A GENERALIZED, STEADY-STATE SIMULATION

OF

WASTEWATER TREATMENT PLANTS

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OF
WASTEWATER TREATMENT PLANTS

by

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SCOPE AND CONTENTS:

Laboratory and field measurements were combined with theory in developing models for the various wastewater treatment processes. Some assumptions were made, both in an attempt to simplify the complex mechanisms encountered and to explain known experiences and observations.

Models for a primary settling tank, a secondary settling tank, a generalized aerobic biological sludge treatment scheme, an anaerobic digestion system and several other unit processes have been developed. The generalized aerobic biological sludge treatment scheme is an attempt to describe in one physical package, all the various activated sludge process modifications.

The executive system used is GEMCS, together with its library of subroutines, such as CONTL1, SEPA01, JUNC01 and

and SETSPI, some of which have been modified slightly.

The models have been tested on the Drury Lane and the Skyway, Burlington, Sewage Treatment Plants, and have been found to agree very well with plant data. The former has a conventional activated sludge process, whilst the latter employs the extended aeration modification.

An inter-active version has been developed, which requires the minimum knowledge of GEMCS for its use. This can be applied as a training and teaching tool for plant operators and students in the field.

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CHAPTER 1

1. INTRODUCTION

Although waste treatment practices have been known ever since the turn of the century, it was not until about the late 1940's that an effort was made to provide firm theoretical bases for design. Significant advances have been made in recent years, resulting in a better understanding of the complex variables affecting the operation of the various unit processes. It is now possible, where it would be beneficial, to bring together the models of the various waste treatment processes, to simulate the operation of full-scale plants, on a computer.

A successful simulation can have great potential applications, a few of which are:

(1) The performance of the individual units and of the plant as a whole can be predicted over a wide range of feed flows and operating conditions,

(2) The computer simulation can help in the selection of an optimal design for a plant to treat a given waste to a satisfactory level, at the least cost,

(3) It can be used effectively in the training of plant operators and as a valuable educational tool for students in the field, and

(4) It can be used for on-line process control purposes.

Several computer simulations have been attempted, both in the United States and in Canada, examples of which include those by Smith (46, 47), Silveston (40, 41), and by Fan and Erickson (10, 11). However, there is a severe limitation in their models for the activated sludge system. They have based their kinetics either on the entire sludge mass or on the volatile suspended matter in the sludge mass, when it is known that microorganisms are the only agents capable of stabilizing the waste. It is for this reason that their models break down when they are applied to the various modification of the conventional activated sludge process, as the composition of the sludge then changes.

One of the major objectives of this work is to develop a means by which the microbial mass may be estimated. The kinetic expressions can then be formulated around the physiological activities of the microorganisms, leading to a more meaningful model for the activated sludge process. This generalized model can then be applied to the various modifications of the activated sludge process.

As a great variety of raw wastes are encountered in wastewater treatment practice, it would be useful to develop generalized models that can handle all of them. However, the parameters pertaining to each type of waste will be different. Consequently, another objective of this work is to compile a series of experiments that can be used to characterize a given wastewater and its treatability parameters. Although the work in this thesis is based primarily on domestic sewage, the same experiments used here may be performed on other wastewaters.

It is also realized that the complexity of a simulation system is discouraging its use by most plant operators or engineers. Furthermore, there is a tendency for interested parties to create their own simulation system rather than to try to understand and use other systems. It is for this reasons that we feel it necessary to develop an interactive version of the computer simulation which would require the minimum knowledge of the simulation system, for its use.

CHAPTER 2

2. LITERATURE REVIEW

The model for the primary settler proposed by R. Smith (46), was derived by plotting the data for suspended solids removal versus overflow rate for full-sized plants, as reported in "Sewage Treatment Plant Design", (38). He obtained the relationship

$$\mathrm{FRPS} = 0.82 \exp(-\mathrm{GPS}/2780) \tag{2.1}$$

where FRPS = fraction of solids removed

GPS = overflow rate usgpd/$\mathrm{ft.}^2$

The fractional removal was applied to all classes of suspended solids, which may not be a valid assumption.

P. Silveston (41), tested the model on two Ontario plants and found that the effluent suspended solids predicted were about 25% higher than that actually observed. This led him to suggest that actual plant data have to be used to achieve a reasonable simulation. He proposed the relationship

$$\mathrm{FRPS} = 1 - \exp(-k/\mathrm{GPS}) \tag{2.2}$$

where k = constant fitted from plant data.

Both models, however, do not account for the effect of turbulence on the settling process. The constant k in Silveston's model could be interpreted to include both the effects of turbulence and the settling characteristics of the feed solids.

Camp (4) has developed a mechanistic model for discrete particle sedimentation in a continuous-flow tank. He first introduced the concept that a real settling tank may be divided into an inlet zone, a settling zone and an outlet zone. The actual sedimentation occurs in the middle zone, whilst turbulence at both the inlet and outlet zones prevent any further sedimentation from occuring. He also introduced the use of batch settling curves to predict the performance of a continuous-flow sedimentation tank.

Most of the models for the activated sludge process have evolved from the complete mixing model first presented by McKinney (25). The original paper was a little vague, and in a later discussion, Washington (47) corrected and clarified several points. However, his model can be interpreted as follows, noting that all the various forms of organic carbon are in their oxygen equivalents:

In the presence of unlimited food the rate of synthesis of the active solids is limited only by the concentration of the active solids, i.e.,

$$\frac{d(\text{MLVSS})}{dt} = k_s'(\text{MLVSS}) \qquad (2.3)$$

But in the case of food-limiting situation, the rate becomes

$$\frac{d(\text{MLVSS})}{dt} = k_s C \qquad (2.4)$$

where MLVSS = oxygen equivalent of active solids

C = oxygen equivalent of substrate

k_s, k_s' = rate constants.

He assumed that the volatile solids in the sludge is entirely active. He also proposed that the rate of substrate removal is proportional to the rate of synthesis of active solids, i.e ,

$$\frac{dC}{dt} = -(1 + k_a) \frac{d(MLVSS)}{dt} \qquad (2.5)$$

The basal metabolism rate was also assumed to be proportional to the concentration of active solids, i.e.,

$$\frac{d(MLVSS)}{dt} = -k_d(MLVSS) \qquad (2.6)$$

By performing mass balances around the stirred tank reactor, he obtained, assuming a food-limiting situation:

$$C_o = \frac{C_i}{1 + (1 + k_a)\, k_s\, \bar{t}} \qquad (2.7)$$

and

$$M_o = \frac{k_s C_o}{k_d + \frac{x}{\bar{t}}} \qquad (2.8)$$

where C_i = influent substrate concentration

C_o = effluent substrate concentration

M_o = effluent active solids concentration

$\bar{t}$ = detention time

and x = fraction of sludge mass wasted.

Estimated values of his constants were given as:

$k_a = 0.5$

$k_d = 0.006 \text{ hr.}^{-1}$

$k_s' = 15 \text{ hr.}^{-1}$ (minimum)

and $k_s = 7 \text{ hr.}^{-1}$ (minimum)

R. Smith (46) in his model, assumed that the rate of substrate removal is proportional to both the concentration of active solids and the substrate concentration, i.e.,

$$\frac{dC}{dt} = - k_s'' \, C \, (\text{MLSS}) \qquad (2.9)$$

as contrasted to equations (2.3) and (2.4). k_s'' is a rate constant given by:

$$k_s'' = 0.0001 \, (1.047)^{T-20} \, (\text{hr})^{-1} (\text{mg/l})^{-1} \qquad (2.10)$$

Erickson, Ho and Fan (11) assumed Michaelis-Menten kinetics with the expression

$$U = \frac{1}{\text{MLSS}} \frac{dC}{dt} = - \frac{U_{max} \, C}{Y \, (C^* + C)} \qquad (2.11)$$

where U_{max} = maximum unit growth rate

C^* = value of C where $U = \frac{1}{2} U_{max}$

Y = yield factor.

It may be noted that equation (2.11) reverts to the form of equation (2.3) when $C >> C^*$, and to the form of equation (2.9) when $C << C^*$.

Little quantitative information exists on the operation of the secondary settler. The models proposed by Ott and Bogan (29), Erickson and Fan (10, 11), and Silveston (41), have assumed that a constant fraction β, of the input solids escapes over the wier and that the underflow solids are compacted by a ratio C. R. Smith (46) proposed a model, based on the data of Villiers (51) where

$$\beta = \frac{556\ (\mathrm{GPS})^{0.494}}{\mathrm{MLSS}^{1.82}\ (\mathrm{TA})^{0.439}} \qquad (2.12)$$

GPS is the settler overflow rate (USgpd/ft.^{2}), MLSS is the inlet mixed liquor suspended solids (mg/l), and TA the aeration time (hours). For some reason he later reverted back to the simple splitter model.

Anaerobic digestion is a complex operation involving several reaction stages and different microorganisms. An accurate description for the process is difficult to obtain. McCarty (24) using Michaelis-Menten kinetics and a completely stirred tank model, arrived at the relationship:

$$\frac{k_{max} F}{F^* + F} = \frac{1}{\bar{t}} \qquad (2.13)$$

where k_{max} = maximum unit growth rate constant

F^* = value of F at which unit growth rate is $\frac{1}{2}\ k_{max}$

F = concentration of biodegradable carbon in effluent

and $\bar{t}$ = digester residence time.

The reported values of k_{max} and F^* are:

$$k_{max} = 0.28 \exp\left[- 0.036\ (35 - T)\right] \qquad (2.14)$$

and

$$F^* = 700 \exp\left[0.10\ (35 - T)\right] \qquad (2.15)$$

where T = temperature of digestion, °C.

His relationship implies that the effluent degradable carbon is independent of the influent value, but depends only on the detention time. He also suggested an expression to estimate the organic carbon of the volatile acids (VAC) in the effluent as:

$$VAC = \frac{200 \exp\left[0.12\ (35 - T)\right]}{1 + k_{max}\,\bar{t}} \qquad (2.16)$$

Extensive cost information is available in the literature. R. Smith (45, 46) presented a thorough investigation of the capital and operating costs of domestic waste treatment unit processes. The capital and operating costs of a unit are calculated as a function of its most significant capacity variable. Michel et al. (26) reported on the total operating and maintenance costs of a treatment plant as a function of the waste flow and also of the population equivalent. Barnard and Eckenfelder (2) included industrial waste treatment costs in their report. A more complete list of references may be obtained from the above reports.

Several papers have been published on the optimization studies of wastewater treatment processes. Erickson and Fan (10) studied the optimization of the hydraulic regime of activated sludge systems. Erickson, Ho and Fan (11) later investigated the modelling and optimization of the step aeration processes, which consists of a series of completely mixed tanks. Shih and Krishnan (39) reported on their studies on the dynamic optimization of industrial waste treatment plant designs. Realizing that many design parameters are not accurate, Berthouex and Polkowski (3) studied the effect of such uncertainties on the optimal design of a treatment plant.

Further references from the literature will be made, as the thesis is developed.

CHAPTER 3

3. THE SIMULATION SYSTEM

3.1 The GEMCS Executive

Any processing or manufacturing plant can be broken down into its component unit processes. The unit process is a basic operation within the framework of the plant, and can usually be identified with a distinct physical piece of equipment, examples of which are primary sedimentation, chlorination, drying, etc. The mathematical model of a unit process is known as a unit computation.

In a simulation system, it is necessary to have a master-mind to execute each unit computation in its logical sequence. Such is the purpose of the executive program. It should also supervise the flow of information between storage locations and the unit computations.

The Chemical Engineering Department of McMaster University, in co-operation with the Canadian General Electric Company, has developed a simple but yet very flexible executive program known as GEMCS (the General Electric-McMaster Simulator) for the simulation of steady-state processes. It has been used successfully in the simulation of several chemical process industries. The extensive work done is well summarized in the book "Chemical Plant Simulation" (5). Only a very brief description of the executive program will be attempted here.

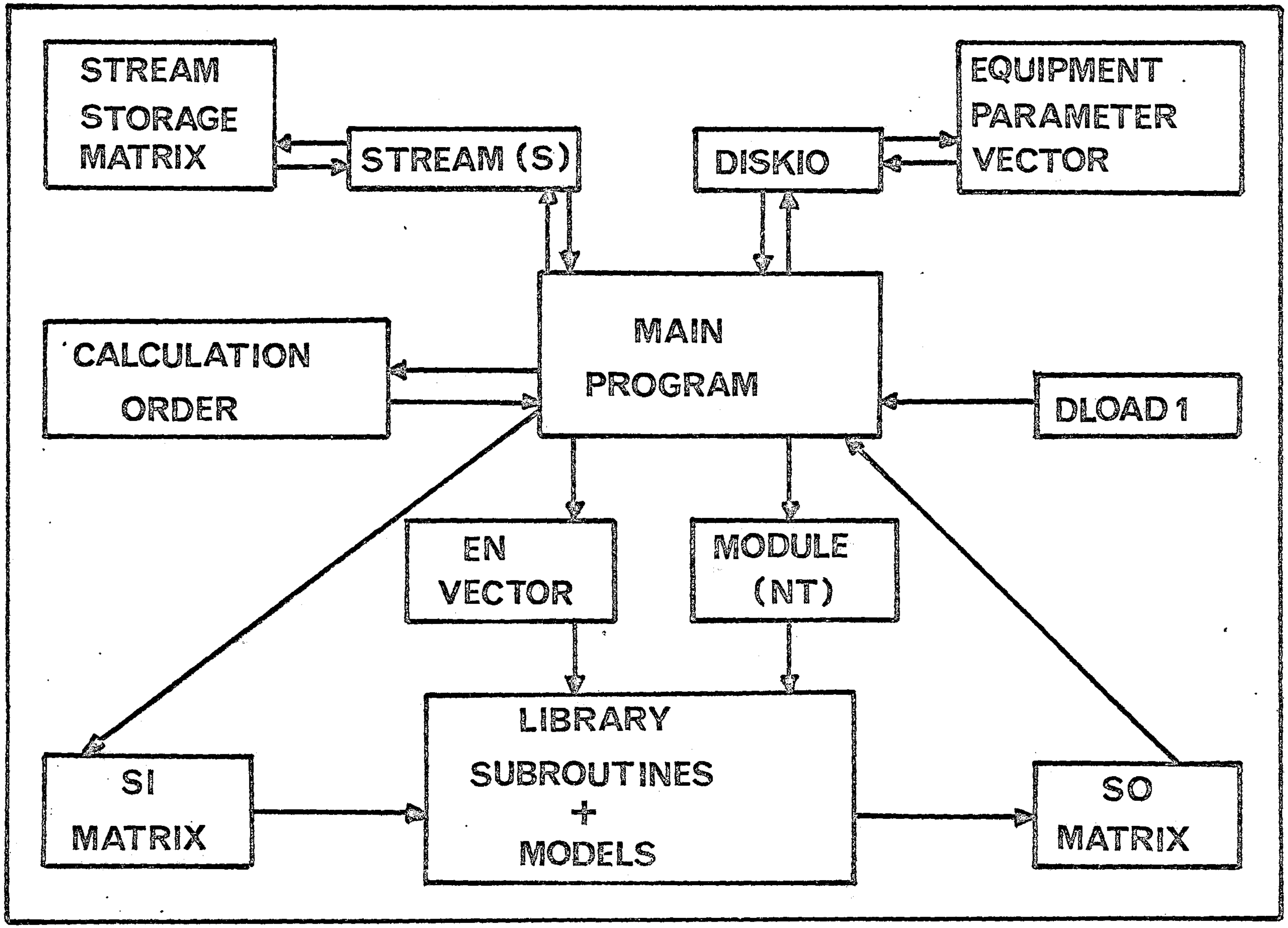


Figure 3.1.1. Information Flow Within the GEMCS Executive

The aid of Figure 3.1.1 is invaluable. The executive program first calls an assistant subroutine DLOAD1 which reads in input streams, equipment parameters and an order of calculation in which to execute the unit computations. The information is then stored for subsequent use. The main program then prepares to execute the first unit computation in the plant. It retrieves the equipment parameters for the unit from the storage location, the EEN vector, via a linking subroutine DISKIO. It then places the equipment parameters (this is done directly by DISKIO) into a working equipment vector, the EN vector. The main program then retrieves from the storage location for the streams, the SN matrix, the input streams flowing into the unit computation. Subroutine STREAM(S) acts as the link between the SN matrix and the main program. The input streams are then placed in the working matrix, the SI matrix. The unit computation is then called and executed using information provided in the SI and EN via the subroutine MODULE(NT) locations. Any output streams generated by the unit computation are stored in the working matrix, the SO matrix, and which are then transferred by the main program into the SN storage matrix.

The other unit computations in the calculation order are similarly executed. In the case where there is a recycle of streams, a control subroutine must be placed in the calculation order to direct the main program to recalculate all the unit computations within the recycle loop, until convergence is reached, within a specified tolerance.

It should be noted that the unit computations deal directly only with the working equipment vector and input and output stream matrices. This creates a uniform pattern whereby the unit computations may be constructed.

3.2 The Stream List

In every process simulation a list of components that will adequately describe any stream within the process has to be selected. Crowe et al (5) have listed several criteria for the selection of stream variables. They include

(1) The variables should be useful to satisfy the objectives of the simulation,

(2) All variables in recycle streams are usually important, and

(3) The unit computations must be able to manipulate the variables to an accuracy consistent throughout the whole system.

These criteria were used as an aid in the selection of the stream variables for the present generalized wastewater treatment plant simulation. In addition, the best features of the stream lists used by Smith (46) and Hoffman (20) were selected and in some cases modified. The stream list used is shown in Table 3.2.1.

No.	Phase	Stream Variable		Units
1	Short List	Stream number		-
2		pH		-
3		Total volumetric flow		igph
4		Temperature		°C
5		Head		ft. of water
6		Water		lbs/hr
7		Dissolved oxygen		lbs/hr
8		Total Organic Carbon (TOC = sum 15-22)		lbsC/hr
9		Dissolved Organic Carbon (DOC = sum 20-22)		lbsC/hr
10		Biochemical Oxygen Demand (BOD)		lbs/hr
11		Total Suspended Solids (TSS)		lbs/hr
12		Volatile Suspended Solids (VSS)		lbs/hr
13	Suspended Solids Phase	Particulate Inorganics	settleable	lbs/hr
14			non-settleable	lbs/hr
15		Microorganisms		lbsC/hr
16		Particulate Organics	settleable, biodegradable	lbsC/hr
17			settleable, non-biodegradable	lbsC/hr
18			scum (floatable)	lbsC/hr
			non-settleable	lbsC/hr

No.	Phase	Stream Variable		Units
20		Dissolved Organics	Purgeable, biodegradable	lbsC/hr
21			Non-purgeable, biodegradable	lbsC/hr
22			Non-purgeable, non-biodegradable	lbsC/hr
23		Alkalinity, as $CaCO_3$		lbs/hr
24				
25				
26				
27		N in NH_3 (dissolved)		lbs/hr
28		N in NO_2^- and NO_3^- (dissolved)		lbs/hr
29		Dissolved P in all forms of phosphates		lbs/hr

Table 3.2.1 Stream List for Wastewater Simulation

It may be noticed that the stream list is divided into three parts. The first part is a list of traditional variables commonly used in wastewater treatment practice. The second part covers the water-insoluble components normally found in wastewaters and the last category includes the water-soluble components. The second and third parts may be further sub-divided into an inorganic and an organic fraction.

The traditional variables in elements 8-12 are not fundamental components in the sense that they may be derived from the finer classification provided in elements 13-22. However, these are the variables that most operators and environmental engineers understand and hence are invaluable in our communication with them. Another reason for retaining these variables is that several of the correlations used in our simulation are expressed in terms of them. A simple simulation can be effected by the use of only these first twelve variables.

Suspended solids can either be organic or inorganic in nature. The inorganic portion is inert and does not take part in any biological processes, although chemically, it may be altered by a changing pH. However, we have to distinguish between a colloidal inorganic solid, which remain in suspension and a settleable inorganic solid which is removed in physical sedimentation.

For the organic suspended solids, we have to distinguish between the non-living organic objects from the living biomass which is active in bringing about the stabilization of the waste-load. The major portion of the non-living organic solids is biodegradable, while the remainder may be relatively non-biodegradable. The inertness may be due to several factors, one of which is a high degree of polymeric crosslinking. It is impossible to distinguish between the biodegradable portion from the non-biodegradable portion, and the distinction, although provided in the stream list is not used.

Physically, the non-living organic solids can be differentiated by their settling characteristics. We can distinguish a colloidal fraction, which remains in suspension, a settleable fraction and a scum (or floating) fraction.

Organics in solution can also be classified as biodegradable and non-biodegradable. Physically, certain organics in solution may be volatilized by purging with air. These are the solvents and other low molecular weight compounds. The non-biodegradable fraction, being largely composed of high molecular weight compounds, is relatively non-purgeable.

Soluble inorganics of interest include the nutrients phosphorus and nitrogen, and the alkalinity causing ion. Inorganic nitrogen is further subdivided into ammonia and the sum of nitrite and nitrate ions. Several blank spaces are left in the soluble inorganics section to facilitate the addition of variables, should the simulation be extended to include tertiary treatment.

The units used are also shown in Table 3.2.1. It should be noted that concentration units facilitate the splitting of streams, while mass flow units facilitate the mixing of streams. A disadvantage of concentration units is that while concentrations based on unit volume are usually measured, the simulation system invariably has to use concentrations based on unit mass. Volumetric and mass concentrations are approximately equivalent under 1%, but become increasingly inaccurate above that. To avoid this complication, mass flow units are chosen.

As in Hoffman et al (20), the organic components are all measured in terms of the carbon content. This greatly facilitates the arithmetic of the biological processes.

The interplay being the variables is schematically represented in Figures 3.2.1 and 3.2.2, together with the analytical procedure followed. This is essentially the outline given by Hoffman et al with slight modifications. Further analytical details are given in "Standard Methods" (48).

The conversion of variables within our "finer" classification to the traditional variables is described in Section 9.1.

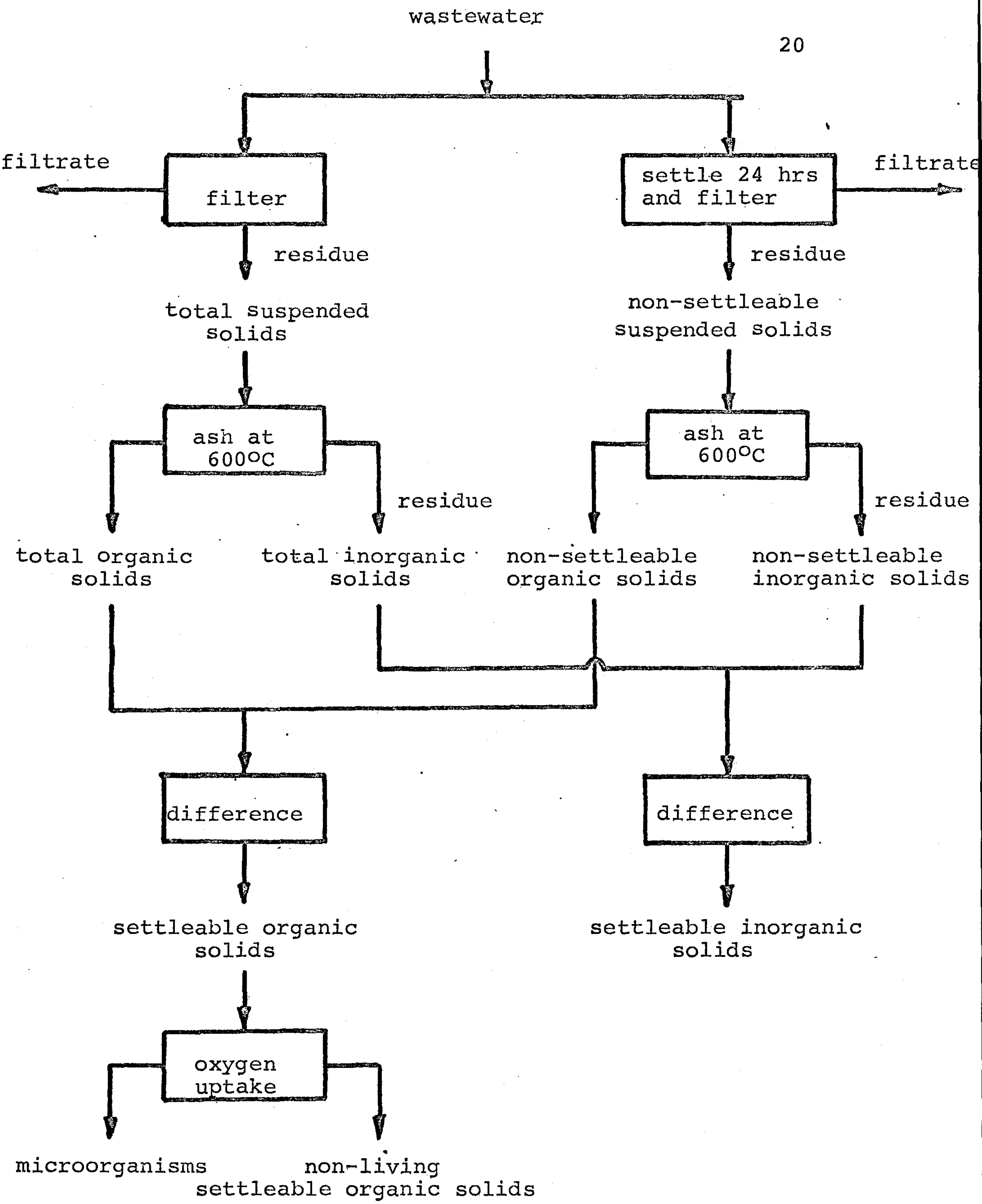


Figure 3.2.1, Inter-relationship Between Solid Components

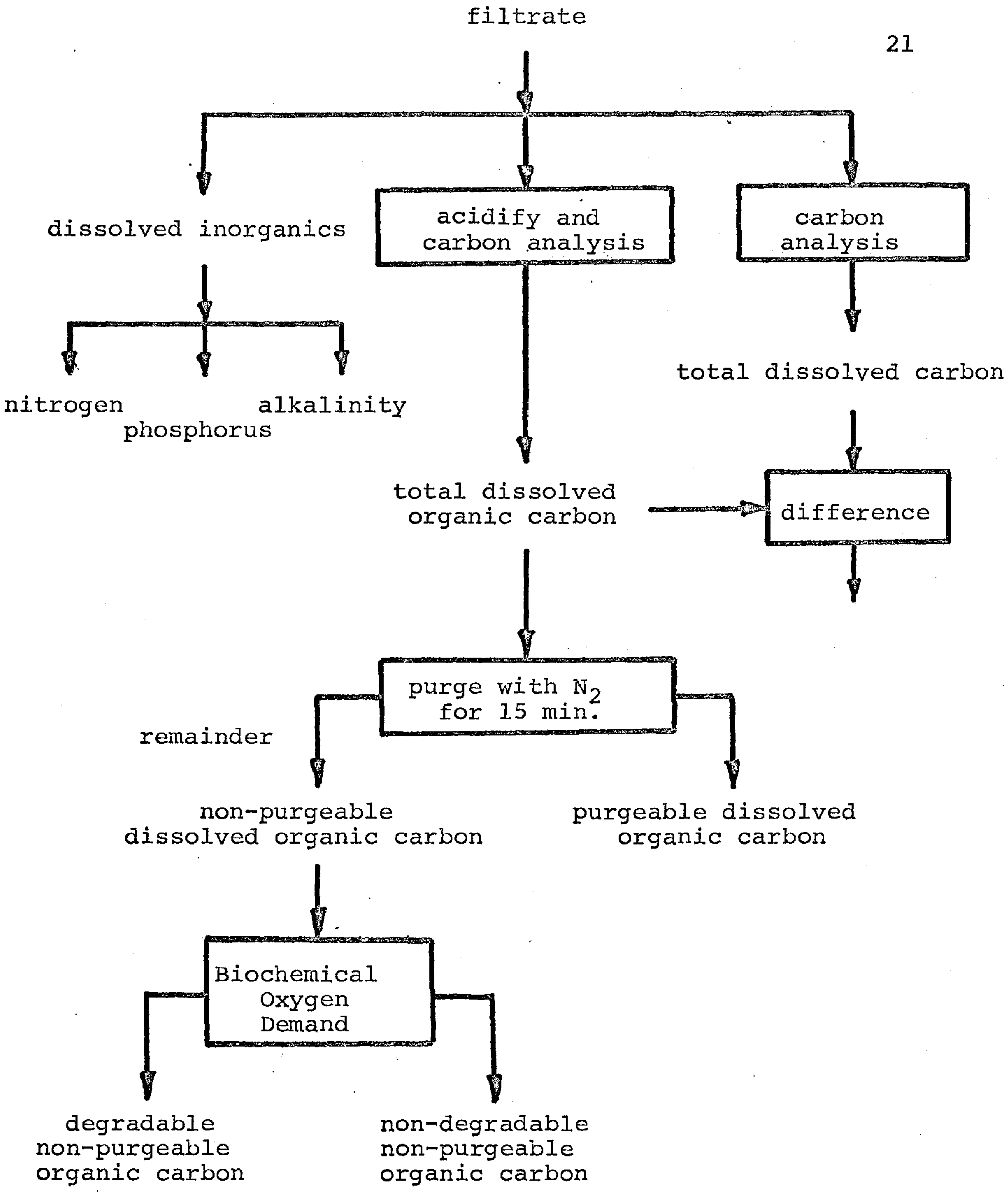


Figure 3.2.2. Inter-relationship Between Dissolved Components

CHAPTER 4

4. PRIMARY SEDIMENTATION

The solid particles carried in suspension by wastewater flows can be partially removed by gravity settling in a relatively quiescent tank. The process, often called primary sedimentation, is used to reduce the sludge load downstream of the units. In the case where no further treatment is provided, primary sedimentation reduces the formation of sludge banks in the receiving waters. In most cases, it is used as a preliminary step ahead of biological treatment, to reduce the amount of solids being carried around in the latter system.

4.1 Theory

During sedimentation, the solid particles in a dilute suspension, may retain their individual shapes and sizes, and settle out as discrete particles. However, many other solids tend to flocculate (coalesce into a larger particle upon contact with each other), as they settle. This increases their settling velocities and hence the flocculation of the particles is a desirable property from this view-point.

