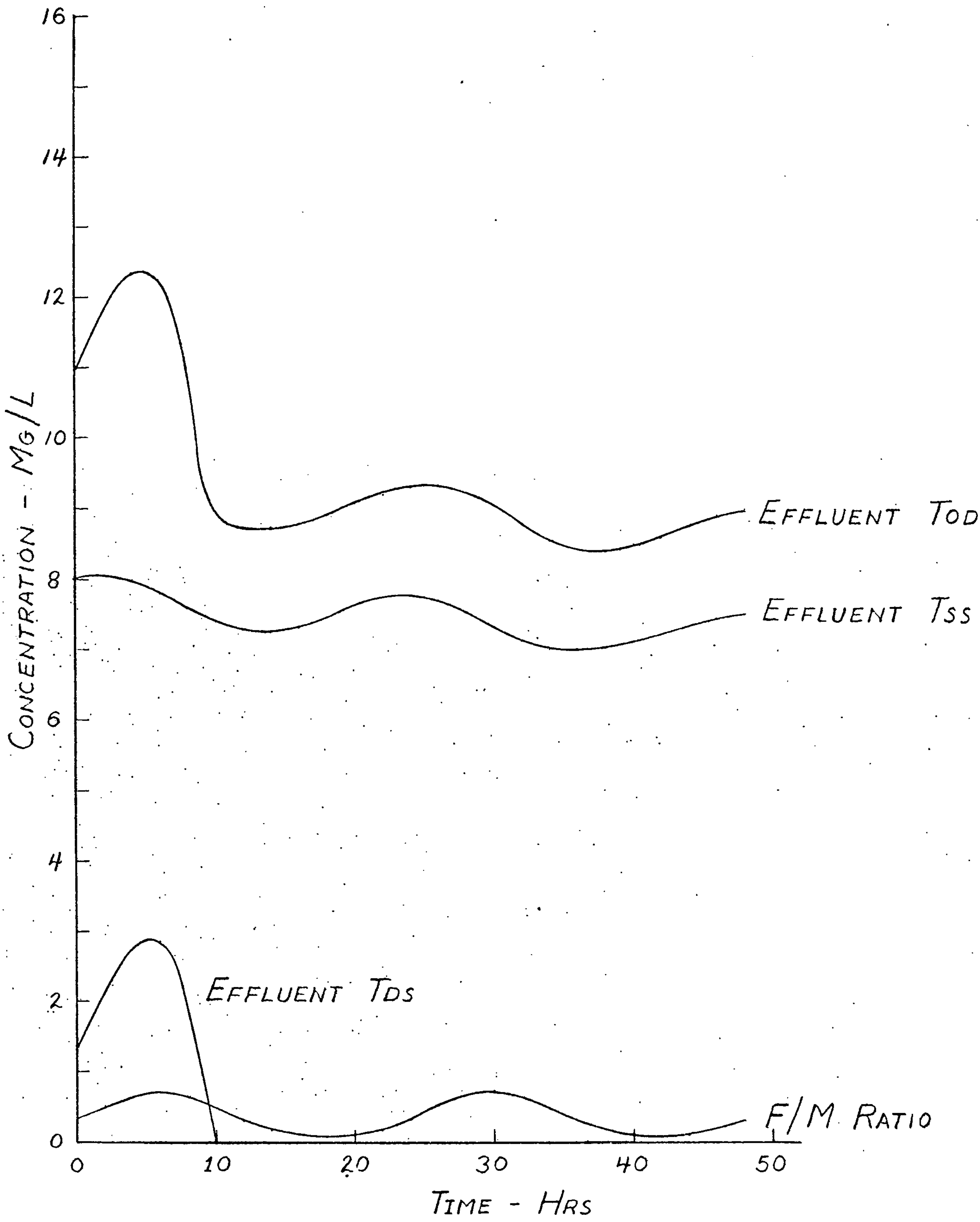


Figure 9 (e). - Effluent TOS, TSS, TOD and F/M Ratio - vs - Time

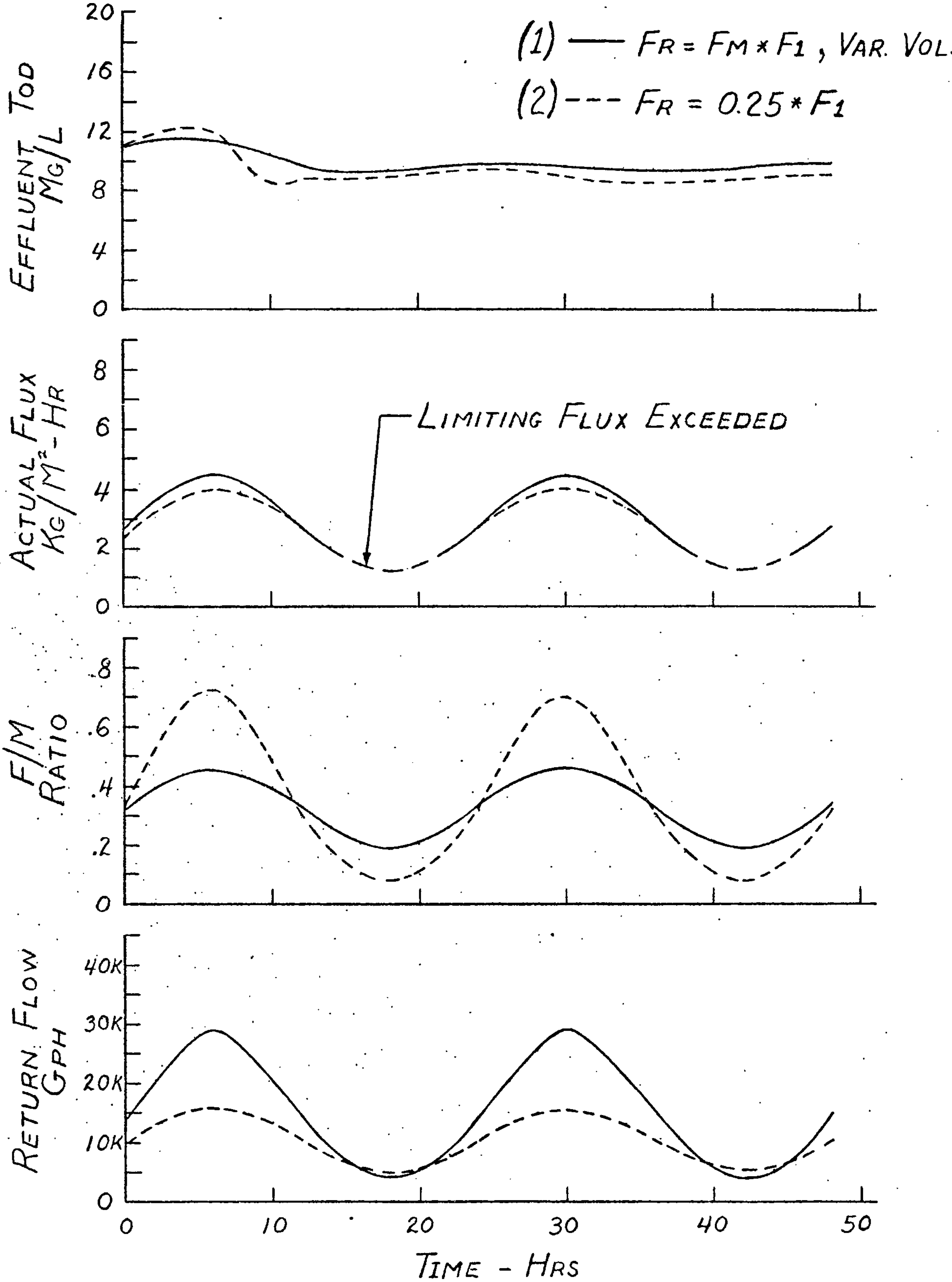


Figure 10. - Response to Simultaneous Variations in Flow and Concentration - Modified Control Algorithms

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APPENDIX

```
C     COMPLETE MIX ACTIVATED SLUDGE PROGRAM
C
      REAL MLSS,MLSSA,KS,KXS
C
      DIMENSION F(5),FR(5),S(5),XS(5),XA(5),XI(5),SNB(5),FM(5),
     C OXYGEN(5),THETA(5),XT(5),FS(5),DS(5),DXS(5),DXA(5),
     C DXI(5),DSNB(5),MLSS(5),V(5),XM(5),VOL(5)
C
C     READ CONSTANTS
      DATA RT,RXA,RXI,KS,KXS,FSM,Y1,Y2,THETAD,DT,VSS02,FRACV,YTOD,
     C BO /5.0,0.35,0.0030,150.0,80.0,0.45,0.66,0.25,6.00,0.083,
     C 1.42,0.80,1.5,0.00045/
C
C     WRITE CONSTANTS
      WRITE(7,5)
    5 FORMAT(19H1THOMAS CONSTANTS)
      WRITE(7,10) RT,RXA,RXI,KS,KSP,KXS,FSM,Y1,Y2,THETAD,DT,VSS02,
     C FRACV,YTOD,BO
   10 FORMAT(5H RT =,F10.3/7H RXA =,F9.3/7H RXI =,F9.3/6H KS =,
     C F10.3/7H KSP =,F9.3/7H KXS =,F9.3/7H FSM =,F9.3/6H Y1 =,
     C F10.3/6H Y2 =,F10.3/10H THETAD =,F6.3/6H DT =,F10.3/
     C 9H VSS02 =,F7.3/9H FRACV =,F7.3/8H YTOD =,F8.3/6H BO =,
     C F12.5//////////)
C
```

```
C
C     READ INITIAL CONDITIONS
C
      DATA F(1),FR(1),FR(2),FR(3),FR(4),FW,V(1),V(2),V(3),V(4),
     C S(1),S(2),S(3),S(4),S(5),XS(1),XS(2),XS(3),XS(4),XS(5),
     C XA(1),XA(2),XA(3),XA(4),XA(5),XI(1),XI(2),XI(3),XI(4),XI(5),
     C SNB(1),SNB(2),SNB(3),SNB(4),SNB(5),SR,XSR,XAR,XIR,SNBR,A/
     C 41666.0,13515.0,0.0,0.0,0.0,1991.5,333000.0,0.0,0.0,
     C 0.0,[illegible],1.36,0.0,0.0,1.0,0.0,3.83,0.0,0.0,0.0,0.0,2269.08,
     C 0.0,0.1,0.0,50.0,1241.21,0.0,0.0,0.0,50.0,50.0,0.0,0.0,0.0,
     C 1.36,14.63,2765.48,4805.76,50.0,232.0/
C
C
C     WRITE INITIAL CONDITIONS
      WRITE(7,6)




    6 FORMAT(19H INITIAL CONDITIONS)
      WRITE(7,20) F(1),FR(1),FR(2),FR(3),FR(4),FW,V(1),V(2),V(3),V(4),
     C S(1),S(2),S(3),S(4),S(5),XS(1),XS(2),XS(3),XS(4),XS(5),
     C XA(1),XA(2),XA(3),XA(4),XA(5),XI(1),XI(2),XI(3),XI(4),XI(5),
     C SNB(1),SNB(2),SNB(3),SNB(4),SNB(5),SR,XSR,XAR,XIR,SNBR,A
   20 FORMAT(8H F(1) = ,F12.3/9H FR(1) = ,F11.3,13H     FR(2) = ,F11.3,
     C 13H     FR(3) = ,F11.3,13H     FR(4) = ,F11.3,10H     FW = ,
     C F14.3/8H V(1) = ,F12.3,12H     V(2) = ,F12.3,12H     V(3) = ,
     C F12.3,12H     V(4) = ,F12.3/8H S(1) = ,F12.3,12H     S(2) = ,
     C F12.3,12H     S(3) = ,F12.3,12H     S(4) = ,F12.3,12H     S(5) =
     C ,F12.3/9H XS(1) = ,F11.3,13H     XS(2) = ,F11.3,13H     XS(3) = ,
     C F11.3,13H     XS(4) = ,F11.3,13H     XS(5) = ,F11.3/
     C 9H XA(1) = ,F11.3,13H     XA(2) = ,F11.3,13H     XA(3) = ,F11.3,
     C 13H     XA(4) = ,F11.3,13H     XA(5) = ,F11.3/
     C 9H XI(1) = ,F11.3,13H     XI(2) = ,F11.3,13H     XI(3) = ,F11.3,
     C 13H     XI(4) = ,F11.3,13H     XI(5) = ,F11.3/
     C 10H SNB(1) = ,F10.3,14H     SNB(2) = ,F10.3,14H     SNB(3) = ,
     C F10.3,14H     SNB(4) = ,F10.3,14H     SNB(5) = ,F10.3/
     C 6H SR = ,F14.3,11H     XSR = ,F13.3,11H     XAR = ,F13.3,
     C 11H     XIR = ,F13.3,12H     SNBR = ,F12.3/5H A = ,F15.3////////)
C
```

```
C
      T = 0.00
      SLUDGE = 500.0
      ZA = 0.208
C
C
C     START CMAS CONTROL PROGRAM
      DO 100 I = 1,48
      DO 101 L = 1,4
      T = T+0.250
C
C
C     COMPUTE SYSTEM DYNAMICS EVERY FIVE MINUTES
      DO 200 J = 1,3
C
C
C     READ INFLUENT PARAMETERS