The simpler case of discrete particle sedimentation will be dealt with first, and then it will be expanded to include the case of flocculent sedimentation.

A discrete particle, settling through a fluid, quickly reaches a terminal velocity. At this point, the gravitational force is exactly balanced by the bouyant and drag forces acting on the particle. This leads to the classical equation of discrete particle sedimentation

$$U_t = \left[\frac{4}{3} \frac{g}{C_D} \left(\frac{P_s - P}{p} \right) D_p \right]^{\frac{1}{2}} \qquad (4.1.1)$$

where U_t = terminal velocity (ft/sec)

g = acceleration due to gravity (ft/sec^2)

P_s = specific gravity of the solid particle

P = specific gravity of the fluid

C_D = drag coefficient

and D_p = diameter of the particle (ft)

The drag coefficient C_D is a function of the particle Reynolds Number and of the sphericity of the particle. This can be obtained from most standard texts on Fluid Mechanics.

Using the fact that a discrete particle quickly reaches a terminal velocity, during sedimentation, we can calculate the removal obtained in a batch settling test.

Consider the sketch of a batch settling column in Figure 4.1.1. If a dilute suspension of discrete particles occupies the entire volume uniformly, at the start of the test, then if a sample is drawn off at a depth h at time t, it will not contain any particles with terminal velocities greater

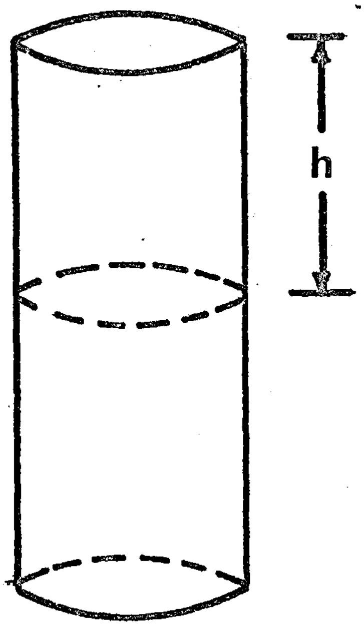


Figure 4.1.1. Settling Column

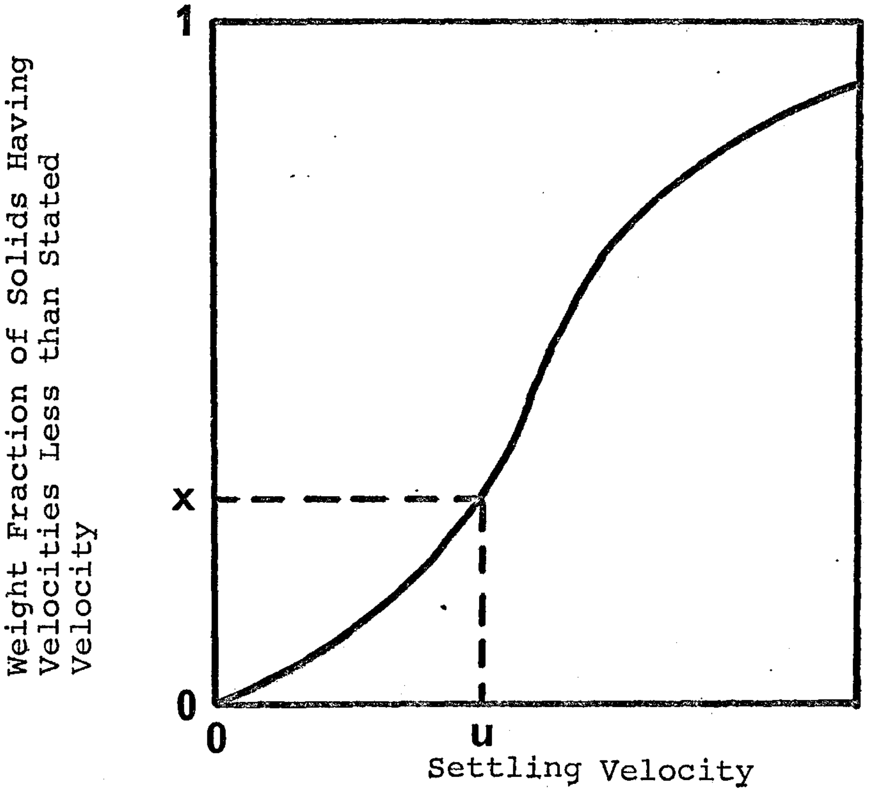


Figure 4.1.2. Settling Velocity Analysis Curve for Suspensions of Non-Flocculating Particles

than $U = h/t$. The fraction of the solids concentration in the sample to the original solids concentration will be the weight fraction of particles having terminal velocities $U \leqslant h/t$. Let this weight fraction be represented by x, and $x = f(u)$ - may be used to represent the settling characteristics of the particles. Figure 4.1.2 shows a typical settling velocity analysis curve for a suspension of non-flocculating particles.

If the liquid above a depth N_o were to be decanted, at time t, it will only contain particles with terminal velocities $\leqslant h_o/t = U_o$. But particles with terminal velocities $U \leqslant U_o$ will have fallen through a distance $h = Ut$, and hence only a fraction $(h_o - h)/h_o = (U_o - U)/U_o$ of such particles will remain in the decanted liquid.

Hence the weight fraction of the solids in the decanted (or clarified) liquid will be

$$\begin{aligned} W_c\ (U_o) &= \int_o^{x_o} (U_o - U)/U_o \, dx \\ &= x_o - \int_o^{x_o} U/U_o \, dx \qquad (4.1.2) \end{aligned}$$

where W_c = weight fractions of solids in decanted liquid

x_o = weight fraction of particles having terminal velocities $U \leqslant U_o$.

and U_o = sometimes referred to as overflow velocity.

The weight fraction of solids not in the decanted liquid (or the weight fraction removal) is then given by

$$W_r\ (U_o) = 1 - W_c\ (U_o) = (1 - x_o) + \int_o^{x_o} U/U_o\ dx \qquad (4.1.3)$$

The integral may be approximated by a summation term and hence equations 4.1.2 and 4.1.3 may be rewritten as

$$W_c\ (U_o) = x_o - \sum_{x=0}^{x=x_o} U/U_o\ \Delta x \qquad (4.1.4)$$

and $$W_r\ (U_o) = (1 - x_o) + \sum_{x=0}^{x=x_o} U/U_o\ \Delta x \qquad (4.1.5)$$

The integral or the summation term can be evaluated with the use of Figure 4.1.2.

If, during the batch settling test, samples are withdrawn at various depths and elapsed times, Figure 4.1.3 will result. The lines shown join points of equal weight-fraction. The slopes of the lines will give the associated terminal velocities.

The weight fraction of solids removed can also be evaluated from Figure 4.1.3. Equation 4.1.5 may be rewritten, for that purpose, as

$$W_r\ (U_o) = (1 - x_o) + \sum_{x=0}^{x=x_o} h/h_o\ \Delta x \qquad (4.1.6)$$

From Figure 4.1.3, if h_A is the average of h_o and h_1, h_β the average of h_1 and h_2, and so on, then the summation term can be evaluated as

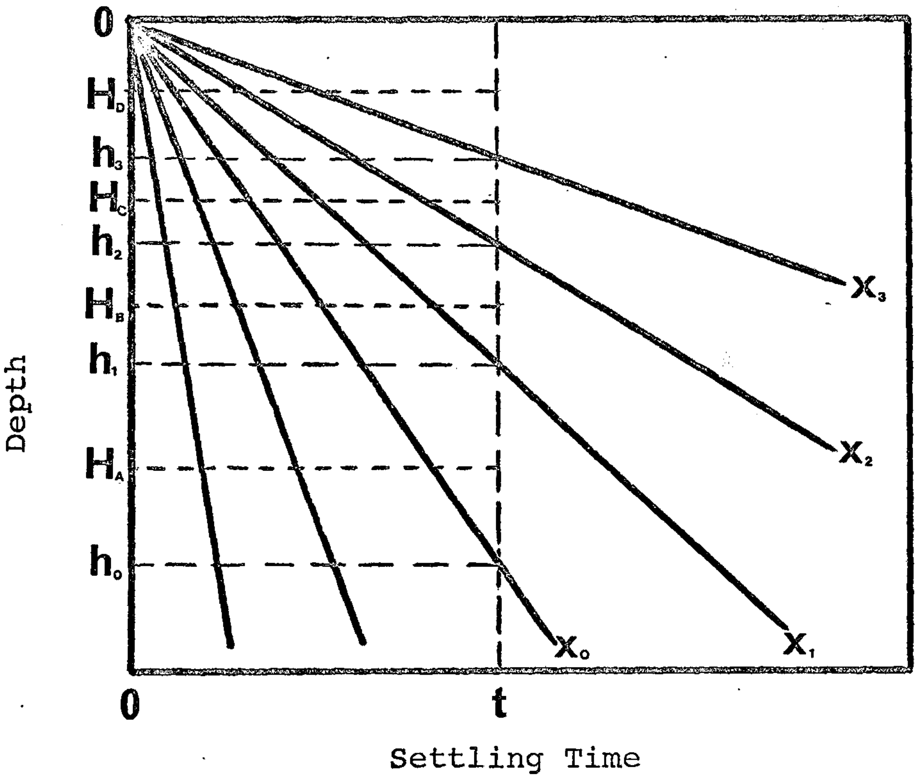


Figure 4.1.3. Settling Curves for Non-Flocculating Solids

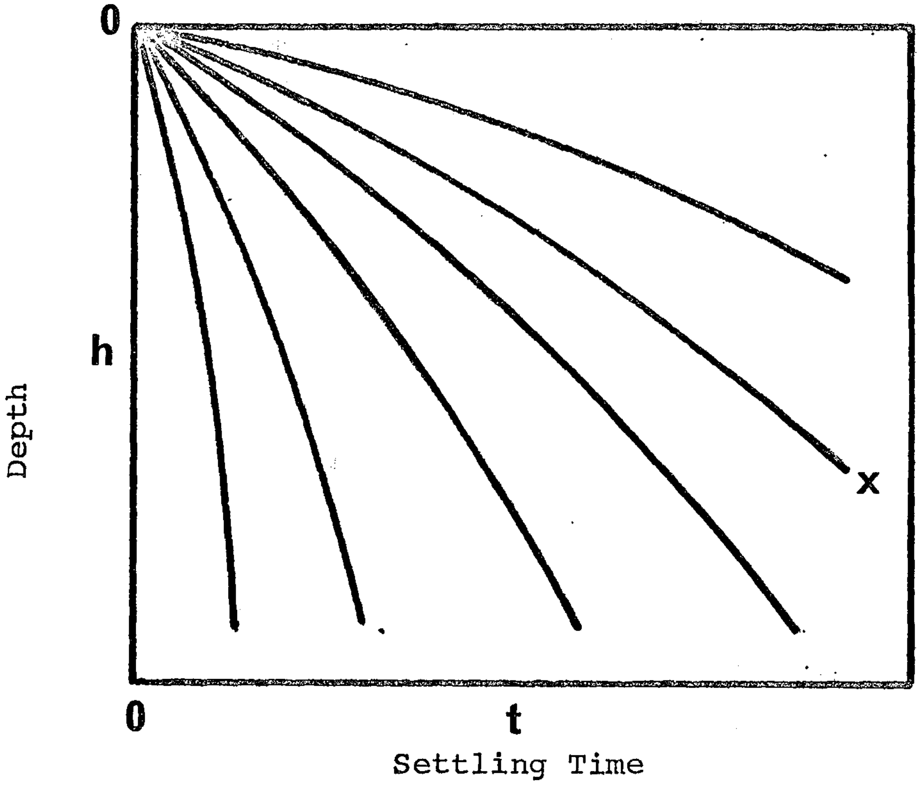


Figure 4.1.4. Settling Curves for Flocculating Solids

$$\sum_{x=0}^{x=x_o} h/h_o \ \Delta x = \frac{1}{h_o} \left\{ h_A(X_o - X_1) + h_\beta(X_1 - X_2) + H_C(X_2 - X_3) + h_D(X_3 - 0) \right\} \qquad (4.1.7)$$

In the case where the particles tend to flocculate upon contact with each other, the settling velocities of the particles are increased, as sedimentation proceeds. Hence there is an added effect of the settling time.

The effect of flocculation is best seen in Figure 4.1.4, which is obtained in the same manner as Figure 4.1.3. The lines joining points of equal weight-fraction are no longer straight, as in the case of discrete particle sedimentation, but curved. The curvature reflects the increasing settling velocity, as the sedimentation proceeds.

Equation 4.1.2 to 4.1.6 still holds and may be used to evaluate the solids removal. Also, a similar procedure, as the one used in obtaining Equation 4.1.7, may be used as a graphical solution.

The batch settling test can be directly applied to a continuous flow primary settling tank, assuming plug flow conditions exist in the tank. The depth h_o refers directly to the depth of the tank and the time t is the residence time of the fluid in the tank. Deviations from plug flow conditions are treated in section 4.3.

4.2 The Correlation of Batch Settling Data

Raw sewage from the Drury Lane, Burlington and Dundas Sewage Treatment Plants were used in the settling experiments. The settling column is 8 in. in diameter and 8 ft. in height. The column has five sampling points, equally spaced 1 ft. apart.

The raw sewage was introduced into the column and allowed to equilibrate to room temperature for at least four hours. This was done to minimize thermal convection currents. Then the suspension was stirred up by blowing air into the sewage for one minute.

Samples were withdrawn initially, just after the mixing, and at regular time intervals from the five sampling ports. Prior to sampling, the sampling lines were flushed to wash out any accumulated solids. The column was also left for 24 hours, and the suspended solids determined. This represented the non-settleable or colloidal portion of the waste. The suspended solids of the samples were determined by vacuum filtration on 0.45 micron membrane filter papers. The papers were dried in an oven set at 103°C for at least half an hour. A Mettler balance with an accuracy of 0.1 mg was used for the weighing. All determinations were done in duplicate, and averaged.

The suspended solids data are given in Appendix A. Two previous runs, performed in 1969 and 1970, as part of a wastewater course, using raw sewage from the Dundas Sewage Treatment Plant are also included. Figure 4.2.1 to 4.2.4 show the weight fraction of settleable solids in the samples withdrawn as a function of time and depth. Equation 4.1.6 was used to calculate the weight fraction of settleable solids removal as a function of depth and time, and the results are tabulated in Appendix A.

In the absence of theoretically derived expressions, empirical correlations had to be derived. However, we note that at constant h_o,

$$\begin{array}{ll} \text{if} & t \to \infty, \text{ then } W_c \to 0 \text{ or } W_r \to 1 \\ \text{and if} & t \to 0, \text{ then } W_c \to 1 \text{ or } W_r \to 0. \end{array} \tag{4.2.1}$$

Also that at constant t,

$$\begin{array}{ll} & \text{if } h_o \to \infty, \text{ (or } U_o \to \infty), \text{ then } W_c \to 1 \text{ or } W_r \to 0 \\ \text{and if} & h_o \to 0 \text{ (or } U_o \to 0), \text{ then } W_c \to 0 \text{ or } W_r \to 1 \end{array} \tag{4.2.2}$$

This suggests a relationship of the form

$$W_c = e^{-kt^{\alpha}/h_o^{\beta}} \tag{4.2.3}$$

$$\text{or} \quad W_r = 1 - W_c = 1 - e^{-kt^{\alpha}/h_o^{\beta}} \tag{4.2.4}$$

By comparing Equations 4.2.4. a d 4.2.2 we note the similiarty between our model and Silveston's model. However, Silveston has assumed that $\alpha=\beta=1$ (note: $GPS \propto \frac{h_o}{t}$).

Figure 4.2.1. Fraction of Settleable Solids Versus Depth and Time

RUN A.1

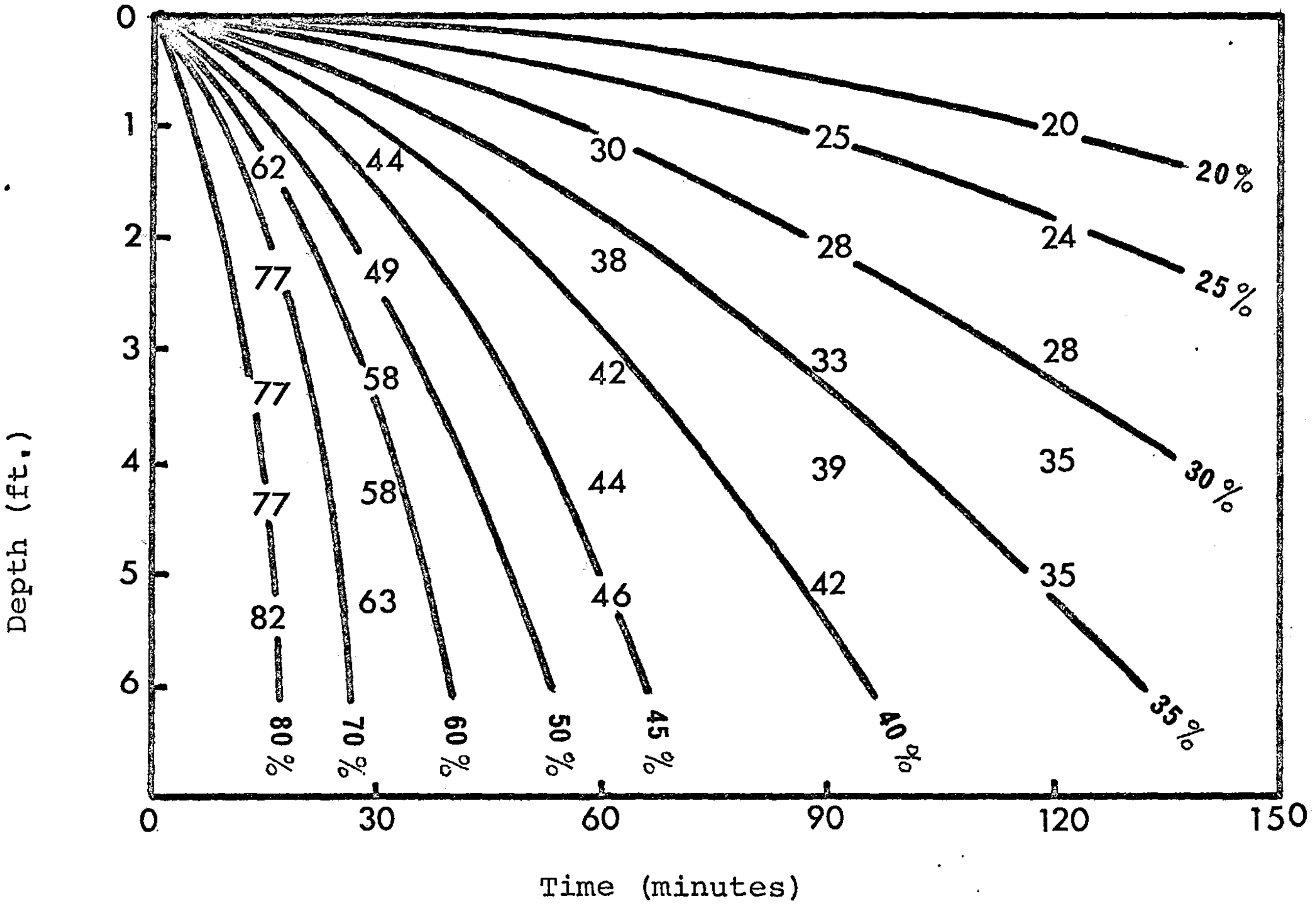


Figure 4.2.2. Fraction of Settleable Solids Versus Depth and Time

RUN A.2

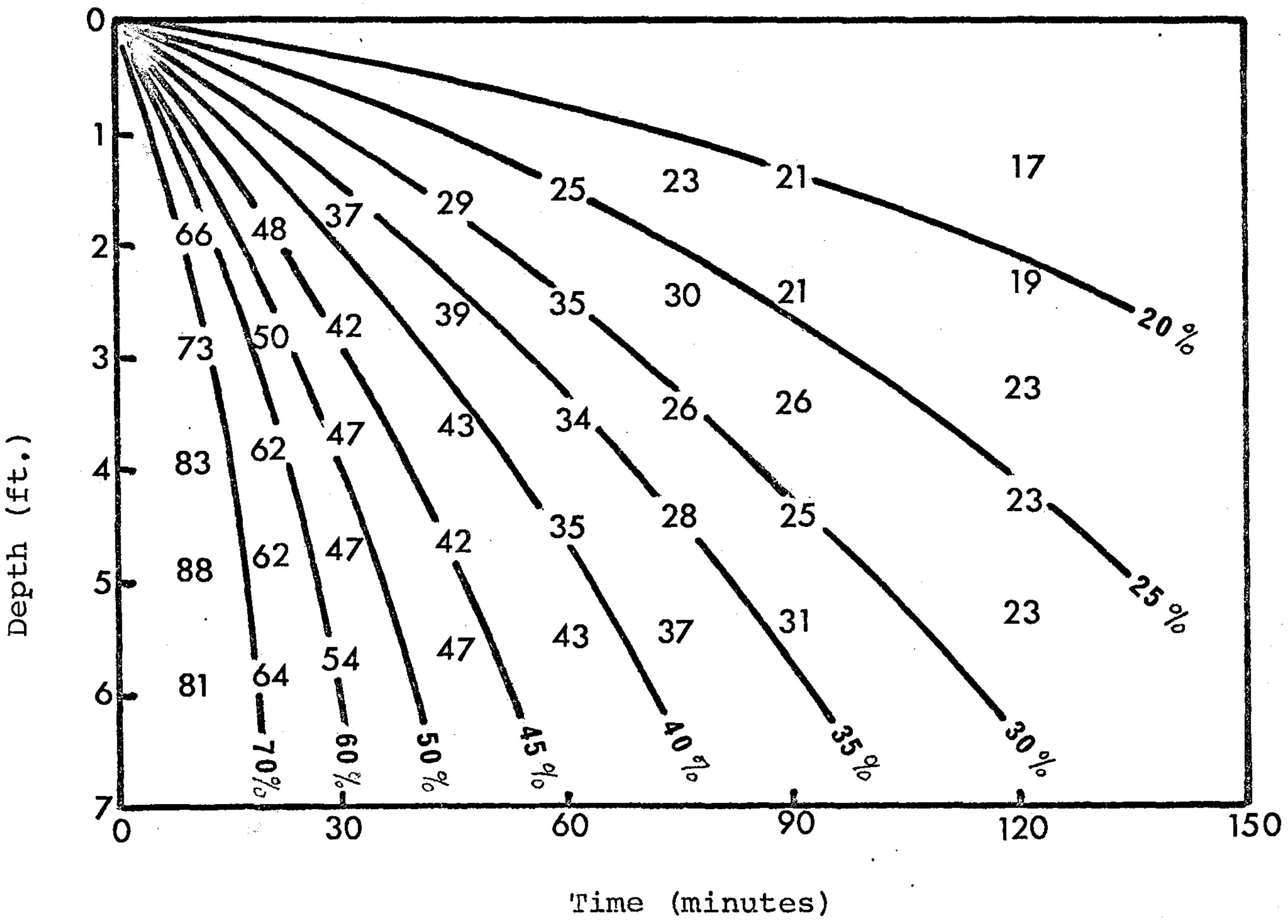


Figure 4.2.3. Fraction of Settleable Solids Versus Depth and Time

RUN A.3

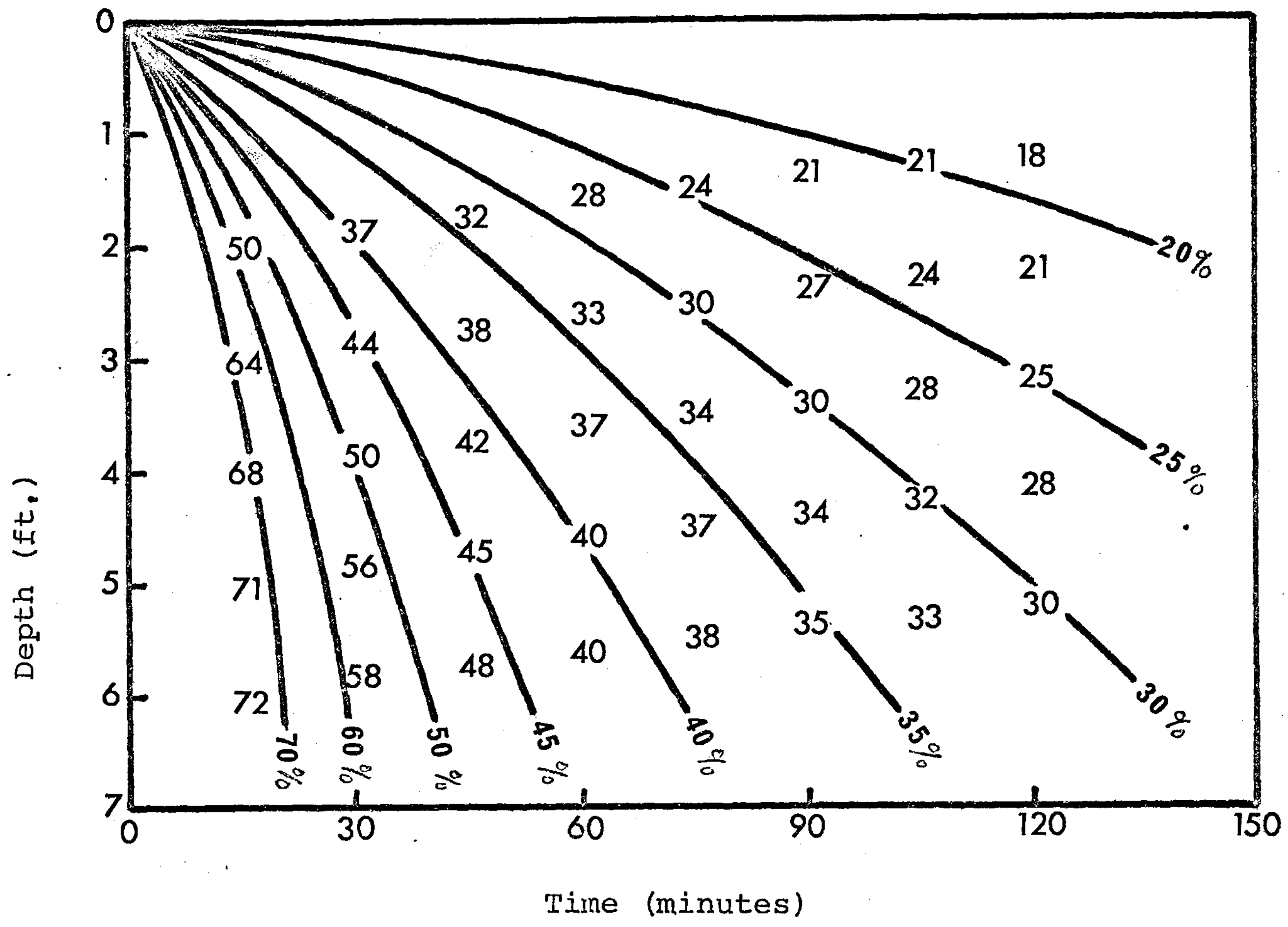


Figure 4.2.4. Fraction of Settleable Solids Versus Depth and Time

RUN A.4

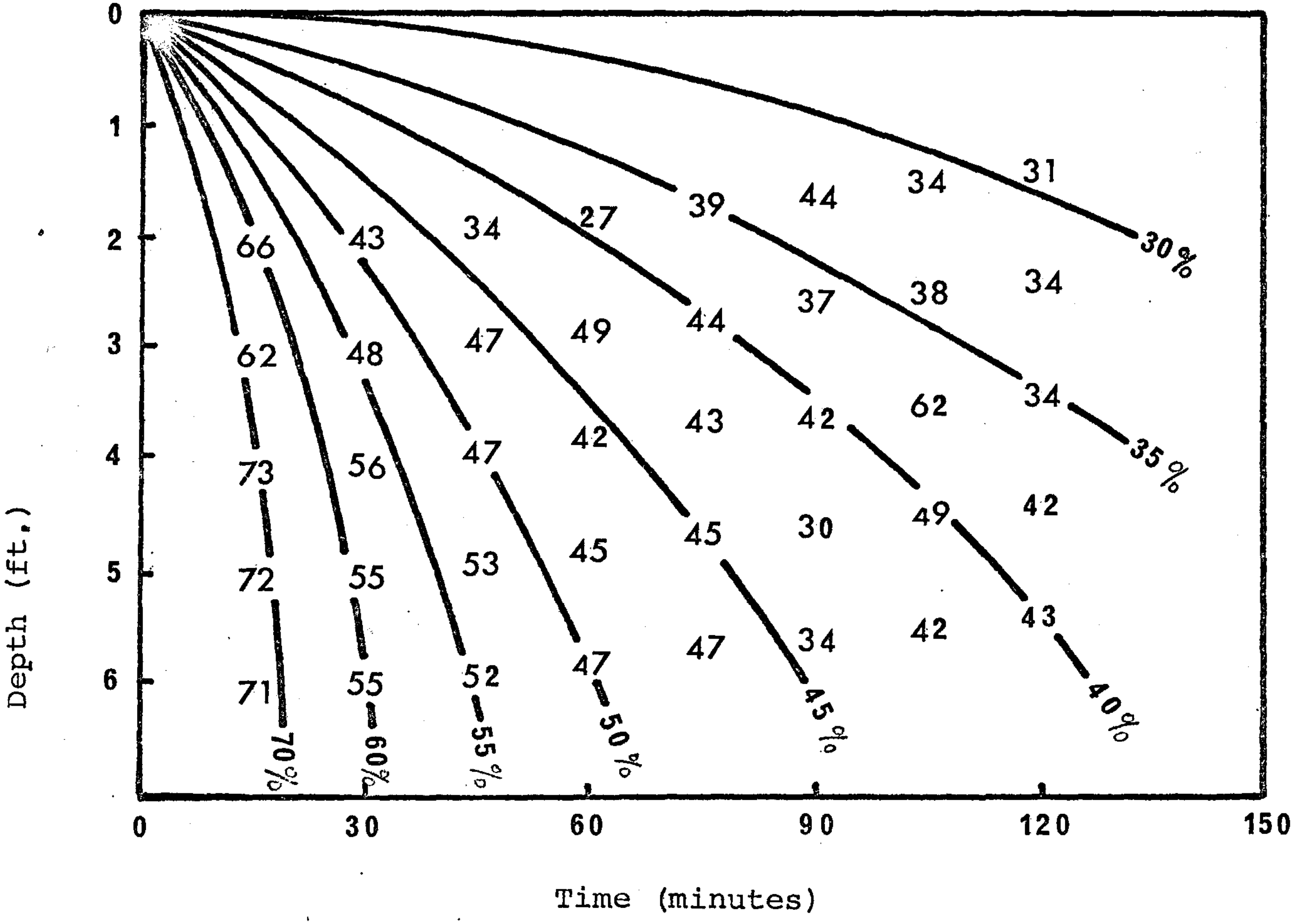


Figure 4.2.5. Comparison of Removals Obtained from Batch Settling and from Correlation

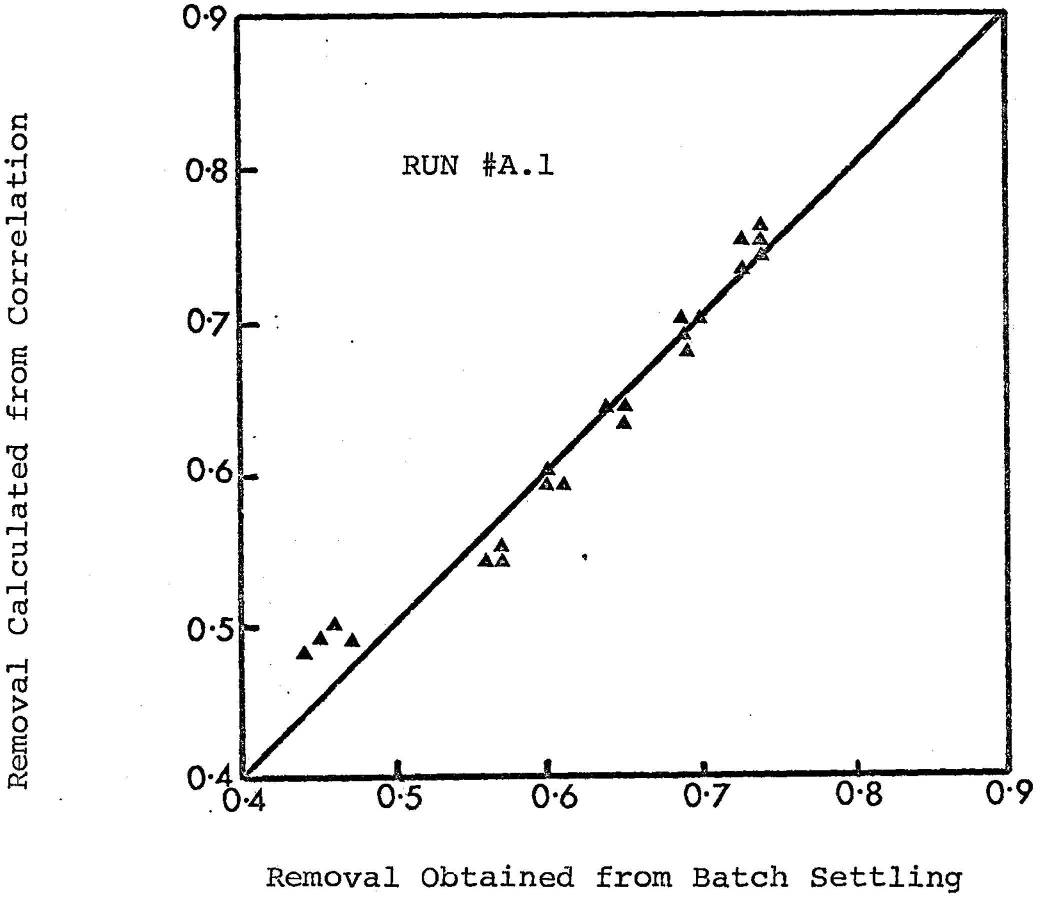


Figure 4.2.6. Comparisons of Removals Obtained from Batch Settling and from Correlation

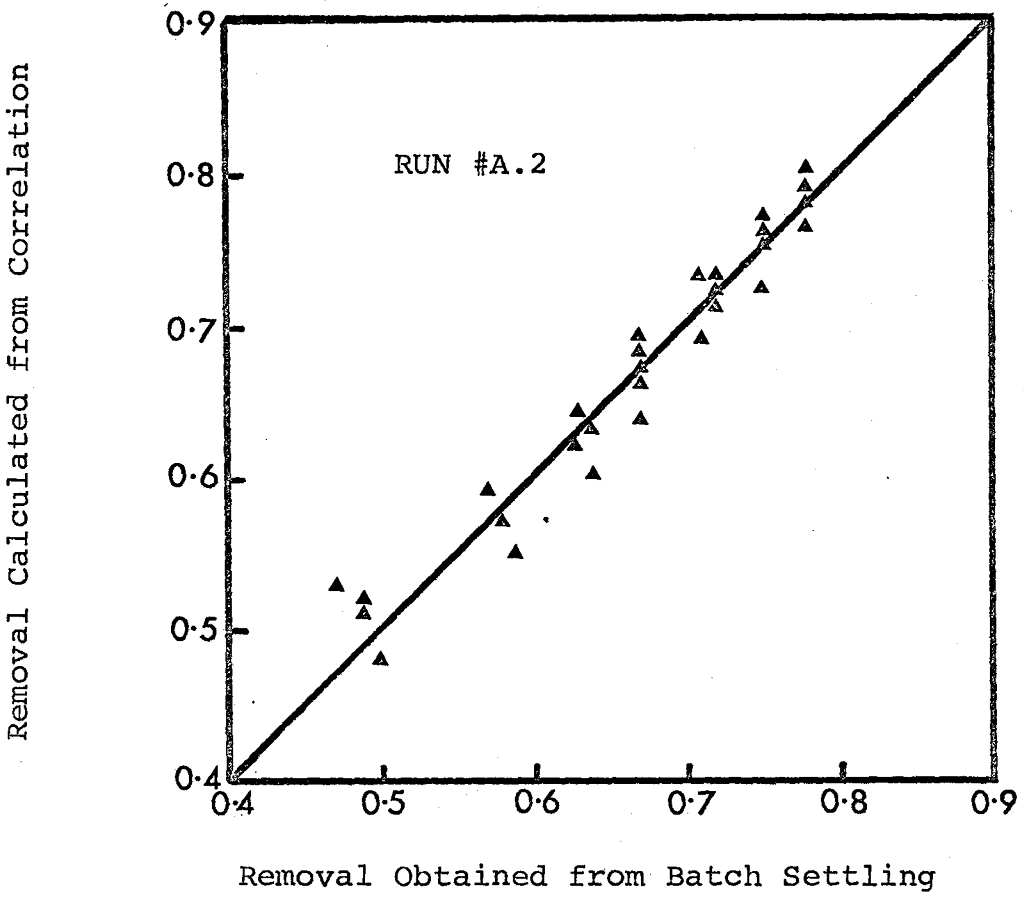


Figure 4.2.7. Comparison of Removals Obtained from Batch Settling and Correlation

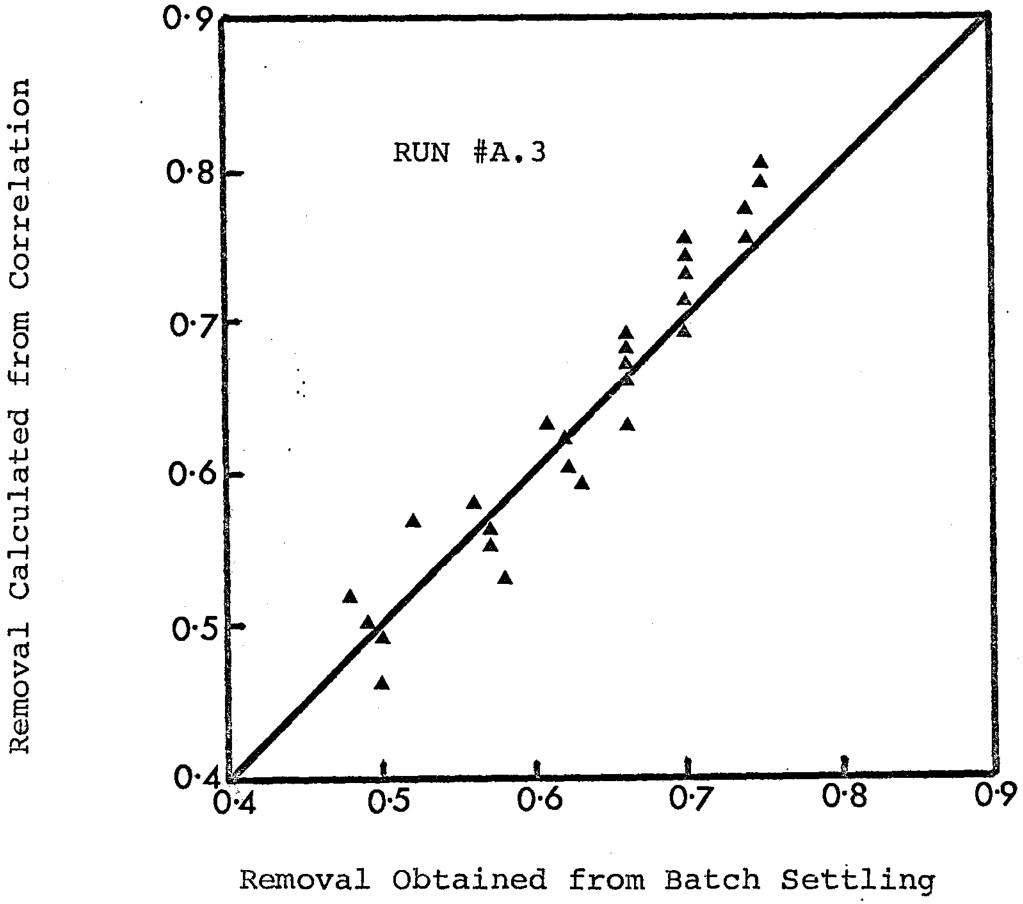
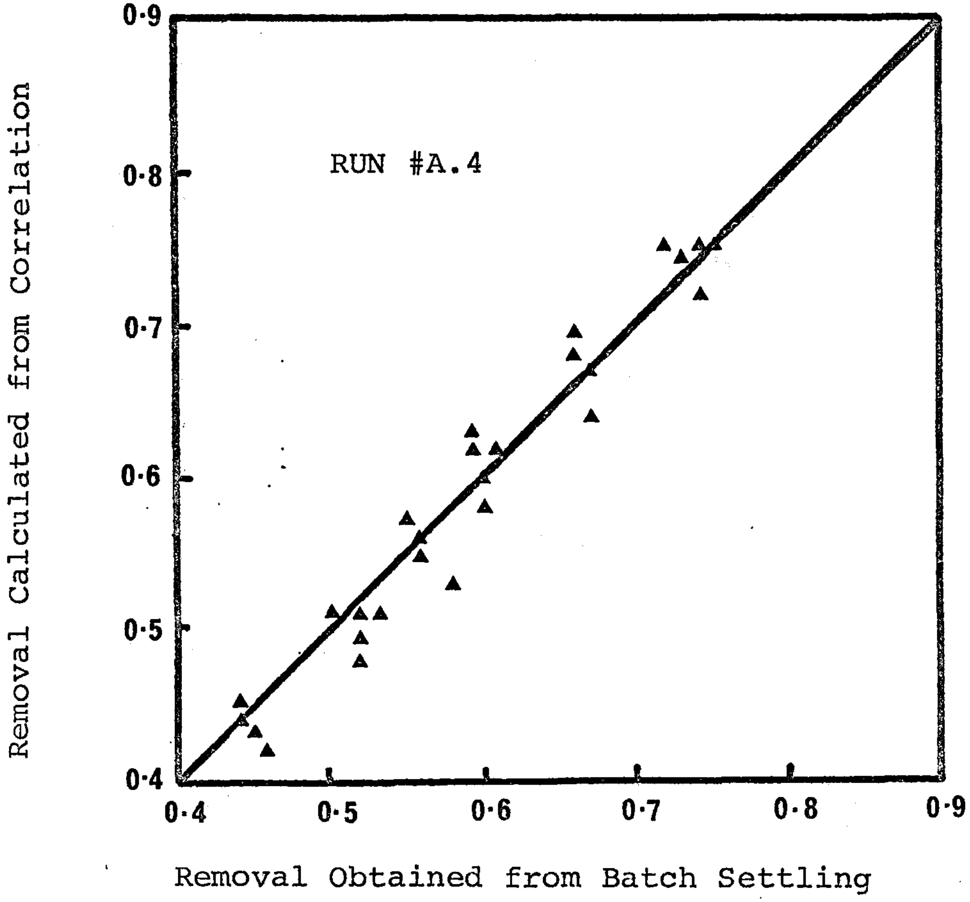


Figure 4.2.8. Comparision of Removals Obtained from Batch Settling and Correlation



A three parameter search, using a SIMPLEX routine was then used to determine k, α and β. The objective function uses a least sum of squares criterion, the sum of squares being $\sum(W_r \text{ experimental} - W_r \text{ correlation})^2$. The values of k, α and β are summarized in Table 4.2.1 and the correlated data are shown in Figures 4.2.5 to 4.2.8.

Run No.	Source of Raw Waste	k	α	β	Correlation Coefficient
A-1	Dundas	0.215	0.473	0.233	0.95
A-2	Burlington	0.239	0.515	0.252	0.94
A-3	Dundas	0.238	0.513	0.251	0.94
A-4	Dundas	0.213	0.273	0.221	0.94

TABLE 4.2.1. Parameters for Quiescent Settling Model
(Note: t is in minutes and h_o is in feet.)

The correlations obtained are good and the closeness in the values of the parameters indicate that the raw waste from the two sources are not too different. The average values of k, α and β obtained are 0.226, 0.494, and 0.239.

4.3 Deviations from Ideal "Plug Flow" Settling

Conditions in a primary settling tank are seldom of the ideal "plug flow" nature. Turbulence and short-circuiting in the flow can be caused by several factors, and their effects on sedimentation have to be accounted for.

Short-circuiting in the flow results mainly from density currents, which are bulk movements of fluids caused by density variations. Temperature differences between the feed and the water in the tank, or the presence of high suspended solids in the feed, will cause these density differences to occur.

Due to poor inlet design, the kinetic energy of the incoming flow can be quite considerable. The resulting energy dissipation can cause turbulent conditions to exist in the inlet zone. Inlet baffles, if properly designed, can reduce the kinetic energy to a large extent.

Several investigators have examined the effects of turbulence on settling. A very good summary of the various approaches used can be found in Fitz (15). Ensign Dobbins (6), starting from the Continuity Equation, made several assumptions and arrived at a simplified expression, for the case of discrete particle sedimentation

$$\frac{dC}{dt} = e \frac{d^2C}{dy^2} + U \frac{dC}{dy} \tag{4.3.1}$$

where C = concentration of solids having settling velocity U

U = settling velocity

y = depth

t = time

and e = eddy diffusivity.

Dobbins has obtained a solution for Equation 4.3.1, but it is too complex for use in a simulation model. A graphical solution of Equation 4.3.1 is available (4), and could be used in conjunction with the batch settling test as outlined in Section 4.2.

Another approach to the problem would be to obtain information on the flow patterns in the tank from a residence time distribution analysis. Fitz (15) used mixed models of combinations of stirred tanks, plug flow volumes and dead spaces to fit the residence time distributions thus obtained, to predict solids removal. His results were not too encouraging.

A dispersion model also does not appear to be promising as it rarely fits the observed exit age distributions. This is to be expected as the dispersion model assumes only relatively small deviations from plug flow with no gross short-circuiting or density currents.

In an attempt to estimate the degree of turbulence in the primary tanks of the Dundas and Drury Lane Water Pollution

Control Plants, tracer studies were carried out, using Rhodamine B dye and a Fluorometer, a Turner and Associates Model III. The experimental technique is well described by Wilson (49). The exit age distributions were followed for at least two residence times. Samples of the influent and effluent were collected during the tracer studies and analyzed for suspended solids.

Eight runs were made, four at Dundas and four at Drury Lane. Due to pump and recorder difficulties, two runs had to be discarded, one from each of the two plants. The exit age distributions are given in Appendix B. The tracer recoveries were poor and were approximately 80-85%. The calculated residence times from the exit age distributions were much lower than the actual fluid residence times. The tracer results are too unreliable for any use.

However, there seemed to be a consistent efficiency factor for each of the two plants, where the efficiency factor is defined as

$$\phi = \frac{\text{observed \% of settleable solids removed}}{\text{theoretical (batch) \% of settleable solids removed}} \qquad (4.3.2)$$

A high efficiency factor will indicate a low degree of turbulence or short-circuiting, while a low effiency factor indicates a highe level of turbulence or short-circuiting.

The theoretical or batch removal is calculated from the equation developed in Section 4.2. The efficiency factors obtained are summarized in the table below:

Plant	Plant Flow (migd)	$\bar{t}$ (mins)	$\emptyset$
Dundas	2.1	66	0.62
(two tanks in parallel)	2.3	60	0.54
	1.8	77	0.56
Drury Lane	2.2	84	0.83
(two tanks in parallel)	2.0	93	0.88
	1.6	116	0.86

TABLE 4.3.1. Efficiency Factors for the Primary Sedimentation Tanks at the Dundas and Drury Lane Treatment Plants.

The average efficiency factor for the primary settlers at Dundas is 0.57 whilst that at Drury Lane is 0.85. The high degree of turbulence in the primary settling tank at Dundas is reflected in the low efficiency factor and is quite evident visually from the effluent turbidity.

Our overall correlation for the primary settler is then described by

$$W_r = \emptyset\left\{1 - \exp\left(-k\,t^{\alpha}/H^{\beta}\right)\right\} \tag{4.3.3}$$

4.4 The Primary Settling Tank Model - PRISET1

A listing of the program is given in Appendix K. The equipment vector for the model is reproduced below.

```
C
C      EN VECTOR
C      *********
C      1.-15.  STANDARD FORMAT
C      4.      NUMBER OF TANKS IN PARALLEL
C      5.      HEAD LOSS THROUGH TANKS (FT OF WATER)
C      7.      FIRST INPUT STREAM (RAW WASTE STREAM)
C      8.      SECOND INPUT STREAM (SUPERNATE FROM THE DIGESTERS - IF ANY)
C      9.      THIRD INPUT STREAM (WASTE ACTIVATED SLUDGE - IF ANY )
C      12.     FIRST OUTPUT STREAM (EFFLUENT)
C      13.     SECOND OUTPUT STREAM (UNDERFLOW)
C      14.     THIRD OUTPUT STREAM (SCUM TROUGH FLOW)
C      16.     LENGTH OF TANK (FEET)
C              = 0.0 IF TANK IS CIRCULAR
C      17.     WIDTH OF TANK (FEET)
C              = RADIUS OF TANK IF CIRCULAR (FEET)
C      18.     DEPTH OF TANK (FEET)
C      19.     NOT CURRENTLY USED
C      20.     SOLIDS CONCENTRATION OF SCUM FLOW (MG/L)
C      21.     EFFICIENCY FACTOR FOR TANKS
C      22.     FRACTION OF FLOCCULATED SOLIDS FROM WASTE ACTIVATED
C              SLUDGE AND DIGESTER SUPERNATE THAT IS RESUSPENDED
C      23.     NUMBER OF UNDERFLOW SLUDGE PUMPS
C      24.     CAPACITY OF PUMPS IGPH EACH
C      25.     FRACTION OF CAPACITY AT WHICH PUMPS ARE RUN
C
C
```

The computations carried out by the program can be explained in the following steps:

(1) The pH of the output streams is initially calculated.

(2) Input streams 2 and 3 are sludge streams carrying solids which have much higher settling velocities than the solids in the raw waste. Hence, the removal of the sludge solids is essentially complete. EN(22) provides

for the small fraction of the sludge solids which do escape over the wiers due to short-circuiting or turbulence.

(3) The removal of the solids in the raw waste is calculated from Equation 4.3.3.

(4) The underflow is calculated from pump capacities. The concentration of the underflow solids is then calculated, for which a maximum value of 6% is assumed. If the pump capacity is insufficient, excess solids over 6% is carried over to the effluent.

(5) The scum flow is then calculated, assuming 90% removal of scum solids. The solids concentration of the scum flow is specified by EN(20).

(6) Soluble components are then split according to the split in water flow among the three output streams.

CHAPTER 5

5. AEROBIC BIOLOGICAL SLUDGE PROCESSES

The theory here represents an attempt to model all aerobic biological sludge processes in one general package. Currently, all the various modifications of the activated sludge process, such as extended aeration, step aeration, contact stabilization and aerobic digestion, have been considered as separate processes. However, a bacterial cell does not know what hydraulic regime it is in, nor does it know what process it is supposed to work under. The kinetics describing the activity of the bacteria should be similar in all cases. The differences in rates observed with the various processes can only be due to differences in composition of the activated sludge mass.

5.1 The Bacteria and its Activities

The morphology of the bacteria is well described in any standard textbook on microbiology. A very brief description will be given here, while the physiological functions of the bacteria and their corresponding kinetic expressions will be described in more detail.

Bacterial cells are small and have sizes of the order of one micron. The cell shape may be spherical (coccus), rod-like (bacillus), or spirally-shaped (spirillum), and is defined to a large part by a relatively tough outer cell wall.

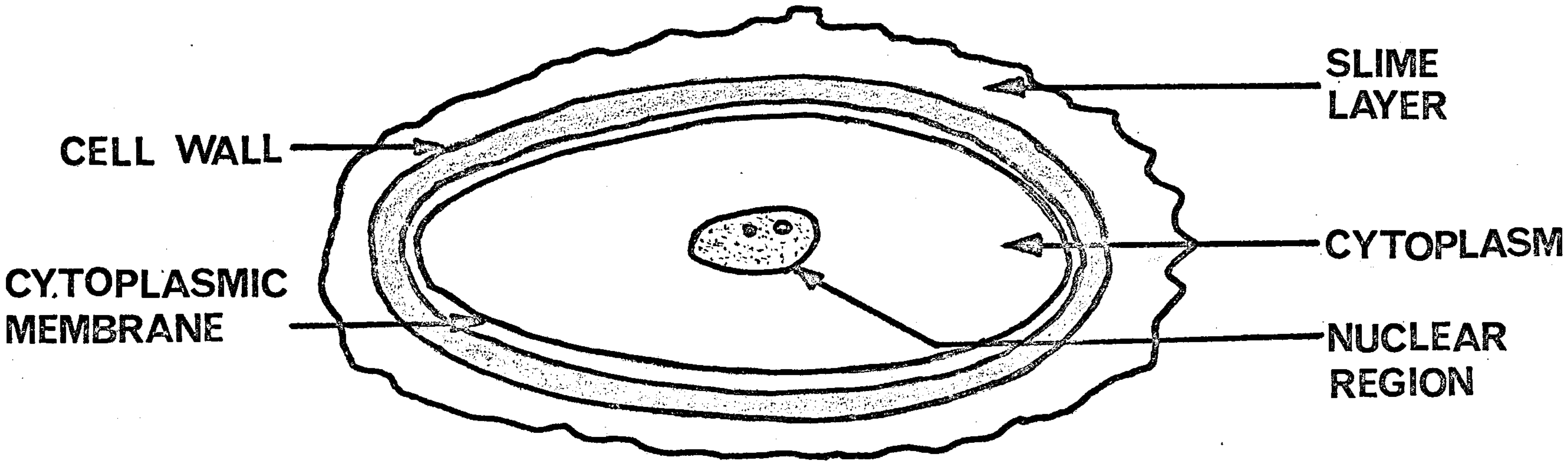


Figure 5.1.1. A Schematic Representation of Bacteria (a Procaryotic Cell)

Inside the cell wall is a semi-permeable cytoplasmic membrane, which is responsible for a selective transfer of nutrients and waste products into and out of the cell. The region within the cytoplasmic membrane includes the cytoplasm and the nuclear region. The cytoplasm is characterized by a relatively high concentration of ribonucleic acid (RNA), which is associated with protein synthesis. The nuclear region contains a high concentration of deoxyribonucleic acid (DNA). The genetic code is stored in the DNA. Some bacteria secrete slimy materials on their surfaces, creating a slimy layer outside the cell wall. A rough sketch of a bacterial cell is shown in Figure 5.1.1.

The activitiy of the bacteria will be described in the following four sections.

(a) <u>Metabolism</u>:

Bacterial cells, like all living cells are capable of feeding and growing. Soluble organic matter (substrate) diffuses into the bacterial cell where they are metabolized and converted partly into new cell matter. The remainder of the organic substrate is respired to provide energy for the cell. The respiration products are mainly carbon-dioxide and water.

Schematically, this may be represented as:

$$\begin{array}{c}\text{soluble degradable}\\\text{organics}\end{array} + \text{microorganisms} + O_2 \longrightarrow \left[\begin{array}{l}\rightarrow \text{New cell matter}\\ \\ \rightarrow \text{Respiration products}\end{array}\right.$$

The yield factor, Y, is defined as the fraction of soluble carbon metabolized which goes into new cell growth. The fraction (1-Y) which is respired will require an equivalent amount of oxygen.

The rate of soluble carbon degradation can be written as

$$\text{rate} = \frac{dC}{dt} = - UM \tag{5.1.1}$$

where C = concentration of soluble degradable carbon

U = f(c) = unit growth rate

and M = concentration of microorganisms (as equivalent carbon)

For the case of a single substrate and a pure culture, the functional dependence of u is described by Michaelis-Menton kinetics as

$$U = \frac{U_{max} \ C}{C^* + C} \tag{5.1.2}$$

where U_{max} = maximum growth rate

and C^* = constant = value of C at which $U = \frac{1}{2}U_{max}$

However, in waste treatment, mixed substrates are generally encountered. Pure cultures are also difficult to maintain and is often less efficient than mixed cultures. Consequently, there is no need to restrict the description of U by Michaelis-Menton kinetics. The measurements of

U and Y as described in Section 5.2 show that a linear correlation

$$U = k_4C \tag{5.1.3}$$

is a better fit. It should also be noted that the Michaelis-Menton equation becomes linear when $C << C^*$.

(b) Endogenous Respiration

Bacterial cells can also utilize stored food products (bacterial fat) to provide energy for its various physiological activities, especially in perids of low external food supplies. This is known as endogenous respiration or sometimes as basal metabolism.

Schematically, this may be represented as

$$\text{stored "bacterial fat"} + O_2 \longrightarrow \text{Respiration products} \tag{5.1.4}$$

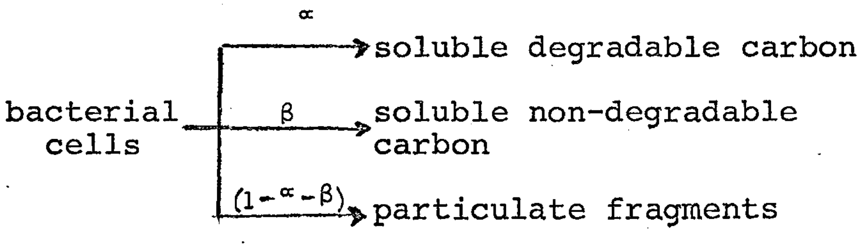
The rate of endogenous respiration should be proportional to the number of bacterial cells present, or is first order with respect to the bacterial concentration, namely,

$$\text{rate} = \frac{dM}{dt} = -k_1M \tag{5.1.5}$$

where k_1 = endogenous respiration rate constant.

(c) Death and Cell Lysis

In cell lysis, the inner protoplasm of the cell is released to the surroundings through a breach in the cell wall. Part of the protoplasm is available as food for other microorganisms, while the remainder consists of relatively non-biodegradable high molecular weight matter, schematically, this may be shown as



(5.1.6)

α is the fraction of soluble degradable carbon, and β is the fraction of soluble non-degradable carbon released during cell lysis. The remaining fraction $(1-^{\alpha}-^{\beta})$ is particulate matter consisting of cell walls, slime layers, various membranes and so on, with varying degrees of biodegradability.

This process explains the build-up of soluble non-degradable carbon during the prolonged aeration of activated sludge.

The rate of death and subsequent cell lysis should also be proportional to the number of bacterial cells present:

$$\text{rate} = \frac{dM}{dt} = -k_2M \qquad (5.1.7)$$

where k_2 = lysis rate constant.

(d) Solubilization of Particulate Organics

In general, solid organic matters have to be solubilized before they can be utilized by the bacteria. This process is speeded up by the secretion of exo-enzymes by the bacterial cells. The solubilized organic matter then diffuses back into the bacterial cell as substrate.

The rate of solubilization should be proportional to the concentration of the organic solids. It should also be proportional to the rate of release of exo-enzymes or equivalently, to the number of bacterial cells present:

$$\text{rate} = \frac{dP}{dt} = - k_3PM \qquad (5.1.8)$$

where P = solid organics concentration (as equivalent carbon),

and k_3 = solubilization rate constant.

The four reactions proposed above involves principally five components, namely the microorganisms (M), the particulate organics other than microorganisms (P), soluble degradable organic carbon (SDOC), soluble non-degradable organic carbon (SNDOC) and carbon dioxide. However, carbon dioxide is partially purged from the system by the air and hence is difficult to monitor. But, it can always be obtained from a mass balance on carbon.

The total soluble organic carbon, SDOC+SNDOC, can be determined by means of the carbon analyzer. The soluble degradable organic carbon can be obtained from the Biochemical Oxygen Demand of the filtrate, using the relationship

$$\text{SDOC} = \text{BOD (filtrate)}/1.9 \qquad (5.1.9)$$

This is discussed in Section 9.1. The SNDOC is then obtained by difference.