      F(1) = 41666.0+20833.0*SIN(3.1416*T/12.0)
      S(1) = 250.0+125.0*SIN(3.1416*T/12.0)
      XI(1) = 50.0+25.0*SIN(3.1416*T/12.0)
      SNB(1) = 50.0+25.0*SIN(3.1416*T/12.0)
C
```

```
C
C     COMPUTE DYNAMICS AND CONTROL REQUIRED FOR EACH REACTOR
      N = 1
      F(N+1) = F(N)+FR(N)
      XT(N+1) = XS(N+1)+XA(N+1)+XI(N+1)
      FS(N+1) = XS(N+1)/XT(N+1)
C
      DS(N+1) = ((F(N)*S(N)+FR(N)*SR-F(N+1)*S(N+1))/V(N)-RT*XT(N+1)*
     C (FSM*(S(N+1)/(KS+S(N+1)))-FS(N+1)))*DT
      S(N+1) = S(N+1)+DS(N+1)
      IF(S(N+1).LT.0.0) S(N+1) = 0.0
C
      DXS(N+1) = ((F(N)*XS(N)+FR(N)*XSR-F(N+1)*XS(N+1))/V(N)+RT*XT(N+1)
     C *(FSM*(S(N+1)/(KS+S(N+1)))-FS(N+1))-RXA*XA(N+1)*
     C (XS(N+1)/(KXS+XS(N+1))))*DT
      XS(N+1) = XS(N+1)+DXS(N+1)
      IF(XS(N+1).LT.0.0) XS(N+1) = 0.0
C
      DXA(N+1) = ((F(N)*XA(N)+FR(N)*XAR-F(N+1)*XA(N+1))/V(N)+RXA*XA(N+1
     C )*Y1*(XS(N+1)/(KXS+XS(N+1)))-RXI*XA(N+1))*DT
      XA(N+1) = XA(N+1)+DXA(N+1)
C
      DXI(N+1) = ((F(N)*XI(N)+FR(N)*XIR-F(N+1)*XI(N+1))/V(N)+
     C RXI*XA(N+1)*Y2)*DT
      XI(N+1) = XI(N+1)+DXI(N+1)
C
      DSNB(N+1) = ((F(N)*SNB(N)+FR(N)*SNBR-F(N+1)*SNB(N+1))/V(N))*DT
      SNB(N+1) = SNB(N+1)+DSNB(N+1)
C
      THETA(N) = V(N)/F(N+1)
      FM(N) = ((F(N)*S(N)+FR(N)*SR)/(XA(N+1)*V(N)))*24.0
      MLSS(N) = XT(N+1)/(VSSU2*FRACV)
      XM(N) = MLSS(N)*V(N)*3.785/1000000.0
      OA = (F(N)*S(N)+FR(N)*SR)/V(N)
      OB = (F(N+1)*S(N+1))/V(N)
      OC = RXA*XA(N+1)*Y1*(XS(N+1)/(KXS+XS(N+1)))
      OD = RXI*XA(N+1)
      OXYGEN(N) = OA-OB-OC+OD
      IF(OXYGEN(N).LT.0.0) OXYGEN(N) = 0.0
C
```

```
C
C     COMPUTE REACTOR CONTROL
        VOL(N) = V(N)/1000000.0



        FR(N) = F(1)*FV(1)
C
C
  300   CONTINUE
C
C