The total concentration of microorganisms and particulate solids, M + P, can be obtained from the volatile suspended solids using the relationship (see also Section (9.1)

$$M + P = VSS/2.1 \tag{5.1.10}$$

The concentration of microorganisms alone can be indirectly measured from its oxygen uptake rate. In addition to the oxygen required for the carbon respired, oxygen is also consumed in the nitrification of ammonia-nitrogen associated with the sludge. A chemical analysis of activated sludge reports an average composition of $C_5H_7O_2N$ (54). The oxidation reaction can then be written as:

$$C_5H_7O_2N + 7O_2 \longrightarrow 5CO_2 + 3H_2O + HNO_3 \tag{5.1.11}$$

Hence each gram of carbon lost through respiration requires 3.73 grams of oxygen or

$$\text{OUR} = 3.73 \left[k_1 + (1-Y)U\right]M \tag{5.1.12}$$

therefore,

$$M = \frac{\text{OUR}}{3.73 \left[k_1 + (1-Y)U\right]}$$

Hence, our aerobic biological system involves four simultaneous, kinetically independent reactions, five components and seven constants. The constants involved are k_1, k_2, k_3, k_4, Y, α and β.

5.2 Chemostat Experiments

The purpose of this series of experiments is to evaluate the functional dependence of the unit growth rate on the soluble degradable carbon concentration. A chemostat is essentially a biological reactor that acts as a continuous-flow, completely stirred tank reactor. The defining equations are easily derived from a mass balance around the reactor

In Figure 5.2.1, Q is the flow rate through the reactor and V the volume of the reactor. The concentration of soluble degradable organic carbon in the feed is C_o and that in the effluent is C. The concentration of micro-organisms in the feed is assumed to be zero while that in the vessel or effluent is M (as equivalent carbon).

Performing a mass balance on the soluble carbon, we have at steady-state,

$$0 = V\frac{dC}{dt} = Q\,(C_o - C) - UMV \qquad (5.2.1)$$

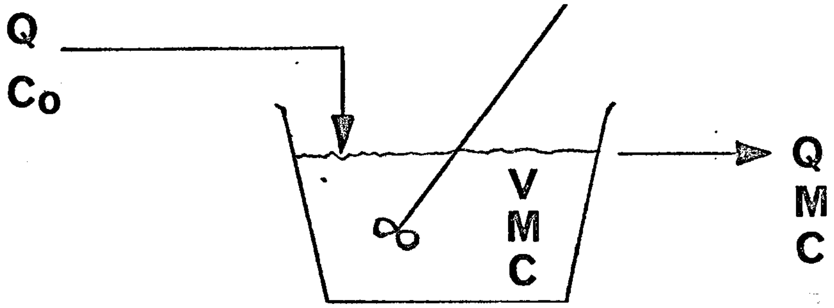


FIGURE 5.2.1. A Schematic Representation of a Chemostat, and Operating Variables.

where U = unit growth rate (see Section 5.1)

$$\text{Hence} \quad U = f(c) = \frac{(C_o - C)}{M\bar{t}} \qquad (5.2.2)$$

where $\bar{t} = V/Q =$ residence time.

Also from definition, the yield factor

$$= Y = M/(C_o - C) \qquad (5.2.3)$$

In our experiments, settled raw sewage was filtered through a two-inch thick layer of glass wool and used as the feed. This was stored in a constant head bottle and allowed to drip into an aerated 6 litre vessel (see Figure 5.2.2). Seeding was accomplished by the addition of about 100 ml of activated sludge to the reaction vessel. After two detention times, the effluent was sampled and analyzed regularly, until a steady-state was reached.

The results from seven runs are summarized in Appendix C. The average value of the yield factor Y obtained is 0.57 with a standard deviation of 0.04. the functional dependence of U is found to be linear with respect to the soluble degradable carbon concentration, in the range studies (25 - 50 mg/l). This is plotted in Figure 5.2.3. The correlation obtained is

$$U = 0.0010\ C = k_4 C \qquad (5.2.4)$$

with a correlation coefficient of 0.85.

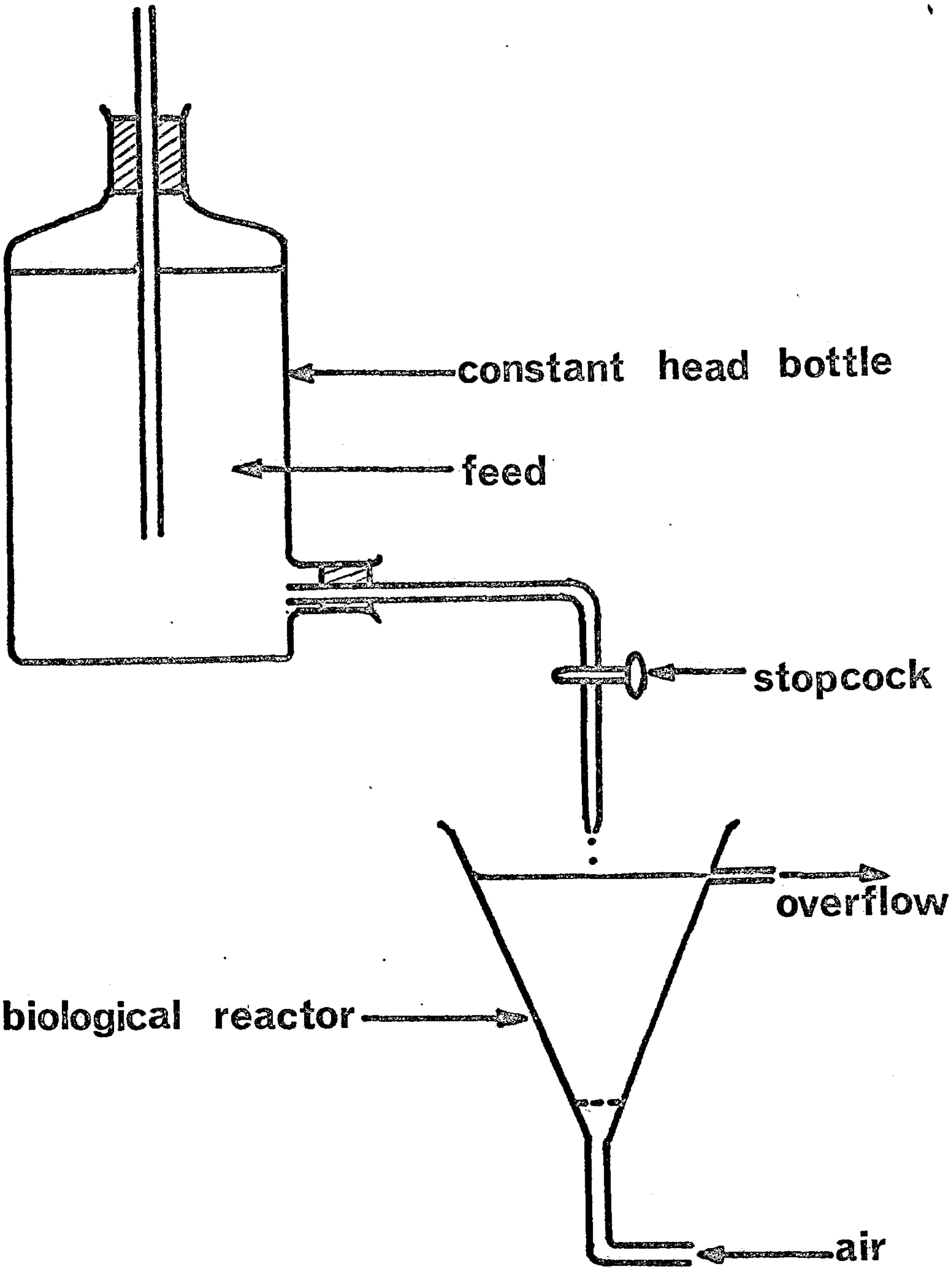
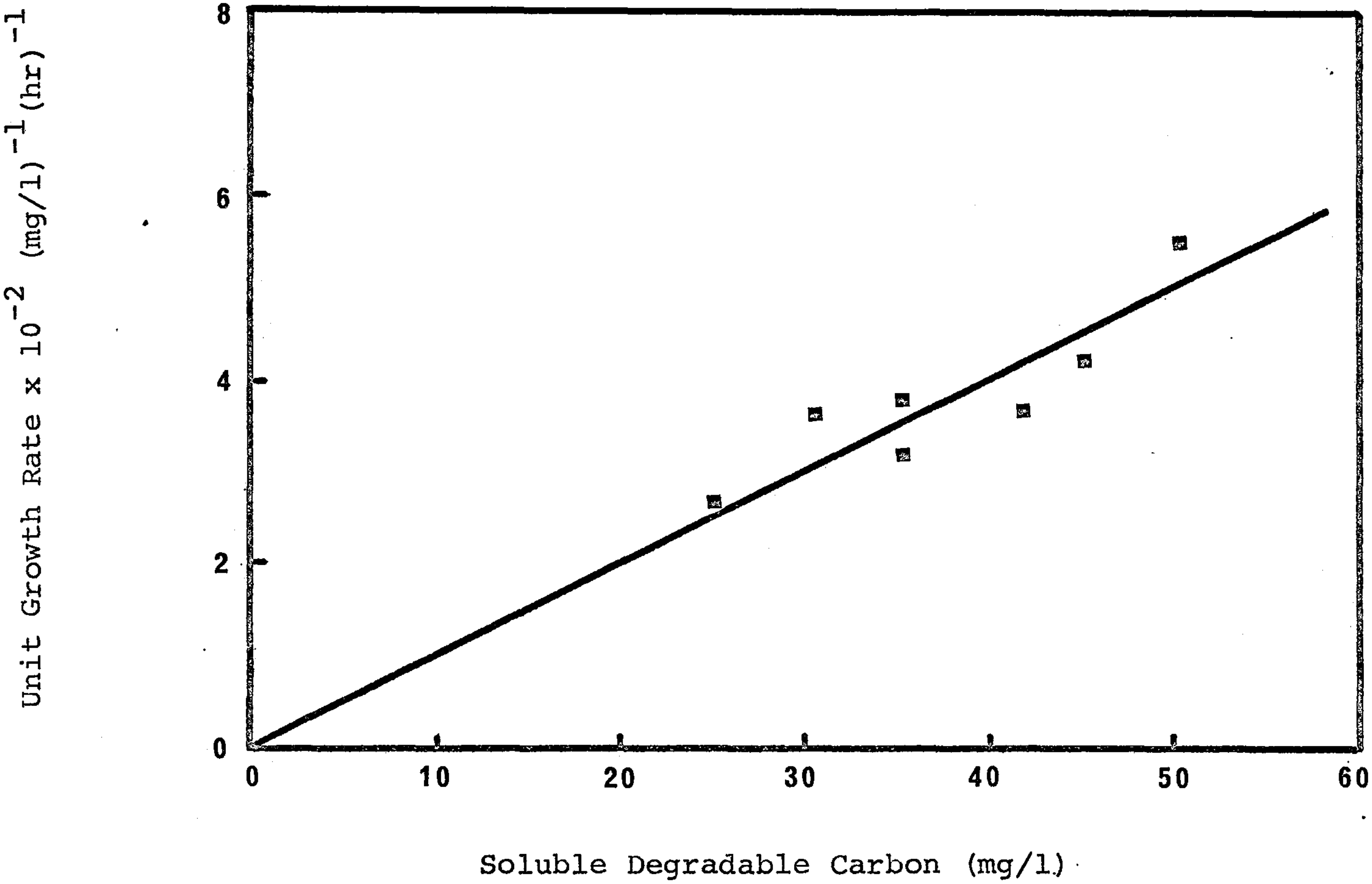


Figure 5.2.2. Experimental Set-Up for the Chemostat

Figure 5.2.3. Unit Growth Rate as a Function of Soluble Degradable Carbon Concentration



We have assumed that the solids in the feed is not significantly solublized in the reactor.

To compare the results obtained we have to convert Equation 5.1.2 to traditional units:

We have $$\frac{dC}{dt} = \frac{d\ BOD_5}{dt} \times \frac{1}{1.9}$$

It is estimated that microorganisms account for approximately 30% of the Mixed Liquor Suspended solids.

Hence $M \times 2.1 = 0.3\ (MLSS)$

Therefore, Equation 5.1.2 becomes

$$\frac{1}{1.9} \times \frac{dBOD_5}{dt} = -k_4 \times \frac{BOD_5}{1.9} \times \frac{0.3}{2.1}\ (MLSS)$$

or $$\frac{dBOD_5}{dt} = -k_4 \frac{0.3}{2.1}\ (BOD_5)(MLSS)$$

$$= -K_s''\ (BOD_5)(MLSS) \qquad (5.2.5)$$

or $$K_s = k_4 \frac{0.3}{2.1}$$

$$= 0.00014\ (hr)^{-1}\ (mg/l)^{-1}$$

Eckenfelder (2) reports a value of

$$K_s = 0.00010 - 0.00013\ (hr)^{-1}\ (mg/l)^{-1}$$

Keshavan et al (22) reports a value of

$$K_s = 0.00016\ (hr)^{-1}\ (mg/l)^{-1}$$

Hence, our results are approximately in agreement with the literature values.

5.3 Aeration Studies of Activated Sludge

As some of the rate proposed in Section 5.1 are expected to be slow, batch studies of aerated activated sludge have to be carried out over an extended period. Return activated sludge is a convenient "reaction mixture" to use, as it contains all the components in our reaction set.

Return activated sludge from the Drury Lane plant was used, and the aeration was carried out in a 6-litre vessel, for twenty five days. Samples were taken periodically, and the following analyses performed:

(1) Biochemical Oxygen Demand of filtrate,
(2) Dissolved Organic Carbon,
(3) Suspended Solids, and
(4) Oxygen Uptake rate.

Inorganic solids were determined both initially and at the end.

Two runs were made with different samples of return activated sludge from the Skyway Plant, Burlington. The results obtained are tabulated in Appendix D. The plots of (P + M), OUR, SDOC and SNDOC versus time are shown in Figures 5.3.1 - 5.3.6. The volatile suspended solids and the oxygen uptake rate were observed to drop with length of aeration. The soluble degradable organic carbon dropped slightly and then remained fairly constant. There was a marked increase in soluble non-degradable organic carbon with aeration in both cases.

To obtain an estimate of the variances in the measurements, a third run was started and allowed to run for a week. Then five samples were withdrawn simultaneously from the reaction vessel and analyzed immediately. The results are also tabulated in Appendix D, together with the variance-covariance matrix and its inverse matrix.

Before the parameter search was performed, an eight constant Q_o was introduced and it is defined as the ratio of the initial concentration of microorganisms, M_o, to that of the total volatile solids, namely,

$$Q_o = \frac{M_o}{(P + M)_o} \tag{5.3.1}$$

where the subscript $_o$ refers to initial values. Otherwise, we have to calculate M_o from the intial value of the oxygen uptake rate, and as M_o is a critical value, an error in the oxygen uptake rate can have a marked effect on the search.

A fourth order Runge Kutta was used to calculate the values of the four components, P, M SNDOC, and SDOC. The

Figure 5.3.1. Volatile Suspended Solids as a Function of Aeration Time

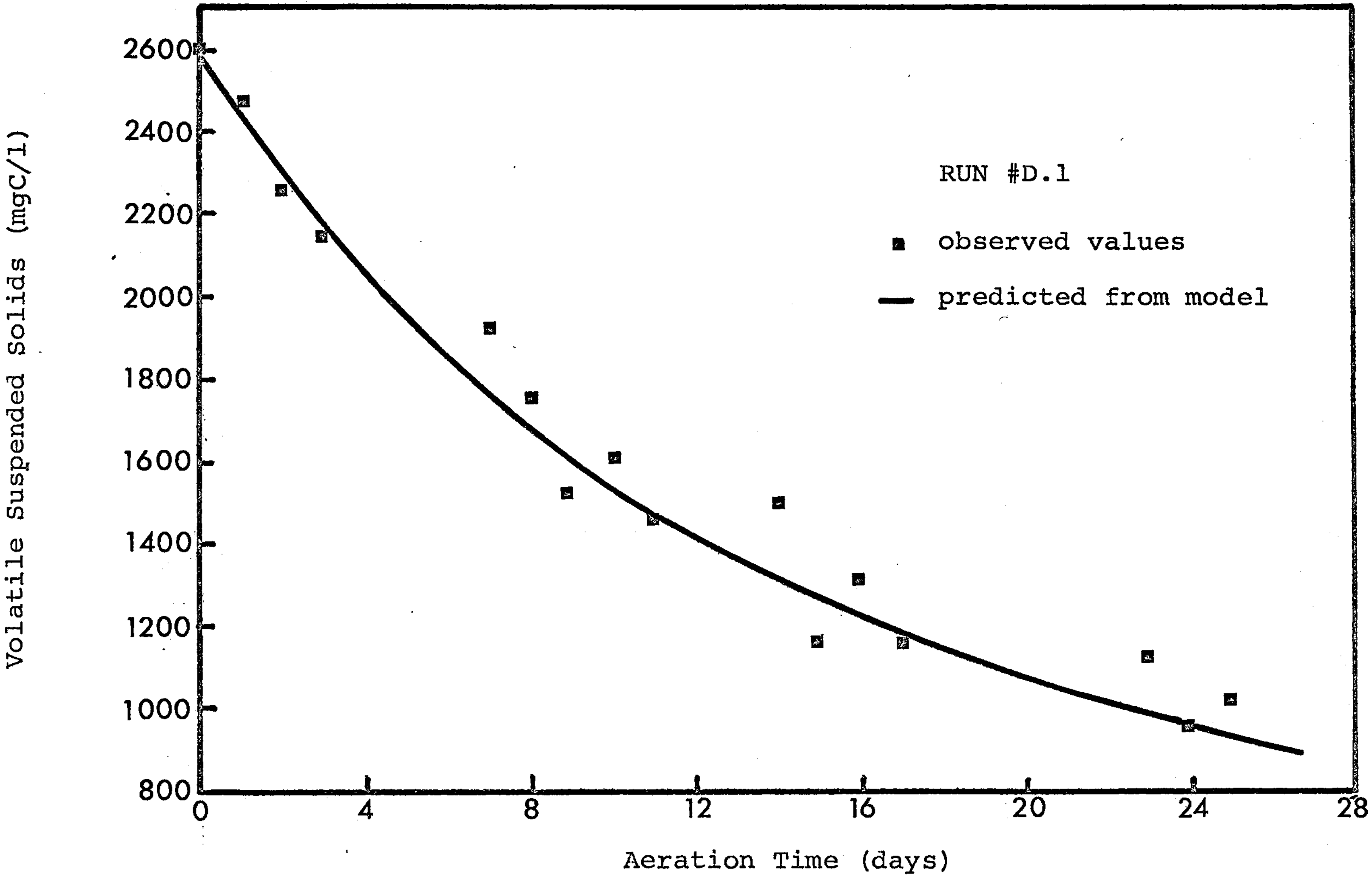


Figure 5.3.2. Oxygen Uptake Rate as a Function of Aeration Time

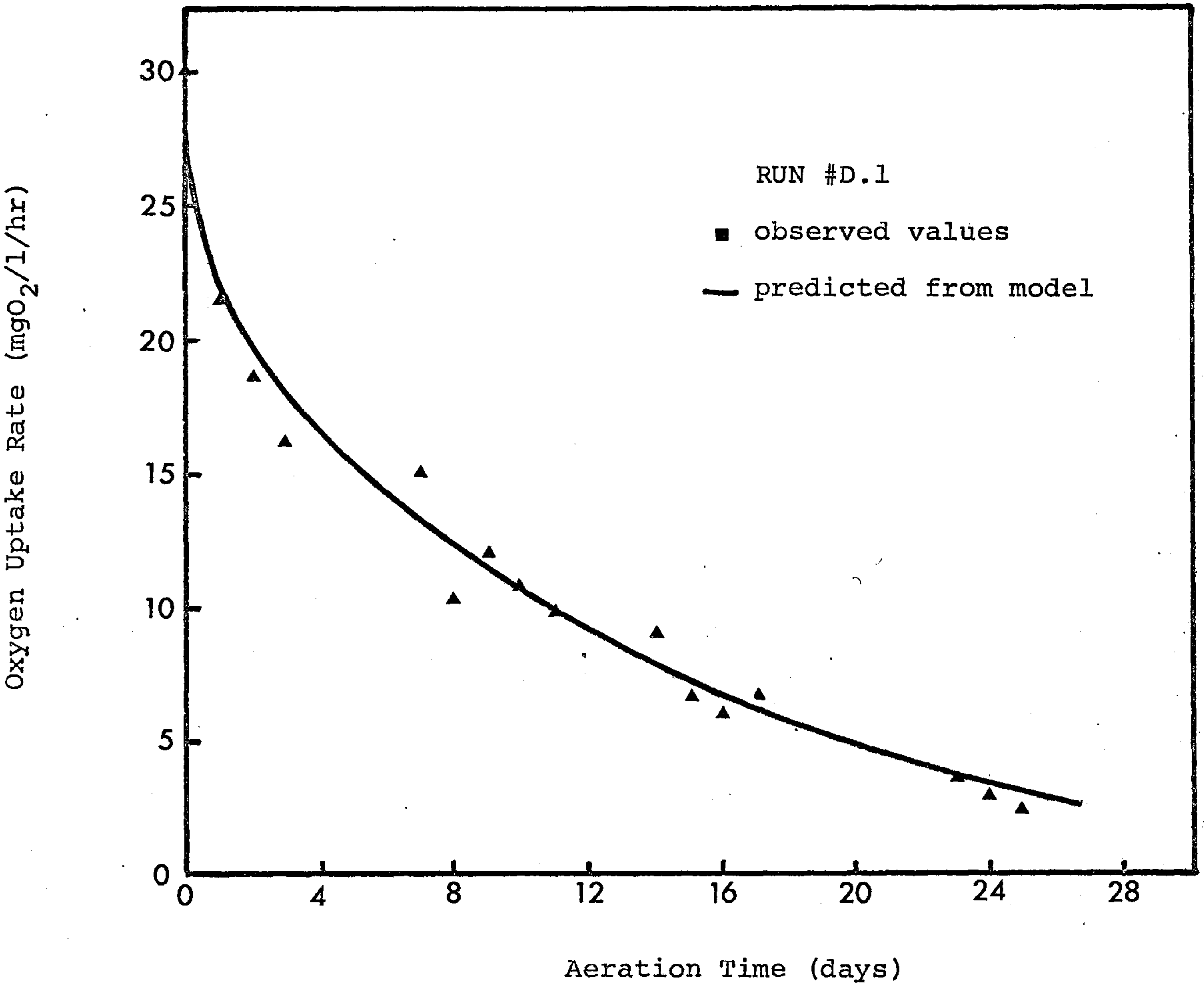


Figure 5.3.3. SNDOC and SDOC versus Aeration Time

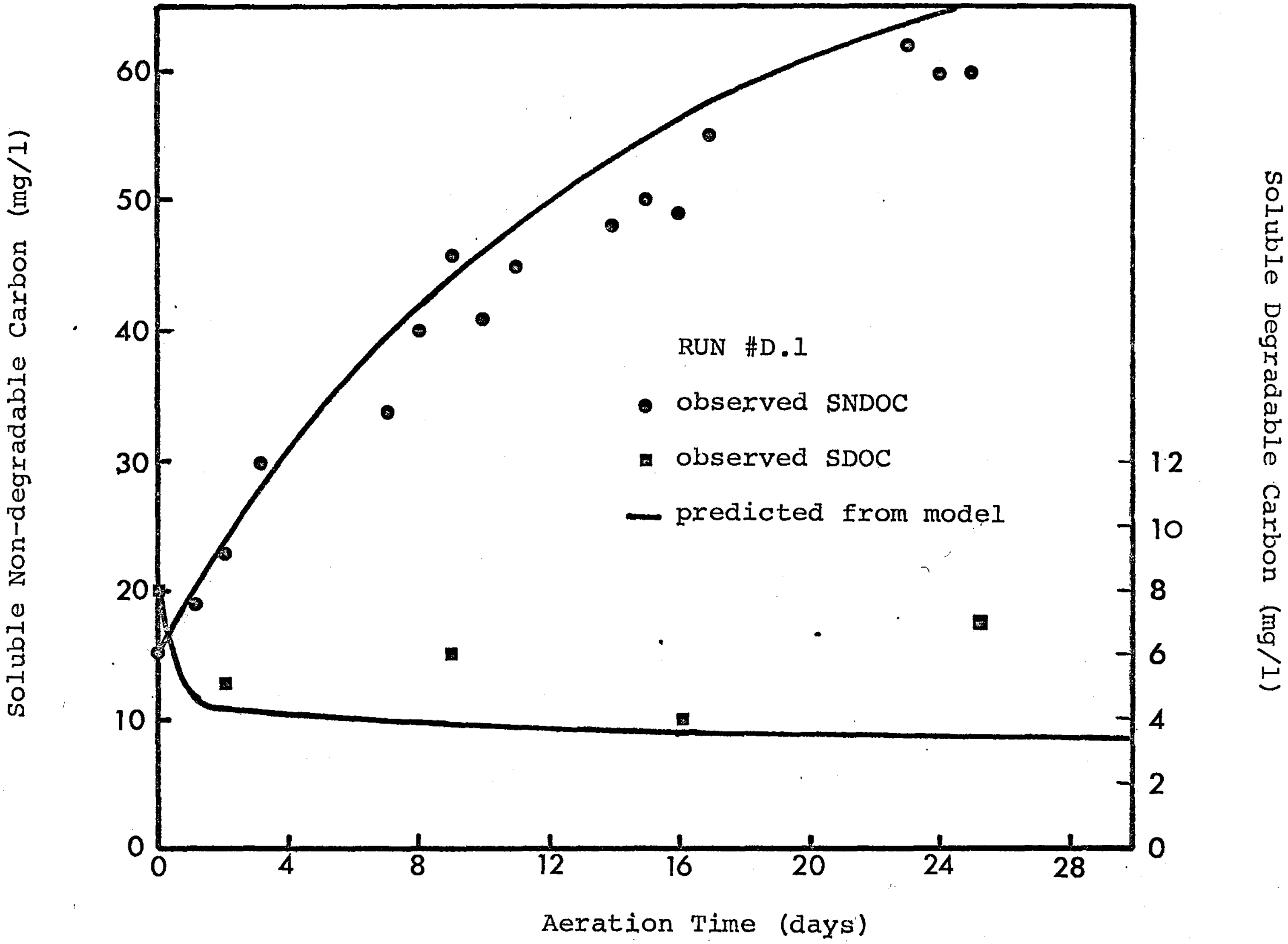


Figure 5.3.4. Volatile Suspended Solids as a Function of Aeration Time

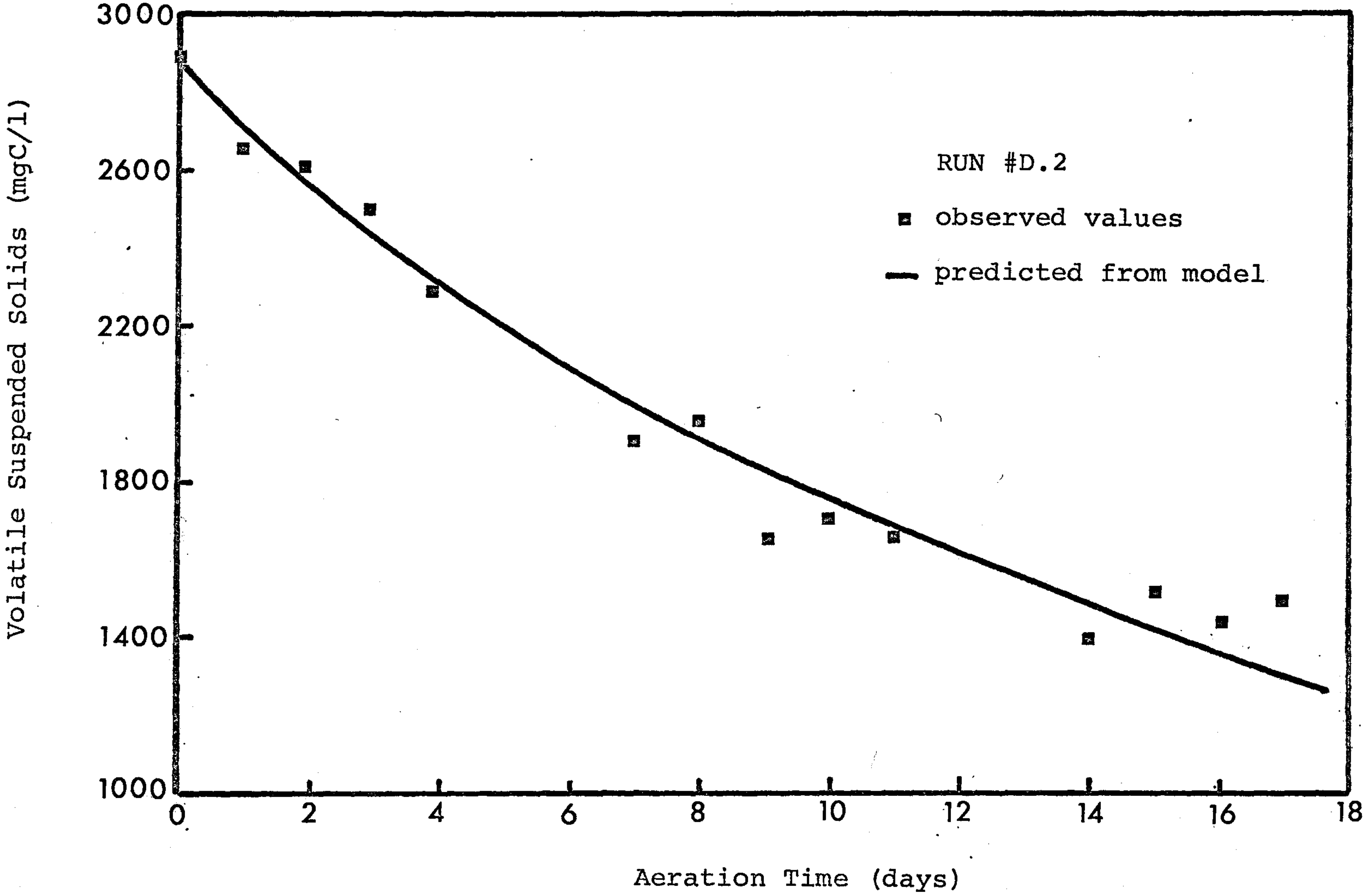


Figure 5.3.5. Oxygen Uptake Rate as a Function of Aeration Time

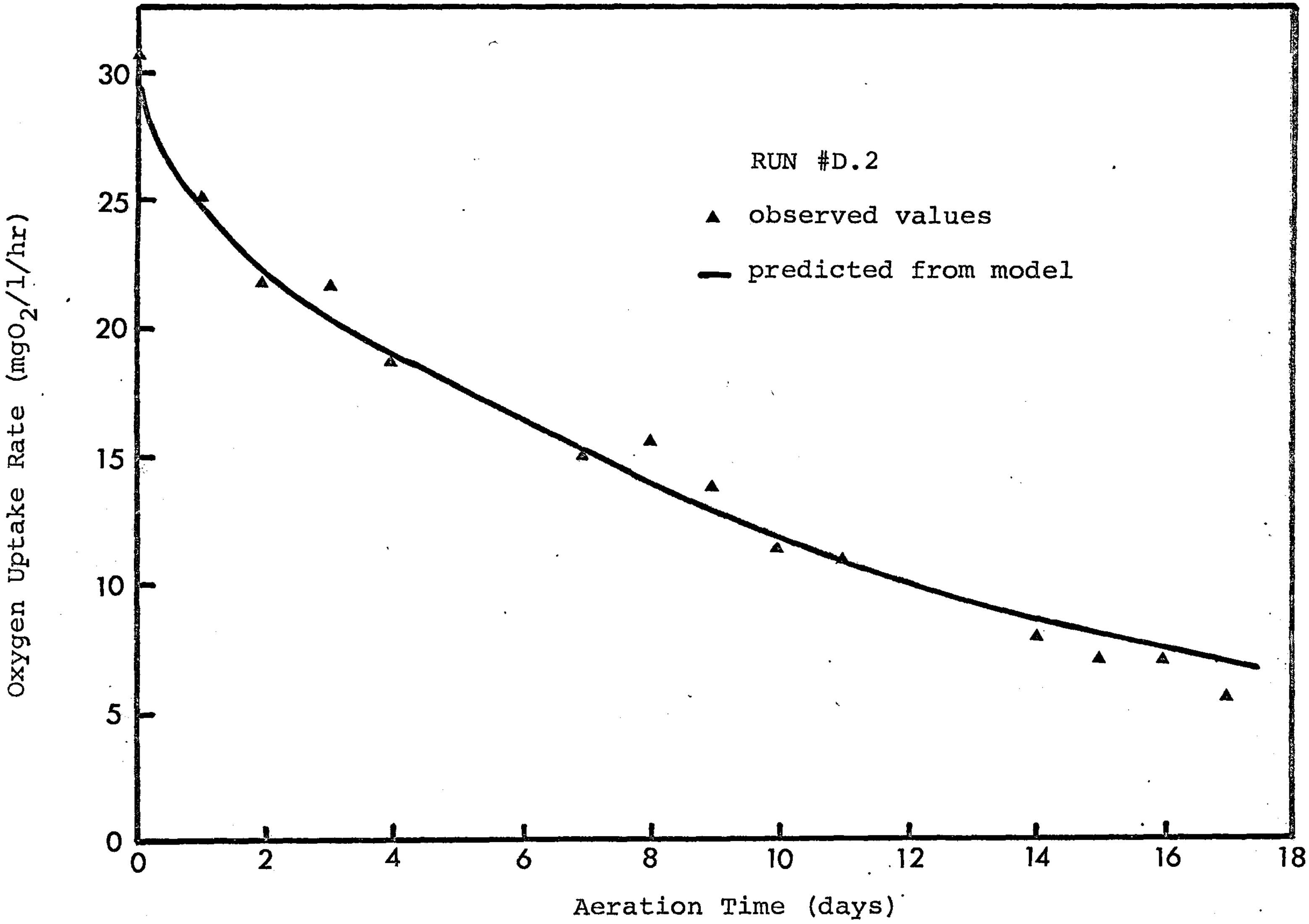
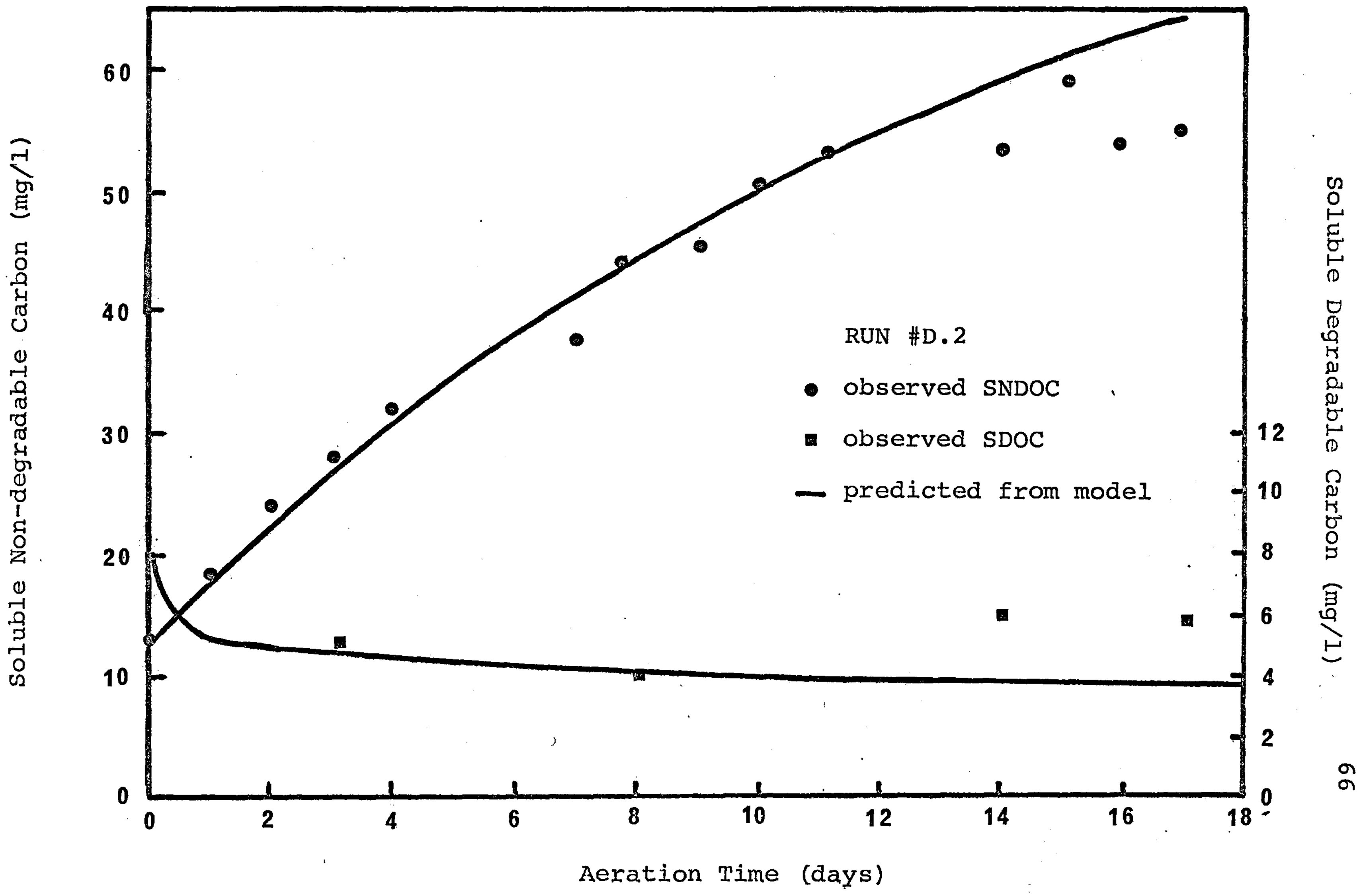


Figure 5.3.6. SNDOC and SDOC Versus Aeration Time



set of differential equations used were

$$\frac{dP}{dt} = \left[- k_3P + (1-\alpha-\beta)k_2\right] M$$

with an intial value of $(1-Q_o)(P+M)_o$ (5.3.2)

$$\frac{dM}{dt} = \left[k_4 \text{ (SDOC)}Y - (k_1+k_2)\right] M$$

with an initial value of $Q_o(P+M)_o$ (5.3.3)

$$\frac{dSNDOC}{dt} = \beta k_2M$$

with an initial value of $(SNDOC)_o$ (5.3.4)

and $$\frac{dSDOC}{dt} = \left[k_3P - k_4(SDOC) + k_2\alpha\right]M \quad .$$

with an initial value of $(SDOC)_o$ (5.3.5)

A SIMPLEX optimization routine was used and the objective function to be minimized is (18)

$$\phi = \sum_{i=1}^{n} \sum_{r=1}^{4} \sum_{s=1}^{4} \sigma^{rs}(y_{ri}-\eta_{ri})\cdot(y_{si}-\eta_{si}) \qquad (5.3.6)$$

where ϕ = objective function to be minimized

n = number of sets of observations made,

σ^{rs} = the $(r,s)^{th}$ element of the inverse of the variance-covariance matrix,

y_{ri} = the i^{th} observation of the r^{th} response

and η_{ri} = the i^{th} prediction of the r^{th} response.

The four responses used are:

(1) Volatile suspended solids (mgC/l), with the predicted value calculated from P + M

(2) Oxygen uptake rate (mgO_2/l/hr), with the predicted value calculated from $3.7M\ k_1+(L-Y)k_4(SDOC)$

(3) Soluble non-degradable organic carbon, SNDOC, (mgC/l), and

(4) Soluble degradable organic carbon, SDOC, (mgC/l)

A schematic representation of the parameter search is shown in Figure 5.3.7.

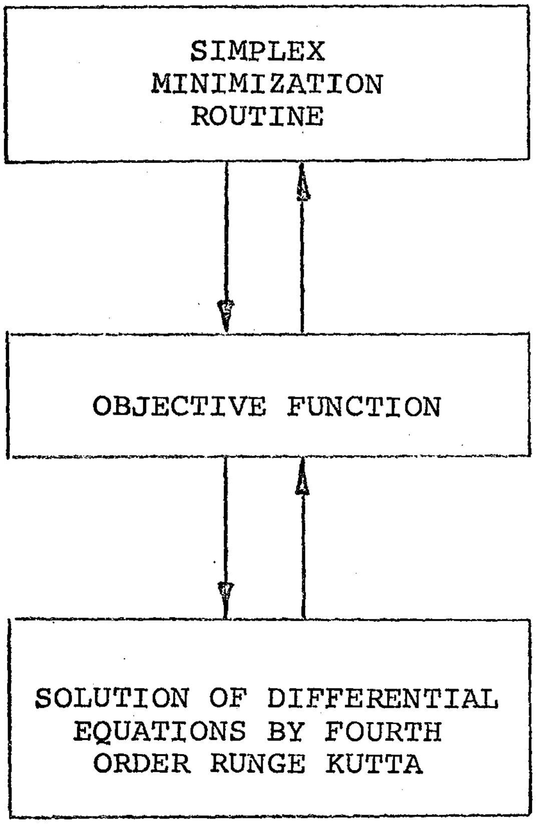


FIGURE 5.3.7. Schematic Representation of Parameter Search

The values of the constants obtained are shown in Table 5.3.1. The fitted curves are shown in Figures 5.3.1 to 5.3.6, together with the observed points.

Run Number	k_1	k_2	k_3	k_4	Y	α	β	θ_o
D-1	0.0029	0.0015	$2.0\text{x}10^{-6}$	$6.0\text{x}10^{-4}$	0.55	0.41	0.082	0.56
D-2	0.0029	0.0014	$1.8\text{x}10^{-6}$	$5.6\text{x}10^{-4}$	0.57	0.44	0.089	0.56

Table 5.3.1. Parameters for the Aerobic Biological Sludge Process Model

The agreement in the values of the parameters in both runs are very good, considering the analytical errors involved. From the Chemostat experiments, the values of k_4 and Y obtained are $1.0 \text{ x } 10^{-3}$ and 0.57. The agreement in the yield factor is good, but the metabolism rate factor is much lower in the "endogenous phase" of the extended aeration studies. The results imply that the metabolism rate is retarded under conditions of prolonged starvation.

Sedivy (37) in his thesis on residual organics found β to be about 1-5%, using glucose as substrate. Our value is a bit high. The value of θ_o obtained suggests that only about half of the volatile suspended solids in the return sludge from the Skyway Plant, is actually "active mass".

No equivalent values for the other constants exist in the literature. Note that the basal metabolism rate constant k_d proposed by other workers ia actually measured from the rate of decrease of volatile suspended solids and which in our case is a combination of k_1, k_2 and k_3. To illustrate that our reaction scheme fits the rate of decrease of volatile suspended solids better than the simple exponential decay, semi-log plots are shown in Figure 5.3.8 and 5.3.9, of the volatile solids versus time. In both runs, our model agrees with the exponential decay model up to about an aeration time of ten days. Beyond that the exponential decay model predicts much lower solids than is actually observed. Our model gives a much better fit beyond ten days, although it still predicts lower solids than is actually observed. This is probably because our model still lacks the ability to predict the concentration of particulate non-degradable organic carbon, which would build up with extended aeration.

As a matter of interest, the k_d value from our data, which is 0.055 day^{-1} (base e) agrees with Pipes and Meade (31) very well. Their data showed a range of k_d between 0.025 to 0.078 day^{-1} with an average value of 0.053 day^{-1}. Eckenfelder (2) reports a value of 0.048 day^{-1}.

As the statistical calculations are quite difficult, the estimation of confidence limits for the various constants

Figure 5.3.8. Log (Volatile Suspended Solids) Versus Time

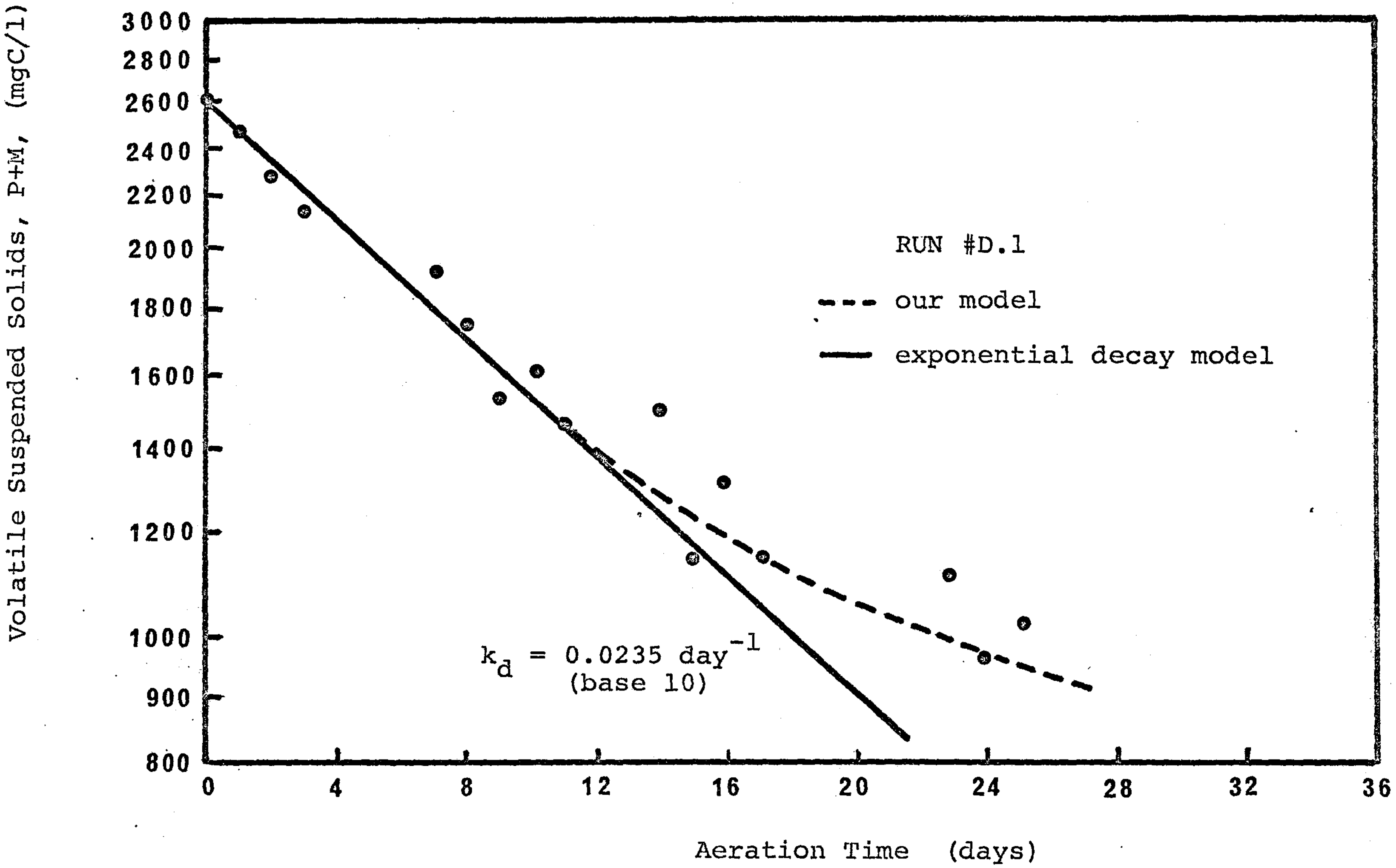
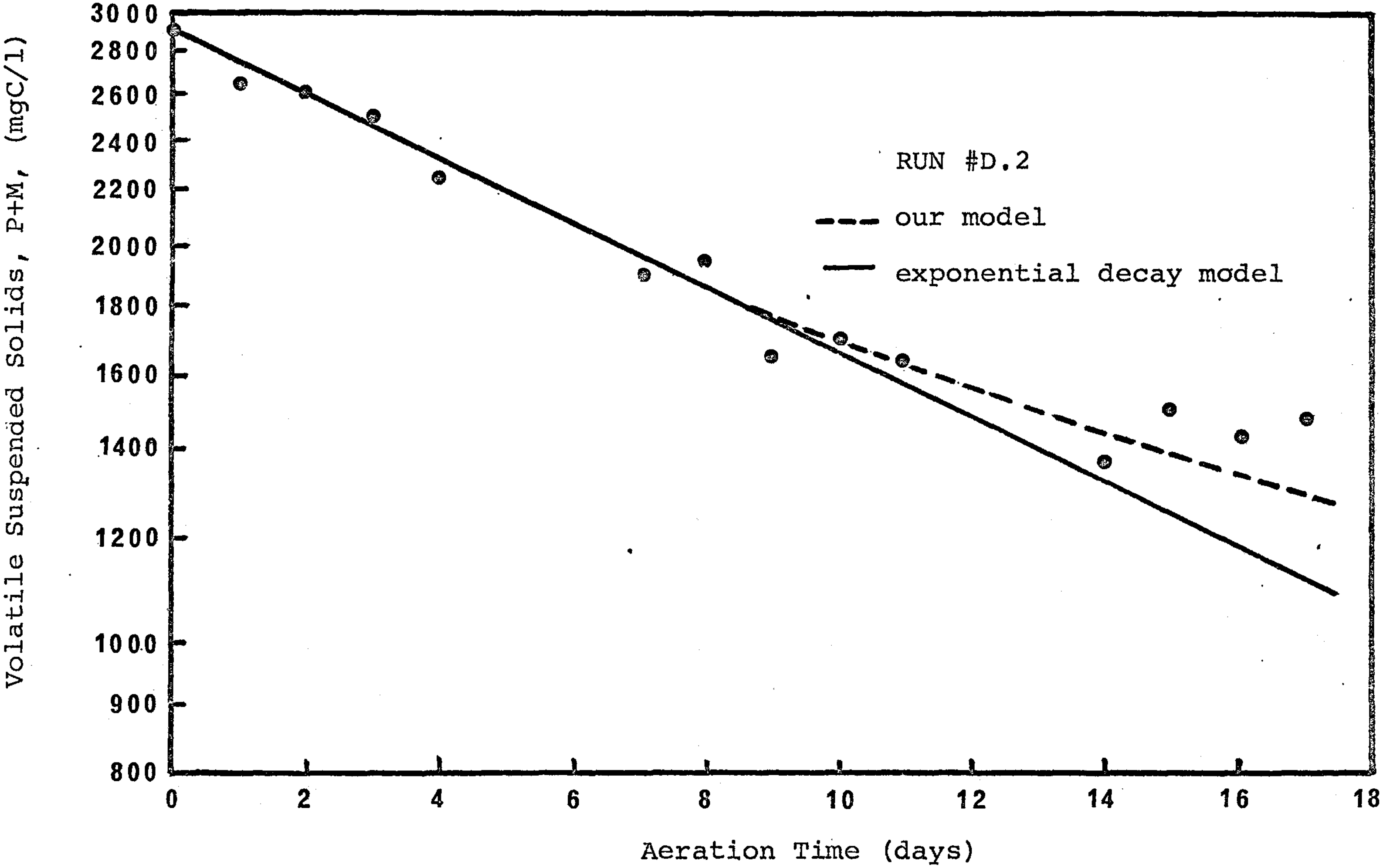


Figure 5.3.9. Log (Volatile Suspended Solids) Versus Time



will not be attempted. Instead, the average sum of squares deviation from the regression line will be compared to the variance obtained in the replicate samples. This is presented in Table 5.3.2.

Run	Number of Points or Samples	Component			
		Volatile Suspended Solids	Oxygen Uptake Rate	Soluble Non-degradable Organic Carbon	Soluble Degradable Organic Carbon
D-1	16	8000	1.2	18.5	1.3 (only 5 points)
D-2	14	8400	1.0	13.6	2.3 (only 5 points)
Replicates	5	6450	2.0	18.5	1.2

Table 5.3.2. Comparison of Average Sum of Squares Deviation from Regression Line, with the Variance from Replicate Samples

The average sum of squares from the regression line compares quite well with the variance from the replicate analysis. This indicates that the model proposed is significant.

No measurements were made on the effect of temperature on the various rates. The above two runs were made at $23^{o}C \pm 2^{o}C$. A temperature correction factor of 1.047 will be used, as proposed by several authors (2, 47). Hence,

$$k_1(T) = 0.0026\ (1.047)^{T-23}$$

$$k_2(T) = 0.0015\ (1.047)^{T-23}$$

$$k_3(T) = 2.0 \times 10^{-6} (1.047)^{T-23}$$
$$k_4(T) = 0.0010\,(1.047)^{T-23}$$
or $$k_4(T) = 0.0006\,(1.047)^{T-23} \quad \text{in food limiting conditions.} \tag{5.3.7}$$

5.4 The Stripping Rate of Purgeable* Soluble Organics

Purgeable soluble organics tend to be stripped off in the aeration process. Hence their removal can occur both by biological action and by physical stripping due to the passage of air (16, 17).

According to mass transfer principles, the mass transfer will depend on the first order of the driving force, or concentration difference and also on the surface area of the air bubbles, namely,

$$\frac{dSPOC}{dt} = - k_L \frac{A}{V} (SPOC - SPOC_b) \tag{5.4.1}$$

where SPOC = soluble purgeable organic carbon in solution

$SPOC_b$ = soluble purgeable organic carbon in bubble

k_L = a mass transfer coefficient

A = surface area of bubbles

and V = volume of reactor

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* Waste treatment terminology reserves the use of the word "volatile" for volatiles at 600°C. The term "purgeable" is then used here to define the soluble organics which can be physically removed by purging with a gas, at normal temperatures.

$$\text{But } A/V = a_V q \tag{5.4.2}$$

where a_V = surface area to volume ratio of air bubbles

and q = volumetric rate of air per unit volume of reactor.

Hence,

$$\frac{d(SPOC)}{dt} = - k_L\, a_V q.(SPOC) \tag{5.4.3}$$

$$= - k_5.q.(SPOC) \tag{5.4.4}$$

Solving,

$$\ln \frac{(SPOC)}{(SPOC)_o} = - k_5\, q\, t \tag{5.4.5}$$

where $(SPOC)_o$ = initial value of SPOC.

To estimate the rate of stripping, settled raw sewage was filtered through a two-inch layer of glass wool and aerated at a fixed rate in a 2 litre vessel (no activated sludge was added). The soluble organic carbon was measured at regular intervals, until no further drop was observed. The remaining soluble organics is non-purgeable. The difference between the soluble organic carbon and the ultimate value (or the non-purgeable organic carbon) is the soluble purgeable organic carbon (SPOC).

Four air rates of 0.5, 1.0, 1.5 and 2.1 cu. ft. air/hr/cu. ft. reactor were used and the results are tabulated in