C     COMPUTE REACTOR SYSTEM PARAMETERS
        FRT = FR(1)+FR(2)+FR(3)+FR(4)
        VT = V(1)+V(2)+V(3)+V(4)
        VOLT = VT/1000000.0
        MLSSA = (MLSS(1)+MLSS(2)+MLSS(3)+MLSS(4))/4.0
        XMT = XM(1)+XM(2)+XM(3)+XM(4)
        FMA = (FM(1)+FM(2)+FM(3)+FM(4))/4.0
        THETAT = THETA(1)+THETA(2)+THETA(3)+THETA(4)
        THETAC = (((XM(1)+SLUDGE)*1000000.0)/(FW*MLSS(1)*3.785))/24.0
        THTACM = 24.0*(100.0+S(1))/(6.0*S(1))
        OXYGNT = OXYGEN(1)+OXYGEN(2)+OXYGEN(3)+OXYGEN(4)
C
C
C     COMPUTE SLUDGE WASTING CONTROL
        FW = 0.1250*FR*THETAC
        THETAC = 8.0
C
```

```
C
C     COMPUTE CLARIFIER PARAMETERS
        FEFF = F(2)-FW-FRT
        TSSEFF = 18.2+0.0136*((F(2)-FW)/(A*10.76*7.48))-0.0033*MLSS(1)
        TODEFF = S(2)+TSSEFF*(FRACV*YTOD)
C
C
C     FIND SOLIDS CONCENTRATION IMMEDIATELY BELOW LIMITING FLUX
        C1 = 1000.0
        C2 = 12000.0
        GTL = 999999.0
C
C
C     TOTAL FLUX FIRST DERIVATIVE
  350   TEMP1 = K0*C1
        GTP1 = ((1.0-TEMP1)*(0.0835*THETAC-0.24)/
     C EXP(TEMP1))+FRT/(A*10.76*7.48*60.0)
        IF(GTP1 .LT. 0.0) GO TO 400
        C1 = C1+500.0
        IF(C1 .GT. 12000.0) GO TO 700
        GO TO 350
C
C
C     COMPUTE SOLIDS CONCENTRATION AT LIMITING FLUX
  400   DO 500 K=1,20
        CPRIME = (C1+C2)/2.0
        TEMP2 = K0*CPRIME
        GTP1 = ((1.0-TEMP1)*(0.0835*THETAC-0.24)/
     C EXP(TEMP1))+FRT/(A*10.76*7.48*60.0)
        GTPP = ((1.0-TEMP2)*(0.0835*THETAC-0.24)/
     C EXP(TEMP2))+FRT/(A*10.76*7.48*60.0)
        IF(GTP1*GTPP.EQ.0.0) GO TO 600
        IF(GTP1*GTPP.GT.0.0) C1 = CPRIME
        IF(GTP1*GTPP.LT.0.0) C2 = CPRIME
  500   CONTINUE
  600   CL = CPRIME
C
```

```
C