Figure 5.4.1. Semi-Log Plot of SPOC Versus Time

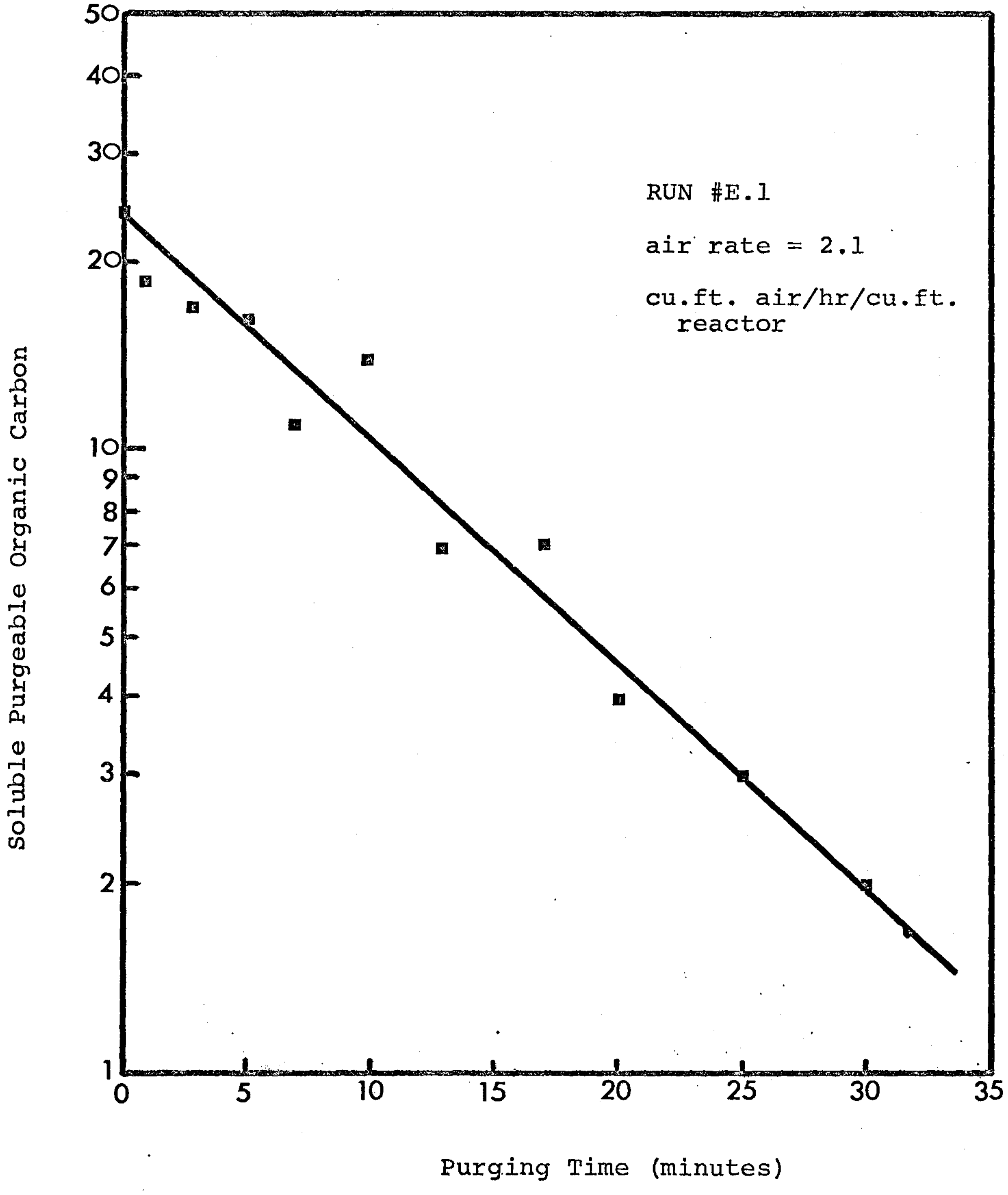


Figure 5.4.2. Semi-Log Plot of SPOC Versus Time

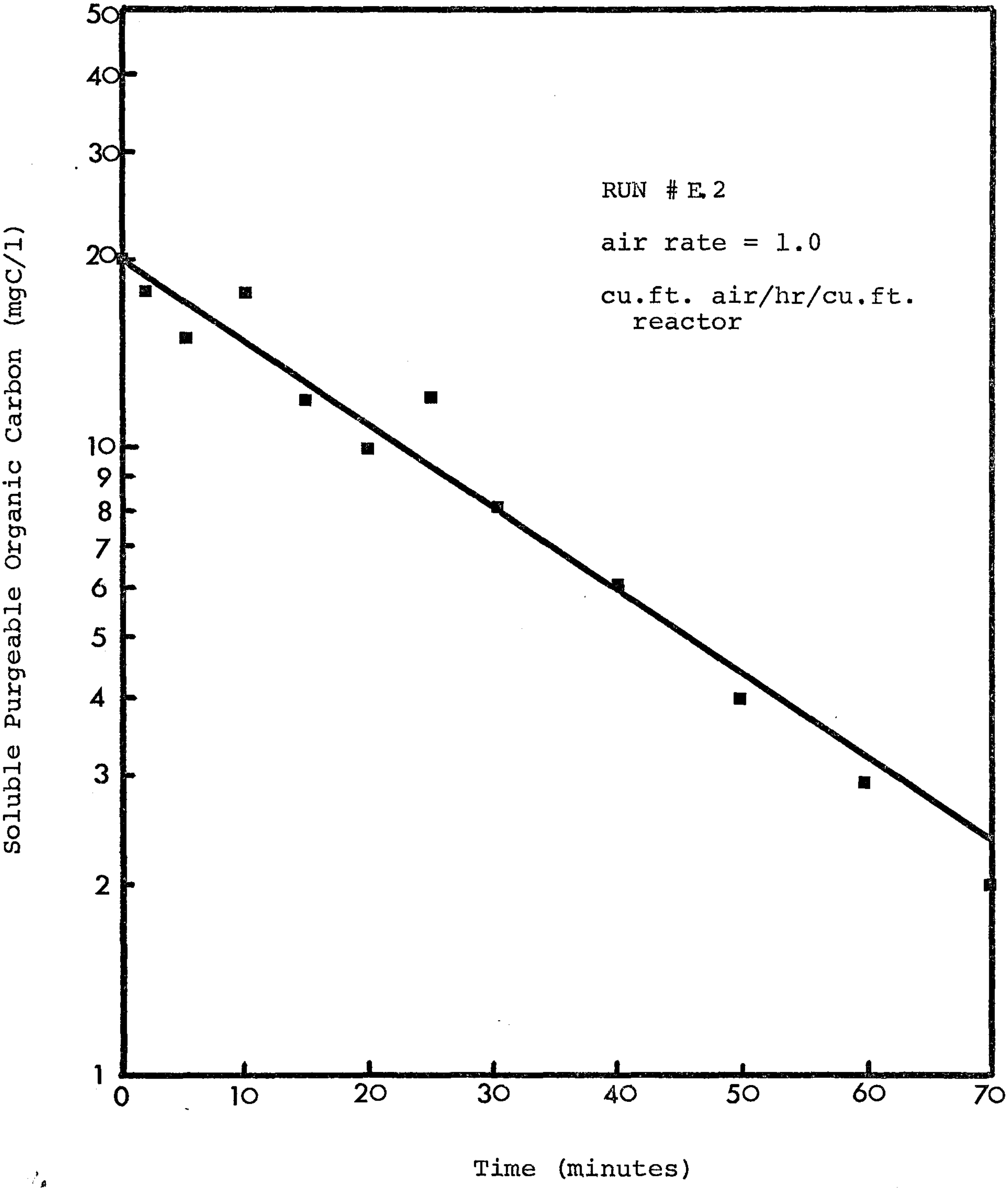


Figure 5.4.3. Semi-Log Plot of SPOC Versus Time

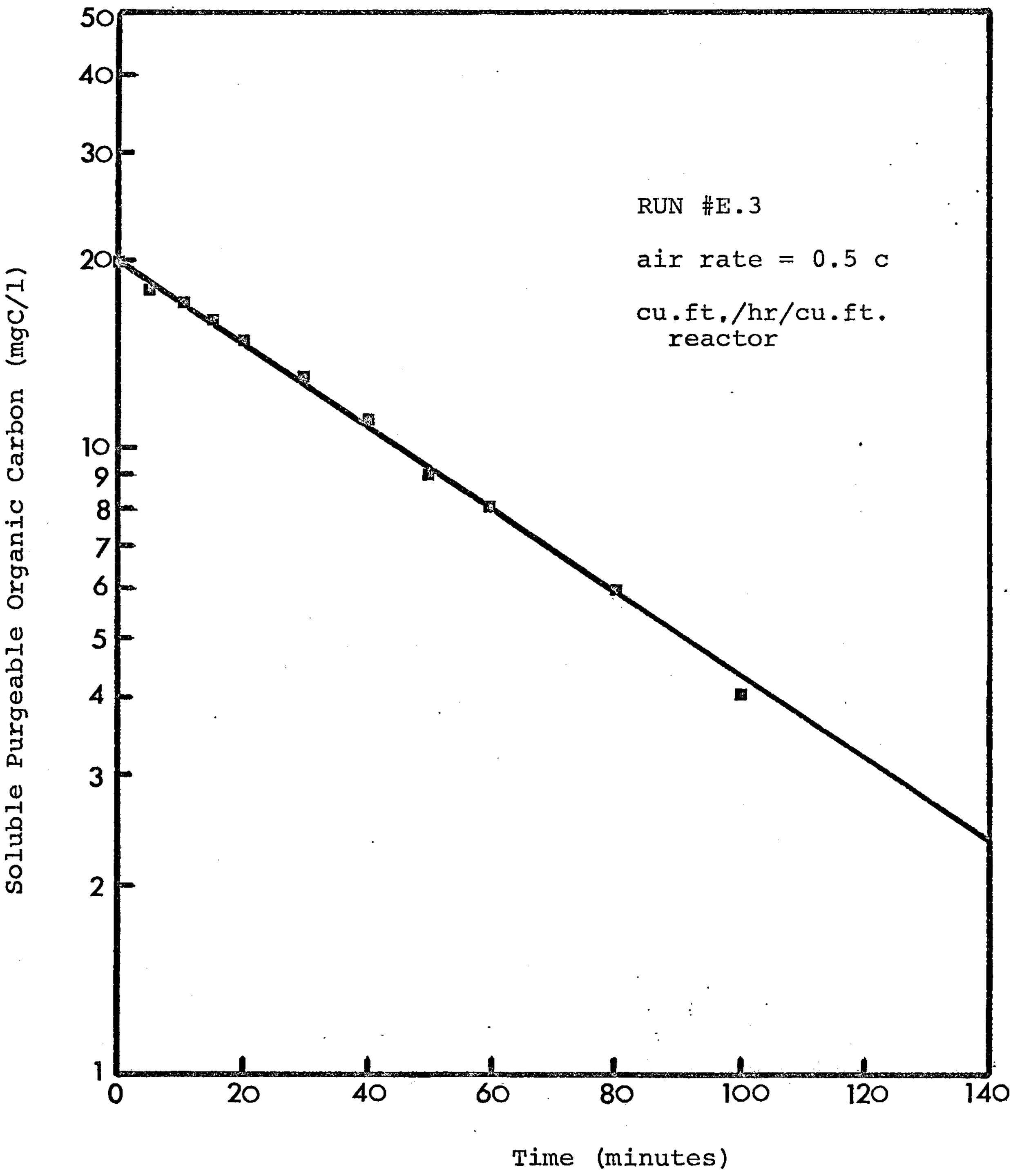
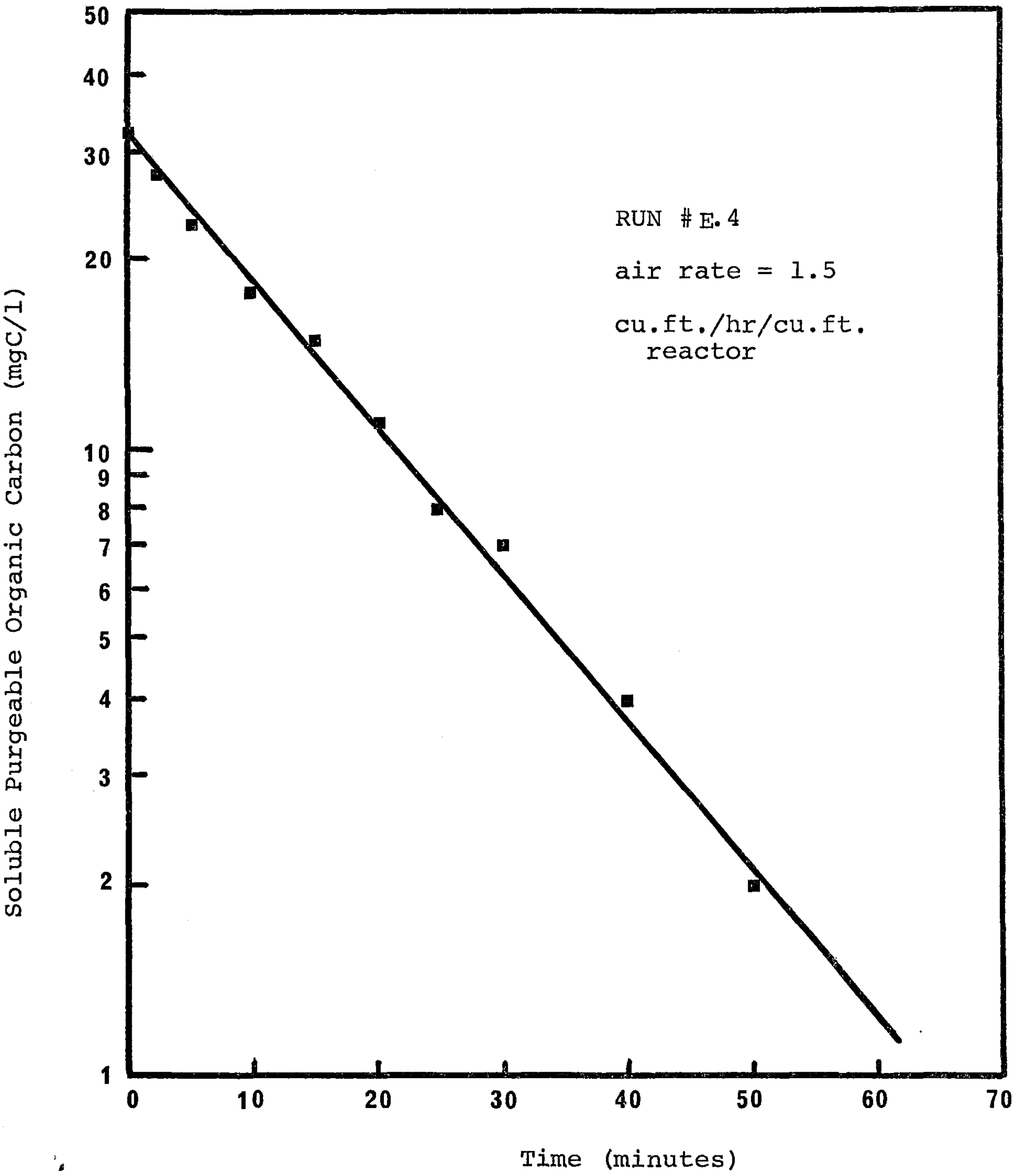


Figure 5.4.4. Semi-Log Plot of SPOC Versus Time



Appendix E. Semi-log plots of SPOC versus time are shown in Figures 5.4.1 to 5.4.4. The slopes of the lines will be $-k_5q$. Table 5.4.1. shows the values of k_5 obtained from the four runs. The average value of k_5 is 2.06 with a standard deviation of 0.27.

Run Number	E-1	E-2	E-3	E-4	Average
q cu.ft.air/hr cu.ft. reactor volume	2.1	1.0	0.5	1.5	
slope = k_5q hr^{-1}	2.18	0.80	0.40	1.40	
k_5 (base e)	2.40	1.85	1.85	2.15	2.06

5.5 Oxygen Transfer Efficiencies

The rate of oxygen transfer can be found by using the same equation as that for the stripping of purgeable organics, namely

$$\frac{d\,[O_2]}{dt} = k_L' \frac{A}{V} \left([O_2]_{sat} - [O_2] \right) \qquad (5.5.1)$$

where $[O_2]$ = concentration of oxygen in liquid

$[O_2]_{sat}$ = saturation concentration of oxygen in liquid

k_L' = liquid film mass transfer coefficient

A = surface area of air bubbles

and V = volume of aeration tank

The saturation concentration of oxygen in water at 1 atm can be calculated from the equation (9)

$$O_{2\ \text{sat., 1 atm.}} = 14.16 - 0.3943T + 0.007714T^2 - 0.0000646T^3 \qquad (5.5.2)$$

where T = temperature in ^oC

$k_L'A$ is a function of the aeration device, the air flow rate and of the depth of the aeration tank. The functional relationship is

$$k_L'A = N.G^{(1-n)}\ H^{(1-m)} \qquad (5.5.3)$$

where N = sometimes referred to as absorption number

G = total air rate, scfm.

H = depth, ft.

and n,m = constant

Table 5.5.1 shows the various values of the constants, for several aeration devices (9).

5.6 Nutrient Balance

The assumption made is that the nitrogen to carbon (N/C) and phosphorus to carbon (P/C) ratios in the raw waste is the same for both the particulate and soluble organic

Unit	N	(1-n)	(1-m)
Aloxite tubes	270	0.85	0.45
Sparjer	210	0.86	0.78
Seran tubes	275	0.8	(0.60)
Carborundum plates	65	0.8	(0.75)

Table 5.5.1. Oxygen Transfer Characteristics of Some Common Diffused Aeration Equipment.

components. This is supported by analyses made by the Ontario Water Resources Commission for the Drury Lane W.P.C.P. This is shown in the table below.

Element Phase	Nitrogen	Phosphorus	Carbon	N/C	P/C
Particulate	22	7	(90)	0.24	0.078
Soluble	23	6	(80)	0.29	0.075

Table 5.6.1. Average Nitrogen, Phosphorus and Carbon Concentrations in Raw Sewage from Drury Lane W.P.C.P. The Nitrogen and Phosphorus Values are Obtained from 29 Analyses by the O.W.R.C. The carbon concentrations are estimated from our analyses.

The composition of the bacterial cells is assumed to be $C_5H_7O_2N$ (54). This has a (N/C) ratio of 0.23. The (P/N) ratio in activated sludge is reported to be about 0.25 (9), hence (P/C) is approximately 0.06.

After the various effluent organic carbon components have been calculated, a mass balance over nitrogen and phosphorus is then performed. All excess nitrogen is assumed to be converted to ammonia and all excess phosphorus to inorganic phosphates.

Downing's data for the rate of nitrification will be used (7):

$$\frac{dNH_3}{dt} = - \frac{G.\ NH_3.\ X}{Y\ (K + NH_3)} \qquad (5.6.1)$$

and $$\frac{dX}{dt} = - Y \frac{dS}{dt} \qquad (5.6.2)$$

where NH_3 = ammonia concentration (mgN/l)

X = Nitrosomonas concentration (mg/l)

G = 0.014 hr^{-1}

K = 1.0 mg/l

and Y = 0.05 gms Nitrosomonas/gm NH_3-N

A slight modification will be made to Downing's equation. This is to account for a decrease in the rate due to an oxygen concentration of less than 1.0 mg/l. The retarding factor f is defined where

$$f = 1 \text{ for } [O_2] \geq 1.0 \text{ mg/l}$$

and $$f = [O_2] \text{ for } 0.0 \leq [O_2] < 1.0 \text{ mg/l} \qquad (5.6.3)$$

i.e.,

$$\frac{dNH_3}{dt} = - \frac{f.G.\ NH_3.X}{Y\ (K + NH_3)} \qquad (5.6.4)$$

The mass of Nitrosomonas is found iteratively and stored in the EN vector as a fraction of the mixed liquor suspended solids mass.

The oxygen requirement during nitrification can be obtained from the equation

$$NH_3 + 2O_2 \rightarrow HNO_3 + H_2O \qquad (5.6.5)$$

Hence, for each gram of NH_3-N converted to NO_3^- , 4.57 grams of oxygen are required.

5.7 The Aerobic Biological Sludge Process Model - ACTSL1 and CSTR2

CSTR 2 is a continuous-flow, completely-stirred tank reactor model of the aerobic biological sludge process. ACTSL1 is a stirred tanks in series model which calls the basic CSTR2 program. ACTSL1 is the program that is actually used as the unit computation. Listings of the two programs are given in Appendix K. The equipment vector for ACTSL1 is reproduced below, of which EN(16) - EN(32) are actually used by the CSTR2 routine.

```
C
C     EN VECTOR
C     *********
C     1.-15.  STANDARD FORMAT
C     4.      NUMBER OF REACTORS IN PARALLEL
C     5.      TOTAL HEAD LOSS THROUGH ACT. SL. TANKS (FT OF WATER)
C     6.      NUMBER OF INPUT STREAMS (= 2.0)
C     7.      FIRST INPUT STREAM (= RETURN SLUDGE FLOW)
C     8.      SECOND INPUT STREAM (= FEED STREAM)
C     11.     NUMBER OF OUTPUT STREAMS (= 1.0)
C     12.     OUTPUT STREAM NUMBER
C
C             NOTE EN(16.-32.) ARE USED BY CSTR2
C     16.     LENGTH OF REACTOR  (FEET)
C     17.     WIDTH OF REACTOR  (FEET)
C     18.     DEPTH OF REACTOR  (FEET)
C     19.     = 1.0 IF NOT USING A RESIDENCE TIME DISTRIBUTION MODEL
C             = EN(34) IF USING A RTD MODEL
C     20.     LYSIS RATE  (K2 /HR)
C     21.     BASAL METAB. RATE  (K1 /HR)
C     22.     RATE OF SOLUBILIZATION OF DEGRADABLE SOLIDS  (K3 /HR)
C     23.     STRIPPING RATE OF VOLATILE ORGANICS  (K5 /HR)
C     24.     MICROORGANISMS YIELD FACTOR  (Y DIMENSIONLESS)
C     25.     FRACTION OF LYSIS PRODUCTS TO SOLUBLE DEGRADABLE CARBON
C     26.     FRACTION OF LYSIS PRODUCTS TO SOLUBLE NONDEGRADABLE CARBON
C     27.     RATE OF AIR ADDITION TO EACH REACTOR (SCF/HR)
C     28.     UNIT GROWTH RATE CONSTANT (K4 /HR)
C     29.     FRACTION OF MLSS THAT IS NITRIFIERS
C     30.     N/C RATIO IN RAW FEED
C     31.     P/C RATIO IN RAW FEED
C     32.     ABSORPTION NUMBER (FOR OXYGEN TRNSFER)
C
C     33.     NOT PRESENTLY USED
C     34.     NUMBER OF CSTR,S IN SERIES - EITHER AN RTD MODEL OR THE
C             ACTUAL NUMBER OF TANKS IN A STEP AERATION PROCESS
C             MAXIMUM OF TEN TANKS IN SERIES
C     35.     FRACTION OF FEED STREAM TO FIRST TANK
C     36.     FRACTION OF FEED STREAM TO SECOND TANK
C     37. -   ETC
C     44.     FRACTION OF FEED STREAM TO TENTH TANK (IF ANY)
C     45.     NUMBER OF BLOWERS USED
C     46.     CAPACITY OF EACH BLOWER  SCF/HR
C
```

ACTSL1 may be used as the step aeration process model or as a model for the activated sludge process and its various modifications. For the contact stabilization process, ACTSL1 will have to be used twice.

The computations carried out by the CSTR2 program may be explained by the following steps:

(1) Stream variables are first converted to concentration units,

(2) The iteration then begins on the effluent concentrations of the reactive components. All inert components are passed through the model. The reaction rates used are:

(a) $$\frac{dM}{dt} = (Yk_4C - k_1 - k_2)M$$

where $M = SO(1, 15)$

$C = SO(1, 20) + SO(1, 21) = C' + C''$

$k_4 = EN(28)$

$k_1 = EN(21)$

and $k_2 = EN(20)$

(b) $$\frac{dS'}{dt} = (-k_3S' + k_2(1-\alpha-\beta))M$$

where $S' = SO(1, 16)$

$\alpha = EN(25)$

$\beta = EN(26)$

and $k_3 = EN(22)$

(c) $$\frac{dS''}{dt} = -k_3S''M$$

where $S'' = SO(1, 18)$ as well as $SO(1, 19)$

(d) $$\frac{dC'}{dt} = -(k_4M + k_5q)C'$$

where $C' = SO(1, 20)$

and q = volume air used/hr/volume of reactor.

(e) $$\frac{dC''}{dt} = (k_3S + k_2\alpha - k_4C'')M$$

where $S = S' + S''$

and $C'' = SO(1, 21)$

(f) $$\frac{dSNDC}{dt} = k_2\beta M$$

where $SNDC = SO(1, 22)$

The concentration of ammonia nitrogen released and the subsequent nitrification to nitrates are also calculated, within the iteration loop. The rate of change of dissolved oxygen is next given by

(g) $$\frac{dO_2}{dt} = k_La\ (O_S - O_2) - \frac{32}{12}\left\{(1-Y)\ k_4C + k_1\right\} M - 4.57\ \left(\frac{dN}{dt}\right)$$

where $O_2 = SO(1, 7)$

O_S = saturation oxygen concentration

k_La = oxygen mass tranfer coefficient

and $\frac{dN}{dt}$ = nitrification rate.

(3) A balance is then made on phsophorus,

(4) The exit pH is next calculated assuming that the carbon-dioxide concentration is in equilibrium with air.

CHAPTER 6

6. SECONDARY SEDIMENTATION

In the activated sludge process the waste to be treated is mixed with a flocculent sludge containing microorganisms and other organic and inorganic solids, and aerated. The microorganisms are used to feed on the soluble portion of the waste and to convert them into more cell mass which may then be settled out. The level of suspended solids used in the activated sludge process range from 2000-4000 mg/l. As the treated water will constitute the plant effluent in most cases, it is important that the activated sludge is removed and the suspended solids concentration in the effluentbe reduced to the level of about 20 mg/l. Secondary sedimentation performs such a purpose.

As the settled sludge will be recycled to the activated sludge tanks, and partially "wasted", it is equally important that we keep the solids content of the sludge high. The benefits resulting from a "thick" sludge are:

(a) It maintains a high level of mixed-liquor suspended solids in the activated sludge tanks,

(b) It reduces pumping costs,

(c) It improves digester operation on the waste sludge and hence requires smaller digester volumes,

(d) It increases the economy of sludge dewatering systems such as centrifuges, vacuum filters, etc., and

(e) It reduces the sludge volume for land or sea disposal.

6.1. Activated Sludge Characteristics

The clarification and thickening propoerties of an activated sludge have been related to its composition and character. A sludge with a relatively high content of inorganic solids (such as clay) will tend to be denser and hence more easily thickened. However, the character of the microorganisms in the sludge can determine whether a sludge will be flocculent and hence have good clarifying properties or whether the sludge will be compact and have good thickening properties.

The microbial population in activated sludge include the bacteria, fungi, protozoa and some rotifiers. The bacteria are the most predominant group, and as they are responsible for stabilizing the organic matter in the waste and in floc formation, they are the most important group as well. Numerous types of bacteria may be found in any sample of an activated sludge, but sometimes one or several genera may predominate, depending on the particular waste being treated.

A brief description of new operating conditions may affect the character of the microorganisms in the sludge will be presented here. Assuming that oxygen is supplied in sufficient quantities, a high food to microorganism ratio will lead to a rapid rate of bacterial metabolism and reproduction. The bacterial cells are highly energetic and will tend to stay as discrete entities. Another reason for the bacterial cells to stay apart, is the high surface area that each cell will enjoy, aiding in the transfer of food and oxygen. This leads to the formation of a dispersed or diffused sludge with poor clarifying and thickening properties.

At a lower food to microorganism ratio, the bacterial cells have less energy and flocs being to form when the cells are brought into contact with each other. The sludge also becomes more compact. The clarifying and thickening properties of the sludge improve.

At a very low food to microorganism ratio the bacterial cells are starved and many will die off. With less viable bacterial cells, the sludge will have a poorer flocculating ability, resulting in a poorer effluent. However, the sludge is still compact and will have good thickening characteristics. The above observations are illustrated in Figure 6.1.1.

In the case where the dissolved oxygen concentration in the activated sludge tanks is low, (0.5 mg/l) there is little oxygen penetration into the biological floc, resulting

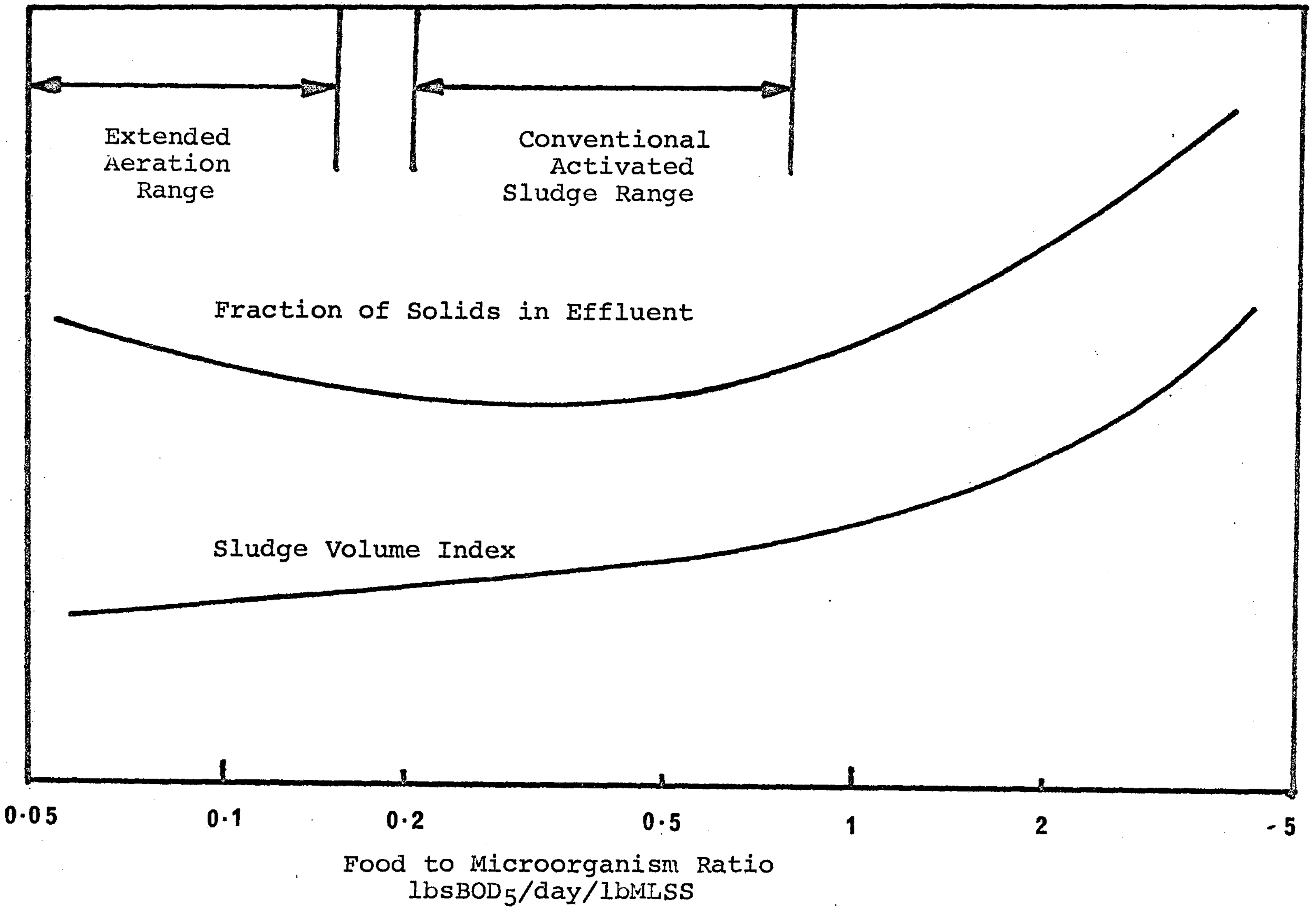


Figure 6.1.1. Trends of Changes in SVI and XRSS with the Food to Microorganism Ratio.

in lowered bacterial growth. This encourages the growth of filamentous bacteria such as the Sphaerotilus, as they have a high surface area/volume ratio, and are more able to absorb the small amount of oxygen present. These filamentous growths render the sludge less compact and hence displays poor thickening properties. The effect of these filamentous growths on the flocculating and hence clarifying properties of the sludge is not too well know or reported.

Most fungi also have a filamentous structure and their growth tends to be stimulated by carbohydrate wastes, or conditions of low pH and nutrient deficiencies.

Prolonged periods of anaerobiasis in the secondary clarifier could lead to the production of gas, which when entrapped could cause the activated sludge flocs to rise, and escape over the effluent wiers. Denitrification could also contribute to the problem of a rising sludge.

6.2 Correlations for Activated Sludge Settling

From the above discussion, we realize that the twin functions of the secondary settling tanks, namely those of clarification and thickening, are very much related to the operating conditions in the activated sludge tanks. The level of clarification obtained can be described by the fraction of suspended solids escaping in the effluent, and the degree of compaction obtained, by the Sludge Volume Index.

The Sludge Volume Index is the volume in ml. occupied by 1 gm of the sludge after settling for half an hour.

Rex Chainbelt, Incorporated, has developed two correlations for this purpose (47):

$$XRSS = \frac{382\ (GSS)^{0.12}\ (FM)^{0.27}}{(MLSS)^{1.35}\ (TA)^{1.03}} \qquad (6.2.1)$$

and $$SVI = 56.1 + 113\ (1.05)^{T-20}\ (FM) \qquad (6.2.2)$$

where XRSS = fraction of solids escaping in the effluent

GSS = overflow rate (usgpd/sq.ft.)

MLSS = mixed liquor suspended solids (mg/l)

FM = food to microorganism ratio (lbs BOD_5 /lb MLVSS/day)

MLVSS = mixed liquor volatile suspended solids

TA = aeration time (hrs.)

SVI = sludge volume index (ml/gm)

and T = temperature (°C)

The above correlations are based on 41 observations and the correlation coefficient for the first equation is 0.63 whilst that of the second is 0.78.

The maximum concentration of the underflow solids can be estimated by the value (10^6/SVI) mg/l. Although this represents the compaction obtained after half an hour of settling, it is a good estimate of the final compaction, as further changes in SVI are small, especially with mixed liquor suspended solids of less than 3000 mg/l. It should be noted that there is a wide misconception that the SVI represents the settling rate of an activated sludge. The half an hour of settling required by the test is not meant to be a measure of the rate, but merely provides a reasonable time for which the sludge to achieve close to the ultimate compaction.

R. V. Villiers (51) performed laboratory scale settling column studies and arrived at the correlation

$$\text{XRSS} = \frac{556\ (\text{GSS})^{0.494}}{(\text{MLSS})^{1.82}\ (\text{TA})^{0.439}} \tag{6.2.3}$$

This correlation does not include the effect of the food to microorganism ratio, as does the previous correlation by Rex Chainbelt Inc. However, there is quite a significant difference in the exponents on the variables, between the two studies.

In a preliminary study, P. Leung from the Chemical Engineering Department, McMaster University, using laboratory scale experiments, arrived at the correlation

$$\text{XRSS} = \frac{2560}{(\text{MLSS})^{1.57}\ (\text{TA})^{0.20}} \tag{6.2.4}$$

This correlation does not include either the food to microorganism ratio or the overflow rate. However, the exponent that he obtained for the effect of the mixed liquor suspended solids is intermediate between those of the earlier studies, but he found a very much smaller effect of aeration time than did the other two investigators. His results are tabulated in Appendix F.

The disparity between the three correlations could be explained if the nature of the raw wastes entering the plants from which the sludges were taken, were somehow significantly different. It would seem necessary to obtain a correlation based on a sludge actually produced by the plant.

In the absence of a good correlation for the sludge produced in the Burlington plants we have to choose either Equations 6.2.1 or 6.2.3. It should be noted that the above equations are developed from quiescent batch column studies and to apply them to real settling tanks, a correction factor of 1.5 is suggested by most authors. We will use the operating data for the Drury Lane Plant, in 1969, as a comparison:

OR = 960 usgpd/sq.ft.
MLSS = 2200 mg/l
TA = 9.6 hrs.
F/M = 0.3 lbs BOD_5/lb MLVSS/day

and the obtained XRSS = 0.090

Using Equation 6.2.1:

XRSS (calculated) = 0.019

XRSS (corrected) = 0.019 x 1.5 = 0.029

Using Equation 6.2.3:

XRSS (calculated) = 0.054

XRSS (corrected) = 0.054 x 1.5 = 0.081

The Rex Chainbelt correlation gives too good an effluent, whilst the Villiers' equation gives a result which is closer to the actual operating condition. Hence, Equation 6.2.3. will be selected for use in our program.

6.3 The Secondary Clarifier Model - SECLAR 1

The listing for the program is given in Appendix K. The equipment vector for the model is reproduced below.

```
C
C     EN VECTOR
C     *********
C     1.-15. STANDARD FORMAT
C     4.     NUMBER OF CLARIFIERS IN PARALLEL
C     5.     HEAD LOSS THROUGH CLARIFIER (FEET OF WATER)
C     12.    FIRST OUTPUT STREAM (EFFLUENT)
C     13.    SECOND OUTPUT STREAM (UNDERFLOW)
C     14.    THIRD OUTPUT STREAM (SCUM TROUGH FLOW)
C     16.    MODE OF OPERATION
C            = 1.0 FOR FIXED FRACTION OF RECYCLE
C            = 2.0 FOR MAXIMUM CONCENTRATION OF UNDERFLOW
C     17.    FRACTION OF RECYCLE IF MODE=1
C     18.    SURFACE AREA OF CLARIFIER (PER TANK)   - SQ.FT.
C     19.    SCUM FLOW CONCENTRATION (MG/L)
C     20.    NUMBER OF UNDERFLOW SLUDGE PUMPS
C     21.    CAPACITY OF PUMPS IGPH EACH
C     22.    FRACTION OF CAPACITY USED
C
```

The computations carried out by the program can be explained in the following steps:

(1) The Sludge Volume Index of the activated sludge is first calculated, based on operating conditions in the aeration tanks. Equation 6.2.2. is used.

(2) The concentration of solids in the effluent,is then calculated from Equation 6.2.3.

(3) Secondary clarifiers can be operated with either a constant fraction of recycle of the underflow or with a constant depth of sludge blanket. In the second case, the underflow solids is at its maximum concentration, which can be estimated from the Sludge Volume Index. In the first case, the sludge blanket

depth is not constant but could drop when the underflow pumps are set too high or could rise and finally escape over the wiers when the underflow pumps are set too low. When there is no sludge blanket, the concentration of solids in the underflow is below the maximum value, as calculated from the SVI. EN(16) determines the policy used in the plant, and the underflow is calculated accordingly.

(4) The scum flow is then determined assuming 100% removal of all incoming scum. The scum solids concentration is determined by EN(19).

(5) Dissolved components are split according to the water flows.

CHAPTER 7

7. ANAEROBIC DIGESTION

The "Sewage Treatment Plant Design Manual" (38) adequately describes the purpose of anaerobic digestion as follows:

> ".....A primary purpose of sludge digestion is to reduce the complex organic matter present in the raw sludge removed by sedimentation processes to a simpler, non-objectionable state. Digestion produces a sludge more amenable to dewatering without nuisance, and it renders the sludge fit for easy disposal by lagooning, dilution or similar means......Digestors also reduce the volume of sludge and in so doing produce gas which can be utilized for heating purposes."

The anaerobic digestion process has several disadvantages which may discourage their use in a wastewater treatment plant. Firstly, a high capital outlay is required, amounting to about 25-35% of the total capital cost. Secondly, digester upsets are frequent, thus requiring constant attention, and thirdly, there is always the hazard of a gas explosion.

7.1 Theory

There are two distinct processes occuring in an anaerobic digester - liquifaction and gasification. Liquefaction of the sludge solids is brought about by the extracellular enzymes secreted by the bacteria, which hydrolyses the complex solids. Cellulose and carbohydrates are converted to simple sugars, alcohols and fatty acids. Proteins are converted to amino acids, while fats and grease are converted to glycerol and fatty acids. The formation of organic acids could result in a depression of the pH, if the alkalinity in the digesting sludge is not sufficient for neutralization. This liquefaction stage of digestion, is also called the acid phase, for obvious reasons, and the bacteria responsible are usually referred to as acid-formers.

In the gasification process, the end products of liquefaction are further broken down to gaseous end products. This could involve the activity of the same bacteria in the first phase, but with the exception that they are not capable of utilizing their own acid end products. This requires the work of a second group of bacteria which metabolize the fatty acids to give methane and carbon dioxide, and convert amino acids to ammonia. The ammonia released tends to neutralize a portion of the acids remaining and raise the pH. The gasification phase is also sometimes referred to as the methane phase, and the bacteria involved as methane-formers.

The digestion process can be schematically represented as:

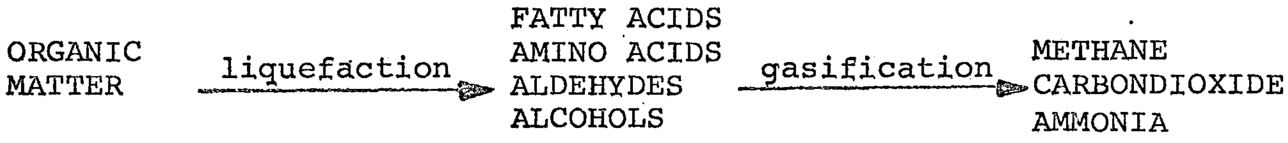


Figure 7.1.1. Schematic Representation of The Digestion Process

Since the digester is operated under anaerobic conditions, the bacterial population has to be composed of either the facultative bacteria or the strict anaerobes. The acid-formers are predominantly facultative and many of them originate from the activated sludge fed to the digester. The methane formers are strict anaerobes, and are a small specialized group of bacteria. They are highly sensitive to pH changes and have an optimum pH range of 6.4 to 7.2. When a digester goes "sour" (or acidic) the methane-formers die off, and the gasification phase is seriously retarded.

A properly operating digester should have the liquefaction and gasification processes proceeding at about the same rate. An upset can be produced by an increase in the liquefaction rate, which could be prompted by a sudden increase in the solids fed to the digester.

To provide a reasonable description of the digestion process we need an expression to account for the rate of liquefaction of the organic solids. If a steady-state operation is reached, the rate of gasification should equal the rate of liquefaction. We would also need an expression to determine the level of volatile organic acids maintained in the digester. This is necessary since the pH and the BOD of the digesting sludge would depend on the amount of volatile acids present.

A model for the anaerobic digester was first proposed by Fair and Moore (13) in 1932. They followed the digestion process in batch reactors and concluded that the rate of gas production is proportional to the amount of "gas" remaining in the digesting sludge:

$$\frac{dy}{dt} = k\,(G-y) \tag{7.1.1}$$

where y = amount of gas produced up to time t

G = total amount of gas produced

and k = rate constant.

They found k to be 0.168 day^{-1}, at 95°F. Since then, other workers have also obtained first order rates. Schulze (36) determined k to be 0.14 day^{-1} at 92°F., and Simpson (42) arrived at a k value of 0.3 day^{-1}.

Since it would be useful to our modelling studies to know the rate of liquefaction of the digesting solids, we have to rearrange Equation 7.1.1. If gas production is a measure of volatile solids destruction, then (G-y) is proportional to the amount of organic solids remaining.

i.e.,

$$(G-y) = a\,S \tag{7.1.2}$$

where S = amount of organic solids remaining

and a = proportionality constant.

The proportionality constant is the volume of gas produced per unit mass of organic solids. This has been reported to be approximately 16-18 cu. ft./lb. solids destroyed, for digesting sewage sludge.

Equation 7.1.1 then becomes

$$\frac{dS}{dt} = -\,K\,S \tag{7.1.3}$$

Since most reactors are operated continuously or semi-continuously, rather than batchwise, we will assume a stirred tank model for the digester. The defining equation for the digester then is:

$$S = \frac{So}{1 + K\bar{t}} \tag{7.1.4}$$

where S = volatile solids remaining

So = feed volatile solids

and $\bar{t}$ = detention time

or

$$R = \frac{S}{So} = \frac{1}{1 + K\bar{t}} \tag{7.1.5}$$

where R = fraction of volatile solids remaining.

Or

$$(1 - R)/R = K\bar{t} \tag{7.1.6}$$

The relation here implies that the effluent volatile solids depend on both the influent volatile solids and the detention time, as contrasted to the theory of McCarty (see Chapter 2). This seems to be a more reasonable expression, and the importance of solids loading is supported by the observations of other workers (13, 19, 50).

Rankine (32) has presented data for the fraction of volatile solids destroyed as a function of the detention time in a conventional digester. His data is tabulated in Appendix G. A plot of $(1 - R)/R$ versus $\bar{t}$ is shown in Figure 7.1.2. K is found to be 0.025 day^{-1}, and the correlation coefficient is 0.65. The range of solids loading employed as 0.033 - 0.135 lbs VM/cu.ft./day.

For the high-rate digestion process, the data of Torpey (50), Roy and Sawyer (34) and Estrada (12) are used. Their data is also tabulated in Appendix G, and the plot of $(1 - R)/R$ versus $\bar{t}$ is shown in Figure 7.1.3. The reaction rate constant K is found to be 0.085 day^{-1}, and the correlation coefficient is 0.58. The range of solids loading employed here is 0.101 - 0.575 lbs/cu.ft./day.

Data on the dissolved biodegradable organic carbon in the supernatant is quite sparse. Hence, the equation

Figure 7.1.2. Conventional Digester Correlation

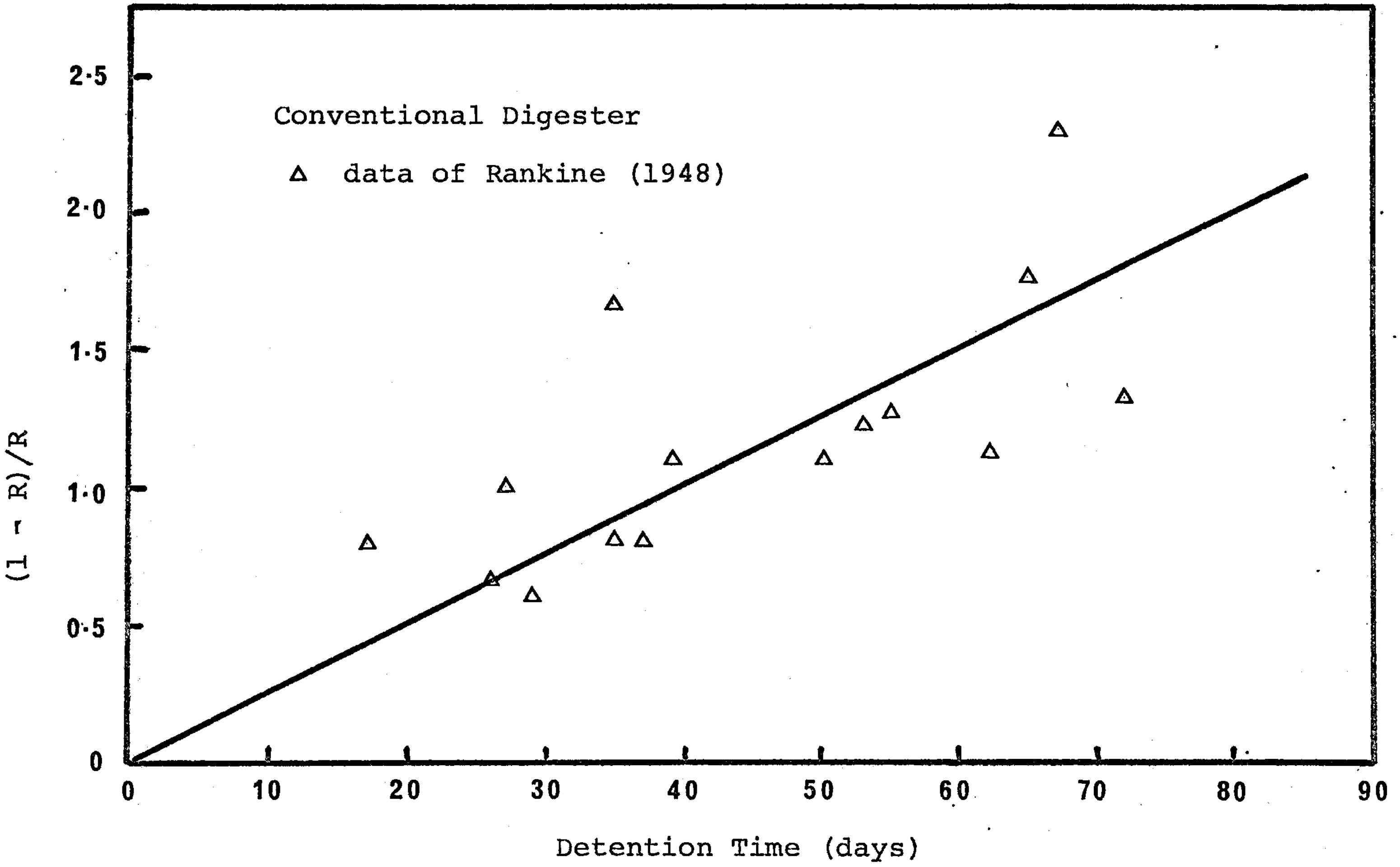
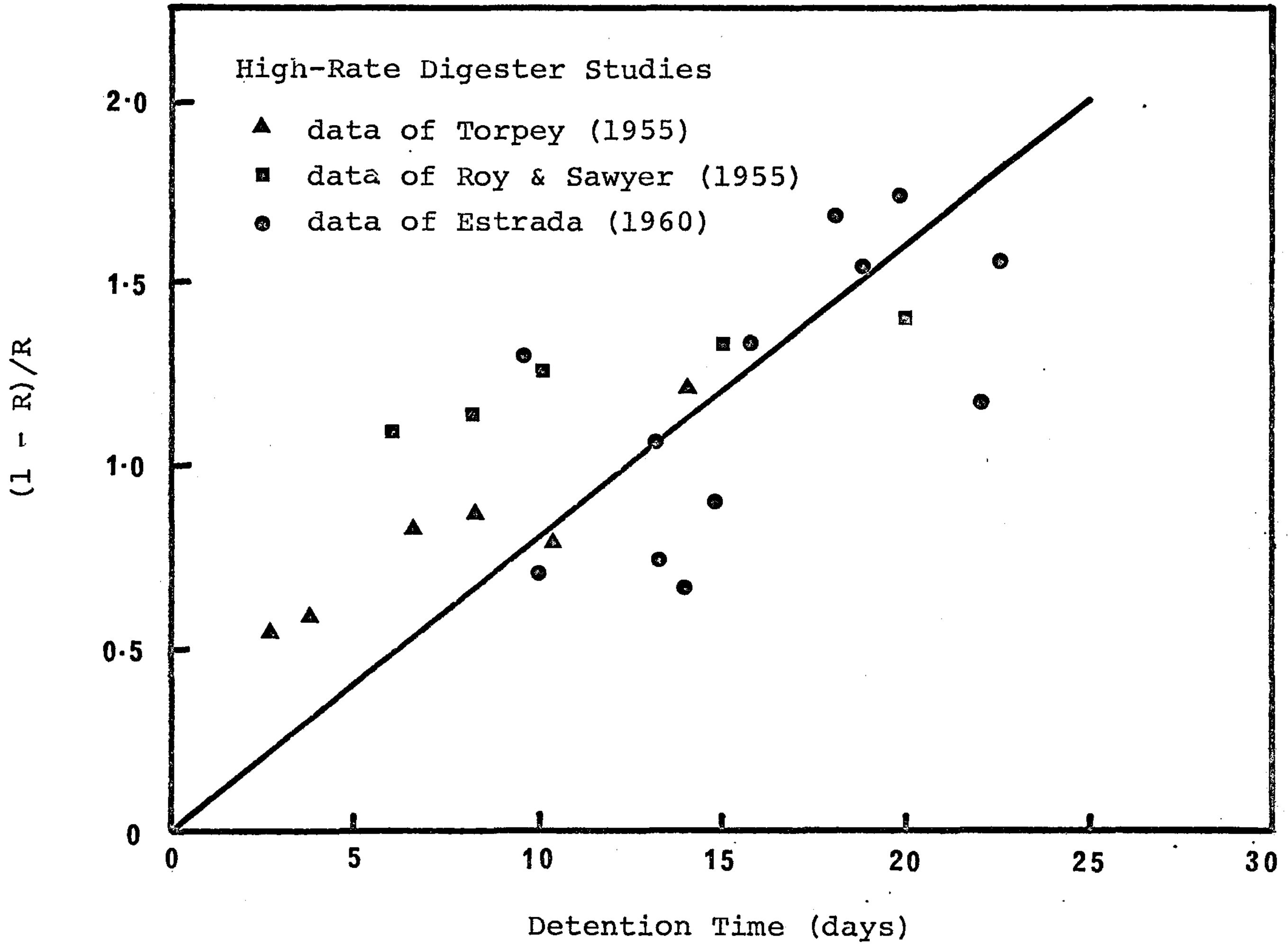


Figure 7.1.3. High-Rate Digester Correlation



proposed by McCarty (see Chapter 2) will be used. He also estimated that the dissolved organic carbon is mainly composed of volatile acids.

The acidity due to the volatile acids is estimated by assuming that acetic acid is the major component, i.e.,

$$\text{acidity (meq/l)} = \frac{\text{soluble organic carbon (mg/l)}}{24.0} \tag{7.1.7}$$

The ammonia evolved tends to neutralize the volatile acids and raise the pH of the digester. Assuming that the nitrogen to carbon ratio in the feed sludge is approximately 0.23 (based on a sludge composition of $C_5H_7O_2N$), the ammonia nitrogen evolved is:

$$\Delta N = 0.23 \Delta C \tag{7.1.8}$$

where ΔN = ammonia nitrogen evolved

and ΔC = organic carbon destroyed

Hence, the alkalinity due to the ammonia is given by

$$\text{alkalinity} = \frac{\Delta N}{14} = \frac{0.23 \Delta C}{14} \text{ meq/l} \tag{7.1.9}$$

The effluent pH is then calculated by the module described in Section 9.2.

7.2 The Anaerobic Digestor Model - ANDIG1

A listing of the program is given in Appendix K. The equipment vector for the model is reproduced below:

```
C     EN VECTOR
C     *********
C     1.-15. STANDARD FORMAT
C     4.     NUMBER OF DIGESTERS IN PARALLEL
C     5.     HEAD LOSS IN DIGESTERS (FT OF WATER)
C     16.    DIAMETER OF DIGESTER (FEET)
C     17.    DEPTH OF DIGESTER (FEET)
C     18.    = 1.0 FOR CONVENTIONAL DIGESTER OPERATION
C            = 2.0 FOR HIGH RATE DIGESTER OPERATION
C     19.    TEMPERATURE OF OPERATION
C     20.    FRACTION OF WATER TO FIRST OUTPUT STREAM (SUPERNATANT)
C            = 1.0 IF FIRST STAGE OF A TWO-STAGE SYSTEM
C     21.    FRACTION OF SOLIDS TO FIRST OUTPUT STREAM (SUPERNATANT)
C            (EXCLUDES SETTLEABLE INORGANIC SOLIDS)
C            = 1.0 IF FIRST STAGE OF A TWO-STAGE SYSTEM
C     22.    FRACTION OF SETTLEABLE INORGANIC SOLIDS TO SUPERNATE
C            = 1.0 IF FIRST STAGE OF A TWO-STAGE SYSTEM
C     23.    STORAGE SPACE FOR GAS PRODUCED
C     24.    FRACTION OF VOLUME THAT IS EFFICIENTLY USED IN DIGESTION
C
```

The computations carried out by the program can be explained briefly by the following steps:

(1) The fluid detention time is first calculated. EN(24) corrects for the fact that a fraction of the digester volume may be filled up with grit, etc., and hence is not available for digestion.

(2) The fraction of volatile solids destroyed is calculated from Equation 7.1.5.

(3) Based on a C:N:P ratio of 1.0:0.23:0.05, the amounts of nitrogen (as ammonia) and phosphorus released are then estimated.

(4) The soluble organic carbon of effluent is then obtained from Equation 2.

(5) The effluent pH is then calculated as discussed in Section 7.1.

(6) If the digester is used as the first stage of a two-stage digester, the contents are normally sent to the second stage, with little or no phase separation. This is maintained by constant stirring. Phase separation is used in the second stage to separate a a clearer supernate from a concentrated solids underflow. There is no known correlation for the solids concentration of the supernate and hence the phase separations is specified by EN(20), EN(21), and EN(22). Soluble components are split according to the water flows.

CHAPTER 8

8. OTHER UNIT PROCESSES

Other unit processes commonly used in wastewater treatment include pretreatment, the use of biological filters (trickling filters) and chlorination. The primary purpose of pretreatment is to remove large and abrasive materials from the wastewater, to protect downstream equipment and pumps. It includes screening to remove the larger solid objects and grit removal.

Biological filters have been used as an alternative to the activated sludge process. In this process, the wastewater is passed over a biological growth, supported on a solid medium. The waste is absorbed by the biological growth and excess solids is sloughed off the "filter" and removed by sedimentation. The contact time is short, being of the order of a few minutes and the effluent is generally unsatisfactory.

Chlorination is practiced to prevent the transmission of pathogenic microorganisms to the receiving waters. It is generally applied to the secondary effluent and in cases where no secondary treatment is supplied, to the primary effluent. In the few cases where no treatment is practiced at all, the raw wastewater is chlorinated, prior to discharge.

The thickening of waste sludges is also practiced. This reduces the volume of sludge to be handled, either for disposal or for further solids processing within the plant. Other methods of dewatering include vacuum filtration, centrifugation and air flotation.

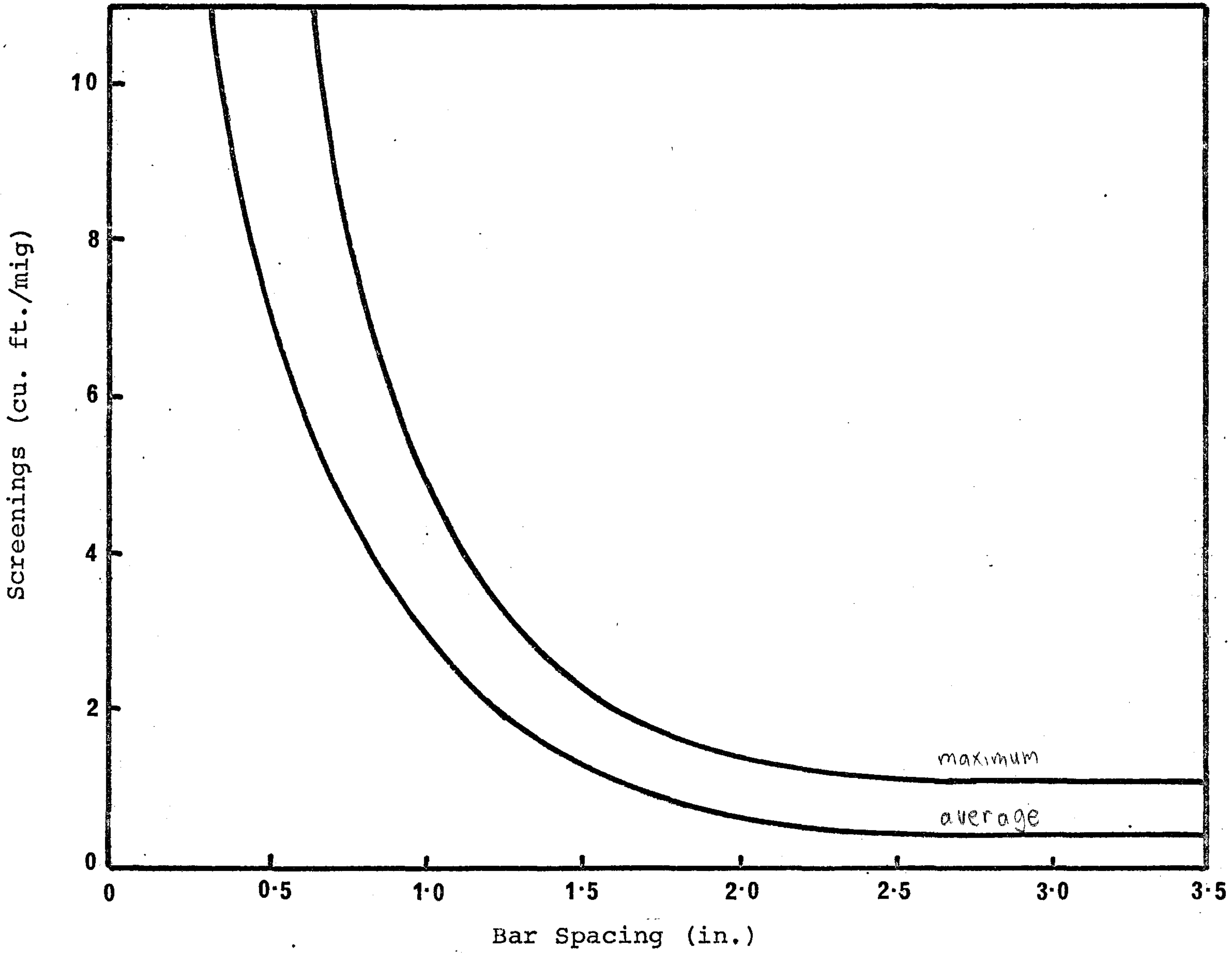
8.1 Pretreatment

Screening devices are usually classified as fine or coarse screens. In the category of fine screens there are perforated plates, wire-meshes and closely spaced bars. The openings are generally 3/16 in. or less. Coarse screens include comminuting devices, bar screens and coarse wire-meshes. The openings may be as large as 3 in.

The choice for the size of the openings is dictated by the size of the largest object which may be allowed to pass. In the majority of cases, a 1 in. opening is quite satisfactory.

The volume of screenings removed is difficult to estimate and depends not only on the screen size but also on the nature of the waste received, and the velocity of flow through the screens. The Rex Chainbelt Company (33) has developed a graph from which the average and maximum amount of screenings may be expected as a function of screen opening. This is reproduced in Figure 8.1.1. The average curve is approximately described by:

Figure 8.1.1. Screenings Volume as a Function of Bar Spacing



$$V = 19 \times 10^{-0.8d} \qquad (8.1.1)$$

where V = volume of screenings cu.ft./musg

and d = screen opening, inches

About 30 lbs. of dry solids may be expected per cu. ft. of screenings.

In grit removal, the object is to separate the non-putrescible solids from the waste flow with the minimum amount of entrained organic matter. This is achieved by differential sedimentation, which is made possible by the fact that the grit particles have subsiding velocities substantially greater than those of the organic solids. The flow-through velocities are also controlled to maintain the organic solids in suspension, by scouring the settled solids.

Velocity control can be maintained by the use of specially designed wiers, such as the Sutro Wier or the proportional wier. More recent developments in velocity-control devices include the use of compressed air to create a spiral current within the grit chamber. More details of the various types of grit chambers in use may be obtained from the "Sewage Treatment Plant Design Manual" (38).

As is the case with the quantity of screenings, the volume of grit to be expected at a plant cannot be confidently predicted. The quantities of grit received will depend on the area served by the sewers, the type of street and land surfaces prevalent in the district and on the percentage of storm sewers feeding into the plant.

Due to the great variation in quantities of grit received, the model written for the grit chamber will require that we specify the volume of grit to be expected in cu.ft./mig. As a rough guide to use in Ontario, a survey of 28 plants having separate sewers gave an average grit volume of 2.4 cu.ft./mig, while 20 plants having partially combined sewers received on the average 3.3 cu.ft./mig.

8.2 Trickling Filters

The theory proposed for the rapid rate of organic removal in a trickling filter is that the waste is biosorped and incorporated into the biological growth, supported on the solid media. As the wastewater passes down through the filter, progressive removal is achieved until the clear effluent emerges. Howland (21) and Schulze (35) have shown that at low concentrations, the rate of removal is of the first order with respect to the concentration of soluble organics remaining:

i.e., $$\frac{C}{C_o} = e^{-k_1 t} \qquad (8.2.1)$$

where C = effluent concentration of soluble organics

C_o = influent concentration of soluble organics

k_1 = reaction rate constant

and t = mean contact time.

Schulze (35) and Howland (21) have also shown that the mean contact time in a trickling filter is directly proportional to the depth and inversely proportional to the hydraulic loading to a power, n, which depends on the solid media used.

i.e., $$t = k_2\, D/Q^n \qquad (8.2.2)$$

where t = mean contact time (min.)

D = depth of filter (ft.)

Q = hydraulic loading (usgpm/sq.ft.)

k_2 = proportionality constant

and n = constant.

Values of n range from 0.55 for spheres (55) to 0.66 for a screen filter (35). The n value for an increasingly popular media, the synthetic Dowpac Plastic Media, is 0.5.

It has also been shown that the reaction rate could decrease with depth. This could arise if the more easily removable portions of the waste are removed at the top of the filter, leaving a less readily degradable matter for the lower portion of the trickling filter. Another possibility exists whereby the microbial population in the filter is stratified with the more efficint bacteria and fungi at the top and progressing downwards to the predator microorganisms.

A general relationship can be developed by combining Equations 8.2.1 and 8.2.2, and with a modification for the effect of depth on the reaction rate:

$$\frac{C}{C_o} = e^{-kD^m/Q^n} \qquad (8.2.3)$$

where k = rate coefficient or treatability factor

m = constant.

In the case where there is no effect of the depth on the reaction rate, m = 1. This has been found to be the case for domestic sewage by several investigators. Schulze (35) determined k to be 0.020 m to be 1.0 and n to be 0.66 for a screen treating settled sewage. McDermott (55) concurs similarly, but his rate coefficient is slightly lower, at 0.018. Germain (56) found m to be 1.0, n to be 0.48 and k to be much higher at 0.088, for the case of the Dowpac Filter Media. However, his data is based on only a few points.