C     COMPUTE LIMITING FLUX AND RETURN SLUDGE CONCENTRATION
         TEMP3 = B0*CL
         GTL = (CL*(0.0835*THETAC-0.24)/EXP(TEMP3)+CL*FRT/
      C (A*10.76*7.48*60.0))*0.0183
         XCL = (GTL*A/FRT*3.785)*1000000.0
C
C
C     COMPUTE ACTUAL FLUX AND RETURN SLUDGE CONCENTRATION
  700    GTA = (MLSS(1)*(F(2)-FW)*3.785/A)/1000000.0
         XCA = ((GTA*A)/(FRT*3.785))*1000000.0
C
C
C
C
C     COMPUTE SLUDGE STORAGE AND BLANKET HEIGHT
         SLGERT = (MLSS(1)*(F(2)-FW)-XCA*FRT)*3.785/1000000.0
         SLUDGE = SLUDGE+SLGERT*DT
         ZA = (SLUDGE*1000000.0)/(XCA*A*1000.0)
C
C
C     COMPUTE RETURN SLUDGE PARAMETERS
         FRAC = XCA/MLSS(1)
         XSR = XS(2)*FRAC
         XAR = XA(2)*FRAC
         XIR = XI(2)*FRAC




         SR = S(2)
         SNSR = SNS(2)
  200    CONTINUE
C
C
  101    CONTINUE
```

```
C     WRITE SYSTEM PARAMETERS
         WRITE(7,25) T
   25    FORMAT(1X,7HTIME = ,F7.2//)
         WRITE(7,30) F(1),F(2),F(3),F(4),F(5),F(5),FR(1),FR(2),FR(3),FR(4)
     C ,FRT,FRT,S(1),S(2),S(3),S(4),S(5),S(5),SR,XS(1),XS(2),XS(3),XS(4)
     C ,XS(5),XS(5),XSR,XA(1),XA(2),XA(3),XA(4),XA(5),XA(5),XAR,XI(1),
     C XI(2),XI(3),XI(4),XI(5),XI(5),XIR,SNB(1),SNB(2),SNB(3),SNB(4),
     C SNB(5),SNB(5),SNBR,MLSS(1),MLSS(2),MLSS(3),MLSS(4),MLSSA,XM(1),XM
     C (2),XM(3),XM(4),XMT,VOL(1),VOL(2),VOL(3),VOL(4),VOLT,FM(1),FM(2),
     C FM(3),FM(4),FMA,THETA(1),THETA(2),THETA(3),THETA(4),THETAT,THETAC
     C ,THTACM,OXYGEN(1),OXYGEN(2),OXYGEN(3),OXYGEN(4),OXYGNT,GTL,GTA,
     C XCA,SLUDGE,ZA,FW,FEFF,TODEFF,TSSEFF
   30    FORMAT(1X,9HPARAMETER,9X,8HINFLUENT,3X,9HREACTOR 1,3X,9HREACTOR 2
     C ,3X,9HREACTOR 3,3X,9HREACTOR 4,3X,9HREACT SYS,4X,6HRETURN //
     C 1X,4HFLOW,18X,6(F12.3)/1X,11HRETURN FLOW,15X,6(F12.3)/1X,
     C 9HSUBSTRATE,5X,7(F12.3)/1X,11HSTORED MASS,3X,7(F12.3)/1X,
     C 11HACTIVE MASS,3X,7(F12.3)/1X,10HINERT MASS,4X,7(F12.3)/
     C 1X,11HNONBIO MASS,3X,7(F12.3)/1X,4HMLSS,22X,5(F12.3)/1X,4HMASS,
     C 22X,5(F12.3)/1X,6HVOLUME,20X,5(F12.3)/1X,9HFOOD/MASS,17X,5(F12.3)
     C /1X,5HTHETA,21X,5(F12.3)/1X,6HTHETAC,68X,F12.3/1X,7HTHETACM,
     C 67X,F12.3/1X,6HOXYGEN,20X,5(F12.3)//1X,13HLIMITING FLUX,1X,F12.3/
     C 1X,11HACTUAL FLUX,3X,F12.3/1X,14HUNDERFLOW CONC,F12.3/1X,
     C 13HSTORED SLUDGE,1X,F12.3/1X,14HSLUDGE BLANKET,F12.3//1X,
     C 10HWASTE FLOW,4X,F12.3/1X,13HEFFLUENT FLOW,1X,F12.3/
     C 1X,12HEFFLUENT TOD,2X,F12.3/1X,12HEFFLUENT TSS,2X,F12.3////////)
C
C
  100    CONTINUE
         STOP
         END
```

TIME = 4.00

PARAMETER	INFLUENT	REACTOR 1	REACTOR 2	REACTOR 3	REACTOR 4	REACT SYS	RETURN
FLOW	77749.865	119892.877	-.000	-.000	-.000	-.000	
RETURN FLOW		41298.419	.000	.000	.000	41298.419	41298.419
SUBSTRATE	466.507	2.098	.000	.000	.000	.000	2.098
STORED MASS	.000	6.081	.000	.000	.000	.000	17.062
ACTIVE MASS	.000	2280.656	.000	.000	.000	.000	6399.507
INERT MASS	93.301	1241.509	.000	.000	.000	.000	3483.668
NONBIO MASS	93.301	59.830	.000	.000	.000	.000	59.830
MLSS		3104.963	-.000	-.000	-.000	776.241	
MASS		8467.762	-.000	-.000	-.000	8467.762	
VOLUME		.719	-.000	-.000	-.000	.719	
FOOD/MASS		.531	-.000	-.000	-.000	.133	
THETA		6.010	-.000	-.000	-.000	6.010	
THETAC						8.000	
THETACM						4.857	
OXYGEN		8.637	-.000	-.000	-.000	8.637	

LIMITING FLUX	7.065
ACTUAL FLUX	5.870
UNDERFLOW CONC	8712.508
STORED SLUDGE	580.000
SLUDGE BLANKET	.287

WASTE FLOW	4009.753
EFFLUENT FLOW	74584.705
EFFLUENT TOD	11.743
EFFLUENT TSS	8.038