8.3 Chlorination

The purpose of the model will be merely to calculate the chlorine requirements in a wastewater treatment plant. Since the effluent will not be directly used as a drinking water supply, but is discharged to a water-course, the criteria for chlorination is not so strict.

The chlorine dosage required depends on the degree of treatment the effluent has gone through. Raw sewage will require a higher chlorine dosage than the effluent from a secondary clarifier. The "Sewage Treatment Plant Design Manual" (38) gives the range of chlorine dosages commonly used, and this is reproduced in Table 8.3.1.

Stream	Chlorine Dosage mg/l
Raw sewage	6 - 12
Raw sewage (septic)	12 - 25
Settled sewage	5 - 10
Settled sewage (septic)	12 - 40
Chemical Precipitation effluent	3 - 10
Trickling filter effluent	3 - 10
Activated sludge effluent	2 - 8
Sand filter effluent	1 - 5

Table 8.3.1. Range of Chlorine Dosages Required for Disinfection.

8.4 Sludge Thickening and Dewatering

Sludge thickening performance is not very well correlated. Hence, only a simple mass balance model will be used. This is a slight modification of the SEPA01 model available from the GEMCS library of routines. The fractions of water (and water soluble components) and solids to the supernatant is supplied as inputs to the program.

Other dewatering devices are also approximately described by the same model.

CHAPTER 9

9. MODULES FOR HANDLING STREAM VARIABLES

There are certain calculations which occur frequently in some or most of the simulation models used in this study. As mentioned in Section 3, the stream elements 13-22 form the basic components of a waste flow. The simulation models directly use these variables in their internal calculations. However, in wastewater treatment practice, the more commonly used variable are those of stream elements 8-12, which include the BOD, SS, VSS, TOC and DOC. Hence it is necessary to convert from the "working" variables to the commonly reported variables.

Another area where calculations are frequently needed is in the pH - alkalinity relationship. Also in the activated sludge model, it is more convenient to use concentration variables (i.e., mg/l) than it is to use flow variables such as lbs./hr. Hence a module is also available to convert component flows into component concentrations.

9.1 Inter-relationship of Stream Variables

A series of experiments were performed to determine the relationships between the stream elements 8-12 and those of 13-22. Section 3.2 gives the relevant defining equations.

The Total Organic Carbon (TOC), which includes both the particulate and dissolved organic carbon forms, was first determined. To ensure that the injection needle would not "filter" out any solids, the sample was subjected to ultra-frequency sonication for five minutes.

The Total Five-day Biochemical Demand ($TBOD_5$), which includes the BOD_5 of both the particulate and soluble components, was then determined using the original sample.

The sample was then filtered on two Whatman's #40 filter papers (ashless). One filter paper was then ashed in a muffle furnace at 600°C and the other was dried at 103°C. This will yield the volatile suspended solids (VSS) of the sample. The filtrate was then used to determine the Dissolved Organic Carbon (SOC) and the Dissolved Five-day Biochemical Oxygen Demand ($DBOD_5$). All the above mentioned analyses were performed according to "Standard Methods" (48).

The results are summarized in Appendix G. The average values obtained for the conversion factors are:

(a) $$\text{FAC1} = \frac{DBOD_5}{SOC} = 1.91$$

with a standard deviation of 0.17

(b) $$\text{FAC2} = \frac{BOD_5\ \text{(particulate)}}{OC\ \text{(particulate)}} = \frac{TBOD_5 - DBOD_5}{TOC - SOC} = 1.24$$

with a standard deviation of 0.12

(c) $\text{FAC3} = \dfrac{\text{VSS}}{\text{OC (particulate)}} = \dfrac{\text{VSS}}{\text{TOC} - \text{SOC}} = 2.09$

with a standard deviation of 0.11

Eckenfelder (8) derived the value of 1.85 for FAC1. Smith (46) used the value 1.87 for FAC1. These two values agreed with our data. Smith reported a value of 0.80 for FAC2, whilst our value of 1.24 is much higher. The value of 2.13 is used by Smith for FAC3, which is close to our value of 2.09.

9.2 pH - Alkalinity Relationships

The major contributors to the alkalinity of municipal wastewaters are the species in the carbonate buffer system and ammonia. To a lesser extent, the phosphates and borates could contribute to the alkalinity.

The equilibrium conditions existing in solution can be described by (49):

For the carbonate system

$$H_2CO_3^* \rightleftharpoons H^+ + HCO_3^- \qquad (9.2.1)$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^= \qquad (9.2.2)$$

where $[H_2CO_3^*] = [CO_2 \text{ dissolved}] + [H_2CO_3]$ (9.2.3)

For the ammonium system

$$NH_4^+ \rightleftharpoons NH_3 + H^+ \qquad (9.2.4)$$

Self-ionization of water

$$H_2O \rightleftharpoons H^+ + OH^- \qquad (9.2.5)$$

The equilibrium constants for the above equations are:

$$k_1 = \frac{[H^+]\,[HCO_3]}{[H_2CO_3^*]} = 10^{-6.3} \qquad (9.2.6)$$

$$k_2 = \frac{[H^+]\,[CO_3^=]}{[HCO_3^-]} = 10^{-10.3} \qquad (9.2.7)$$

$$k_n = \frac{[H^+]\,[NH_3]}{[NH_4^+]} = 10^{-9.3} \qquad (9.2.8)$$

$$\text{and} \quad k_w = [H^+]\,[OH^-] = 10^{-14.0} \qquad (9.2.9)$$

The definition for alkalinity can then be expressed as

$$[ALK] = [HW_3^-] + 2\,[CO_3^=] + [NH_3] + [OH^-] - [H^+] \qquad (9.2.10)$$

where $[ALK]$ = alkalinity equivalents/litre

$[HCO_3]$ = bicarbonate ion concentration moles/litre

$[CO_3]$ = carbonate ion concentration moles/litre

$[NH_3]$ = free ammonia concentration moles/litre

$[OH^-]$ = hydroxyl ion concentration moles/litre

and $[H^+]$ = hydrogen ion concentration moles/litre

Due to the conservation of mass, we note that

$$[H_2CO_3{}^*] + [HCO_3{}^-] + [CO_3{}^=] = \text{constant} = [C_T] \quad (9.2.11)$$

and $$[NH_3] + [NH_4{}^+] = \text{constant} = [C_N] \quad (9.2.12)$$

Hence, from Equations 9.2.6 and 9.2.7, as well as from 9.2.11

$$[C_T] = \left\{\frac{[H^+]}{k_1} + 1 + \frac{k_2}{[H^+]}\right\}[HCO_3^-]$$

or $$[HCO_3{}^-] = [C_T]\left\{\frac{1}{\frac{[H^+]}{k_1} + 1 + \frac{k_2}{[H^+]}}\right\} \quad (9.2.13)$$

Similarly

$$[CO_3{}^=] = [C_T]\left\{\frac{k_2}{[H^+]}\right\}\left\{\frac{1}{\frac{[H^+]}{k_1} + 1 + \frac{k_2}{[H^+]}}\right\} \quad (9.2.14)$$

and $$[NH_3] = [C_N]\left\{\frac{1}{1 + \frac{[H^+]}{K_n}}\right\} \quad (9.2.15)$$

Therefore

$$[ALK] = [C_T]\left\{1 + \frac{2k_2}{[H^+]}\right\}\left\{\frac{1}{\frac{[H^+]}{k_1} + 1 + \frac{k_2}{[H^+]}}\right\}$$

$$+ \left[C_N\right] \left\{ \frac{1}{1 + \frac{\left[H^+\right]}{k_N}} \right\} + \left[OH^-\right] - \left[H^+\right] \qquad (9.2.16)$$

This is the defining equation used to relate the four variables $[ALK]$, $[C_T]$, $[CN]$ and pH. Given three of the variables, the fourth may be calculated. Note also that if streams are mixed, and assuming a closed system, there must be conservation of $[ALK]$ $[C_T]$ and $[C_N]$.

On expanding Equation 9.2.16, we obtain a polynomial of the fifth order in H^+:

$$\begin{aligned}
&\left[H^+\right]^5 + \left[H^+\right]^4 \left\{ [ALK] + k_1 + k_N \right\} \\
&+\left[H^+\right]^3 \left\{ [ALK]\ (k_1 + k_N) + k_1k_N + k_1k_2 - k_w - k_1[C_T] - k_N [C_N] \right\} \\
&+\left[H^+\right]^2 \left\{ k_1 [ALK]\ (k_2+k_N) + k_1k_2k_N - k_Nk_w - k_1k_N [C_T] \right. \\
&\qquad \left. -k_1k_w - 2k_1k_2[C_T] - k_1k_N [C_N] \right\} \\
&+\left[H^+\right] \left\{ k_1k_2k_N [ALK] - k_1k_Nk_w - 2k_1k_2k_N [C_T] \right. \\
&\qquad \left. -k_1k_2k_w - k_1k_2k_N [C_N] \right\} \\
&\qquad -k_1k_2k_Nk_w = 0 \qquad (9.2.17)
\end{aligned}$$

We could simplify the above equation by making some order of magnitude simplifications. Roughly, $[ALK] \approx [C_N] \approx [C_T] \approx 10^{-3}$.

This means that in the pH range of 5-9, the terms $[OH^-] - [H^+] \ll [ALK]$ in Equation 9.2.16. Hence we can drop out these two terms resulting in:

$$[C_T]\left\{1 + \frac{2k_2}{[H^+]}\right\}\left\{\frac{1}{\frac{[H^+]}{k_1} + 1 + \frac{k_2}{[H^+]}}\right\} = [ALK] - [C_N]\left\{\frac{1}{1 + \frac{[H^+]}{K_N}}\right\}$$

On expansion, a third order polynomial in $[H^+]$ results:

$$[H^+]^3 [ALK] + [H^+]^2\left\{k_N\left([ALK] - [C_N]\right) + k_1\left([ALK] - [C_T]\right)\right\}$$
$$+ [H^+]\left\{k_1k_N\left([ALK] - [C_N] - [C_T]\right) + k_1k_2\left([ALK] - 2[C_T]\right)\right\}$$
$$+ k_1k_2k_N\left\{[ALK] - [C_N] - 2[C_T]\right\} = 0$$

Equation 9.2.19 has been found for the several cases tried to give only one real root and two imaginary roots. This is very fortunate and helps simplify the solution of the cubic equation, for which a simple interval bisection technique is used. The bisection subroutine uses the geometric mean of the left and right estimates of the solution, in its convergence.

9.3 Inter-conversion Between Mass Flow and Concentration

Although the units used for the stream variables are for mass flow, it is frequently useful to convert them into concentration units. The model for the aerobic biological processes has its rate equations all in terms of component concentrations. The summary report generated has all the values expressed in concentrations, which is more meaningful than mass flows.

Due to the analytical procedures used in wastewater treatment, soluble components are usually expressed as milligrams per litre of water, while solid components are expressed in milligrams per litre of sample. In the case where the concentrations involved are less than 1000 mg/l (0.1%) the difference between the two is negligible. However, since sludges of up to 80,000 mg/l (8%) are handled in our system, the distinction should be made.

For soluble components we then use

$$C_i = \frac{F_i}{W} 10^{-6} \qquad (.3.1)$$

where C_i = concentration of soluble component i (mg/l)

F_i = mass flow of soluble component i (lbs/hr)

and W = mass flow of water (lbs/hr)

For particulate components we use

$$C_i = \left(\frac{F_i}{Q}\right) \times 10^{-5} \qquad (9.3.2)$$

where C_i = concentration of particulate component i (mg/l)

F_i = mass flow of particulate component i (lbs/hr)

and Q = total volumetric flow of stream (gal/hr)

CHAPTER 10

10. WASTEWATER TREATMENT COSTS

Besides the technical aspects of wastewater treatment, we have to concern ourselves with the costs that such a program would entail. In the expectation of increased activity in the area of pollution abatment, it is becoming more essential that we have accurate cost estimates to base our designs on. A large part of current practice has been to use "rules of thumb" which have fairly large safety factors built into them. An optimal design for a treatment plant, subject to the requirements of the regulatory bodies, can be arrived at by combining the technical section of our simulation with the corresponding cost estimates.

For each unit process in wastewater treatment, capital costs as well as operating and maintenance costs are available as a function of the most prominent capacity factor. For example, the capital cost of the activated sludge tanks is derived as a function of its volume. Most of the correlations are based on the same idea as the six-tenths capacity factor used in Chemical Engineering.

The bulk of the correlations come from the work of Russell and Swanson as reported in Smith's paper in 1969 (46), and from Eckenfelder and Barnard (2). Industrial waste treatment costs are also given in the latter report.

The capital costs are all updated to 1969 costs by the use of the Engineering News Record Index of 1120. This index, being based on changes in the price of steel, cement, lumber and common labour, is most appropriate for wastewater treatment process equipment. The capital cost correlations used are summarized in Table 10.1.

The total cost of the unit processes (installed) is then the sum of the separate costs. It is assumed that the duplication of a unit merely doubles the cost for the unit. This does not take into account that there may be savings due to shared pipings or channels or other factors.

The Physical Plant Cost can then be found by adding the cost of the control house and site improvements on to the total unit processes cost. The Engineering Costs added to the Physical Plant Cost will give the Direct Plant Cost. The Engineering Cost factor is obtained as a fraction of the Physical Plant Cost. As given in Smith (46)

$$\mathrm{CENG} = 8.0 \left(\frac{1{,}000{,}000}{\text{Physical Plant Cost}} \right)^{0.146} \qquad (10.1)$$

where CENG = Engineering Cost factor.

The Fixed Capital Cost can then be computed by adding the Contractor's fee (10% of Direct Plant Cost) and the contingency costs (15% of Direct Plant Cost) to the Direct Plant Cost. These figures are suggested by Smith (46) and

Unit	Capacity Variable	Capital Cost $
Pretreatment	Design flow, Q, migd	$21800\ (A)^{0.63}$
Primary Sedimentation	Surface Area, SA, thousand sq. ft.	$17300\ (SA) + 6700\ (SA)^{0.1}$
Activated Sludge Tanks	Volume, V, mig	$27000\ (V) + 67000$
Air Blowers	Blower capacity, C, thousand cfm	$13600 + 7600\ (C)$
Final Sedimentation	Surface area, SA, thousand sq. ft.	$16200\ (SA) + 6900/(SA)^{0.13}$
Return Sludge Pumps	Pump capacity, PC, migh	$4700 + 1700\ (PC)$
Anaerobic Digester	Volume, DV, thousand cu. ft.	$1340\ (DV) + 1800\ (V)^{0.13}$
Chlorinator	Design flow, Q, migd	$12600\ (Q)^{0.47}$
Vaccum Filter	Filter area, FA, hundred sq. ft.	$16500 + 48000\ (FA)$
Sludge Incinerator	Sludge handing capacity, S, lbs/day	$7.1\ (S) + 0.3\ (S)^{1.61}$
Sludge Drying Beds	Surface area, A, sq. ft.	$2.23\ (A)$
Sludge Thickener	Surface area, SA, thousand sq. ft.	$(SA)(24200 + 11700/\exp(SA/13.3))$
Trickling Filter (Dowpac)	Volume, FV, thousand cu. ft.	$66000\ (FV)^{0.6}$

Table 10.1. Capital Cost Correlations

```
                         FIXED CAPITAL ESTIMATE
                         **********************
DRURY LANE SEWAGE TREATMENT PLANT - BURLINGTON. CAPITAL COST IN  1962

    PRETREATMENT                               $       28567.21
    PRIMARY SETTLING TANKS                             32399.94
    ACTIVATED SLUDGE TANKS                            115112.80
    AIR BLOWERS                                        36785.71
    SECONDARY SETTLING TANKS                           56952.29
    SLUDGE RETURN PUMPS                                 6658.21
    ANAEROBIC DIGESTERS                               118303.96
    CHLORINATOR                                         9270.00
                                                ---------------
    TOTAL UNIT PROCESSES (INSTALLED)           $      404050.13
    CONTROL HOUSE                                      81877.54
    PLANT SITE                                          7579.74
                                                ---------------
    PHYSICAL PLANT COST                        $      493507.41
    ENGINEERING                                        43768.61
                                                ---------------
    DIRECT PLANT COST                          $      537276.02
    CONTRACTOR≠S FEE (0.1 DPC)                         53727.60
    CONTINGENCY (0.15 DPC)                             80591.40
                                                ---------------
    FIXED CAPITAL COST                         $      671595.03
                                                ---------------
```

Table 10.2. Capital Cost for Drury Lane Plant

are about average in the Chemical Process Industry. The derivation of the Fixed Capital Cost is summarized in Table 10.2, for the case of the Drury Lane, Burlington Water Pollution Control Plant. The actual plant cost in 1962 was $676,033.78, while the estimated cost was $671,595.03. The difference is less than 1%.

The operating and maintenance costs of the unit processes are normally reported in the literature together as one cost. Smith (46) and Eckenfelder and Barnard (2) have reported them in terms of annual costs (utilities excluded). This necessitates the use of a "Labour Index" to bring these costs up to date. However, we can avoid this by converting the annual costs to man-hours required per year, by dividing by the labour cost $/man-hours for the year in which the correlations were obtained. This was calculated from the average wage of $110/week or approximately $3.00/man-hour in 1966 (26). The annual cost is then computed by multiplying the man-hours required by the current labour cost. Table 10.3 summarizes the operating and maintenance man-hours used in the program.

Again we have assumed that the duplication of a unit will double the number of man-hours required to operate and maintain the units.

The sum of the Operating and Maintenance Costs for the unit processes will give the total labour cost. This, together with supervision, utilities, sludge haulage, chemical and plant supplies, will give the Direct Operating and Maintenance Cost. Supervision is assumed to be 10% of the Total Labour Cost. Chemical and plant supplies are assumed to be 6% and 5% of the Total Labour Cost, repectively. These estimates are obtained from the Ontario Water Resources Commission annual reports on their plant operations. The estimates of power consumption provided by Michel (26) can be correlated to give the following annual power consumption P in kwh:

For Primary Plant $P = 101000\ Q^{0.65}$

For Trickling Filter Plant $P = 162000\ Q^{0.65}$

For Activated Sludge Plant $P = 378000\ Q^{0.65}$

where Q is the plant flow in migd.

Sludge haulage fees in Ontario vary and from the annual reports of the Ontario Water Resources Commission, an approximate correlation is obtained as:

Sludge haulage costs $= 8000\ (Q)^{0.5}$ \$/yr.

where Q = sludge volume hauled, mig/yr.

Indirect costs are generally not significant, the most important of which is for laboratory analyses. The bigger plants usually conduct their own analyses, while the smaller ones tend to send them away to be done. The Net Operating and Maintenance cost will then be the sum of the Direct and Indirect costs.

To obtain the true annual cost, we have to take into account the cost of the Fixed Capital Investment. In the case of owned capital, we have to include depreciation and opportunity costs. The capital recovery factor to use is:

$$CRF = \frac{S\ (1 + S)^n}{(1 + S)^n - 1} \qquad (10.2)$$

where CRF = Capital Recovery Factor

S = interest rate that owned capital can obtain elsewhere

and n = expected life of plant.

The cost of the Fixed Capital Investment to the municipality of company, annually, is then

$R = CRF\ (L_o - I_s)$

where R = amortization

I_o = Fixed Capital Investment

and I_s = scrap value of project at the end of n years.

In the case of borrowed capital, which is the usual case with most municipalities, we have to add debt retirement plus accrued interest to the Net Operating and Maintenance Cost to obtain the true Annual Cost. The factor can be calculated from the same equation, but the interest rate on the loan s and the debt reitrement period n may be different.

The derivation of Total Annual Cost is shown in Table 10.4, again, for the case of the Drury Lane, Burlington Water Pollution

Control Plant. The actual operating cost in 1969 was $103,520.52, while the projected cost was $109,116.34, which is about 5% higher.

Unit	Capacity Variable	Annual Operation & Maintenance man/hr. Requirements
Pretreatment	Plant flow, Q, migd	$133(Q) + 510(Q)^{0.37}$
Primary Sedimentation	Surface area, SA, thousand sq. ft.	$222(SA) + 555(SA)^{0.5}$
Activated Sludge including blower and final sedimentation	Aerator volume, V, mig and plant flow, Q, migd	$720(Q) + 590(Q)/V^{0.67}$
Anaerobic Digester	Digester volume, DV, thousand cu. ft.	$13(DV) + 144(DV)^{0.5}$
Chlorinator	Plant flow, Q, migd	$30(Q) + 170(Q)^{0.37}$
Vacuum Filter	Plant flow, Q, migd	$0.27(Q) + 154(Q)^{0.37}$
Sludge Incinerator	Plant flow, Q, migd	$400(Q) + 1600(Q)^{0.37}$
Sludge Drying Beds	Surface area, A, sq. ft.	$0.014(A) + 20(A)^{0.37}$
Trickling Filter	Volume, FV, thousand cu. ft.	$10(FV) + 210(FV)^{0.5}$

Table 10.3. Annual Operating and Maintenance Man-Hour Requirements

```
                          ANNUAL OPERATING COST
                          *********************
DRURY LANE SEWAGE TREATMENT PLANT - BURLINGTON.  TOTAL ANNUAL COST IN 1969

          UNIT PROCESSES                   MAN-HOURS          COST $/YR
     PRETREATMENT                            819.67            2868.84
     PRIMARY SEDIMENTATION                  1442.33            5048.16
     ACTIVATED SLUDGE                       2850.95            9978.31
     ANAEROBIC DIGESTION                    1028.51            3599.78
     CHLORINATION                            250.29             876.01
     SLUDGE HAULING                                            7332.12
                                       --------------     --------------
     TOTAL UNIT PROCESSES O AND M           6391.74     $     29703.22
     SUPERVISION (0.1 L)                                       2970.32
     UTILITIES                                                10261.24
     CHEMICALS  (0.06 L)                                       1782.19
     PLANT SUPPLIES (0.05 L)                                   1485.16
                                                          --------------
     DIRECT O AND M COST                                $     46202.14
     LABORATORY                                                   0.00
                                                          --------------
     NET O AND M COST                                   $     46202.14
     ANNUITY PAYMENTS                                         62914.20
                                                          --------------
     TOTAL ANNUAL COST                                  $    109116.34
                                                          --------------
```

Table 10.4. Operating Costs for Drury Lane Plant

CHAPTER 11

11. INTER-ACTIVE VERSION

An inter-active version of the simulation was written to enable the user to set up a dialogue with the computer. This can be used in the following ways:

(1) As a teaching tool to train operators and other students,

(2) To enable plant personnel to predict plant performance due to changes in feed flows and/or operating conditions, and

(3) As a quick and accurate aid to plant designers.

An important feature of the inter-active version is that it requires only a very minimum knowledge of the GEMCS system for its use. This is achieved through a series of questions and answers posed by the computer. Of course, a user with a good knowledge of GEMCS, can manipulate and use the inter-active version with greater flexibility.

The inter-active version consists of four subroutines and a slightly modified version of the main program of GEMCS. The four subroutines are FLWCHT, CASET, ICLOAD and ENSET. Their functions will be described below.

FLWCHT enables the user to set up his own plant layout, together with the physical dimensions of the various units. It has an enlarged process flow diagram covering most of the common unit processes encountered in wastewater treatment plants. This is shown in Figure 11.1. Ths units are selected or by-passed by the use of the mixer-splitter module. The majority of the data set is read in by DLOAD1, to minimize the use of the teletype to input such information. Module numbers, module types, input and output stream numbers and so on are predetermined for all the units in the process flow diagram and hence can be read in by DLOAD1. The calculation order and the physical dimensions of the various units are determined by a dialogue with the user.

CASET is used to generate a random case study. It generates a random feed by multiplying the average value of each component flow by a random factor ranging between 0.5 and 2.0. It also generates a failure in one of the plant units. The purpose of the subroutine is to teach operators what to do in the event that such a flow or plant failure occurs, as well as to locate the cause of such a failure.

ICLOAD is the analytical laboratory of the simulation. All information regarding stream flows and component concentrations are supplied through ICLOAD. A charge is levied for each analysis performed, the object of the game being to locate and correct a plant failure with the minimum number of analyses. A surcharge is also placed on any unsatisfactory effluent. Five cents is levied on each pound of suspended solids and Biochemical Oxygen Demand, above the regulatory level of 20 mg/l for both. This provides the incentive to correct a plant failure with the minimum delay.

ENSET enables the user to change any operating conditions by changing the appropriate values of the EN vectors. The process flow diagram however, cannot be changed. This must be done through FLWCHT.

In addition to the above four subroutines, slight changes are made to the other modules, primarily to suppress excessive printing.

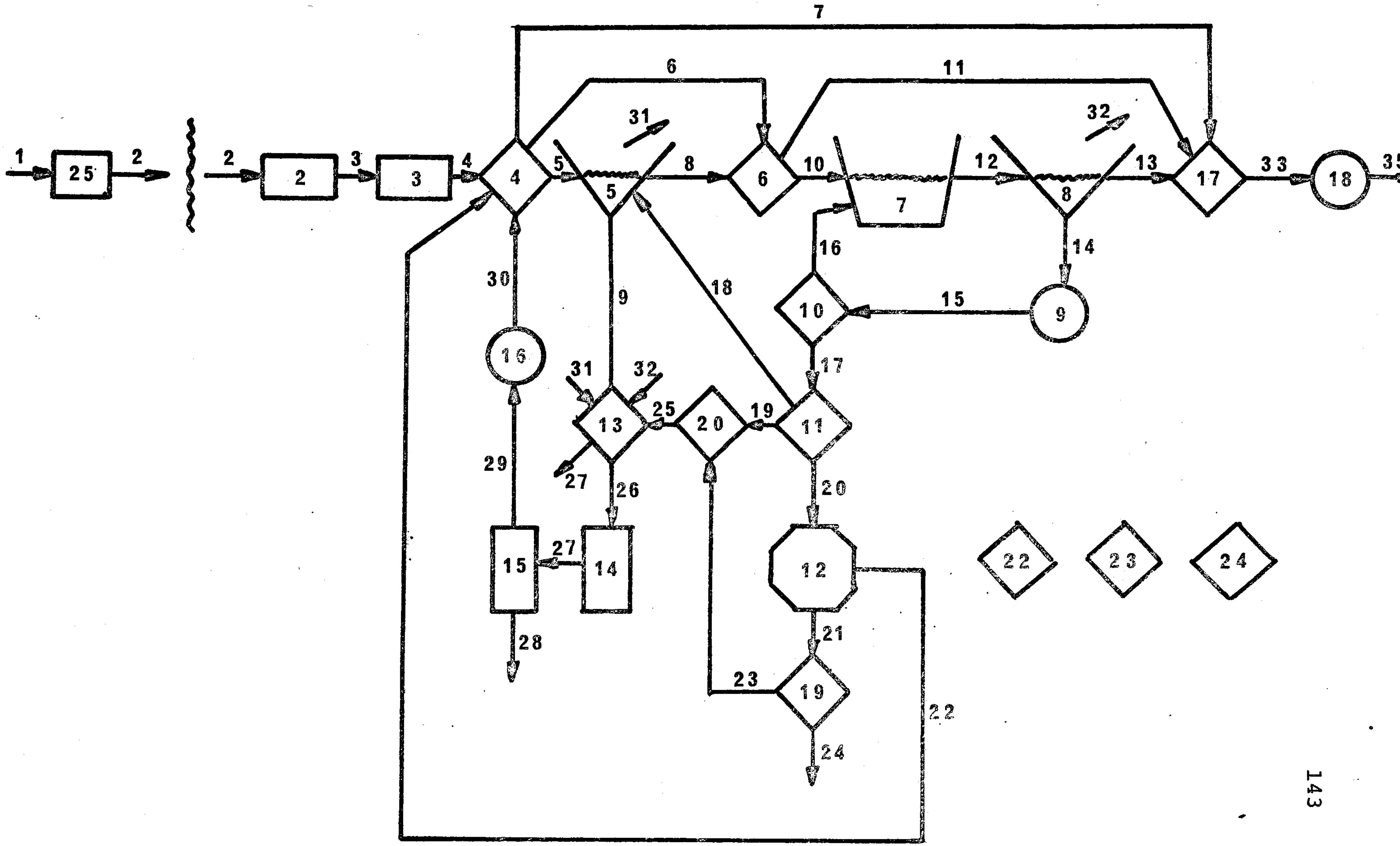


Figure 11.1. Process Flow Diagram for the Interactive Version

Key to Figure 11.1.

Module Number	Equipment
2	SCREEN1 - Screens
3	GRIT1 - Grit chambers
4	MIXER1
5	PRISET1 - Primary clarifiers
6	MIXER1
7	ACTSL1 - Activated sludge tanks
8	SECLAR1 - Secondary clarifiers
9	SETSP1
10	MIXER1 - Control sludge wasting
11	MIXER1
12	SEPAO1 - (Thickener)
13	MIXER1
14	ANDIG1 - First stage digestion
15	ANDIG1 - Second stage digestion
16	SETSP1
17	MIXER1
18	CHLOR1 - Chlorinator
19	MIXER1
20	MIXER1
22	C0NTL1
23	C0NTL1
24	REPTO1 - Report generator
25	CASET - Case generator

CHAPTER 12

12. TEST RUNS

The two plants selected for simulation are the Drury Lane and the Skyway Sewage Treatment plants. The former is a conventional activated sludge process, whilst the latter employs the extended aeration modification. In addition to testing the various models developed, the two simulations should show that the same kinetics can be used for the activated sludge process, regardless of the process modification.

The base cases used will be the average flow and operating conditions for 1969, obtained from plant data and also from the Ontario Water Resources Commission's Annual Summaries. The 1969 data were chosen, as the operating and flow conditions were fairly constant throughout the year. Due to the diurnal variation in the feed flows, the steady-state models can, at best, predict the average performance of the various units. It is for this reason that no attempt was made to collect base case data on any particular day, as this would require at least a twenty four hour sampling schedule, for a week.

12.1 Simulation of the Drury Lane, Burlington Sewage Treatment Plant

The process flow diagram for the plant is shown in Figure 12.1.1, and the design data is summarized in Appendix I.

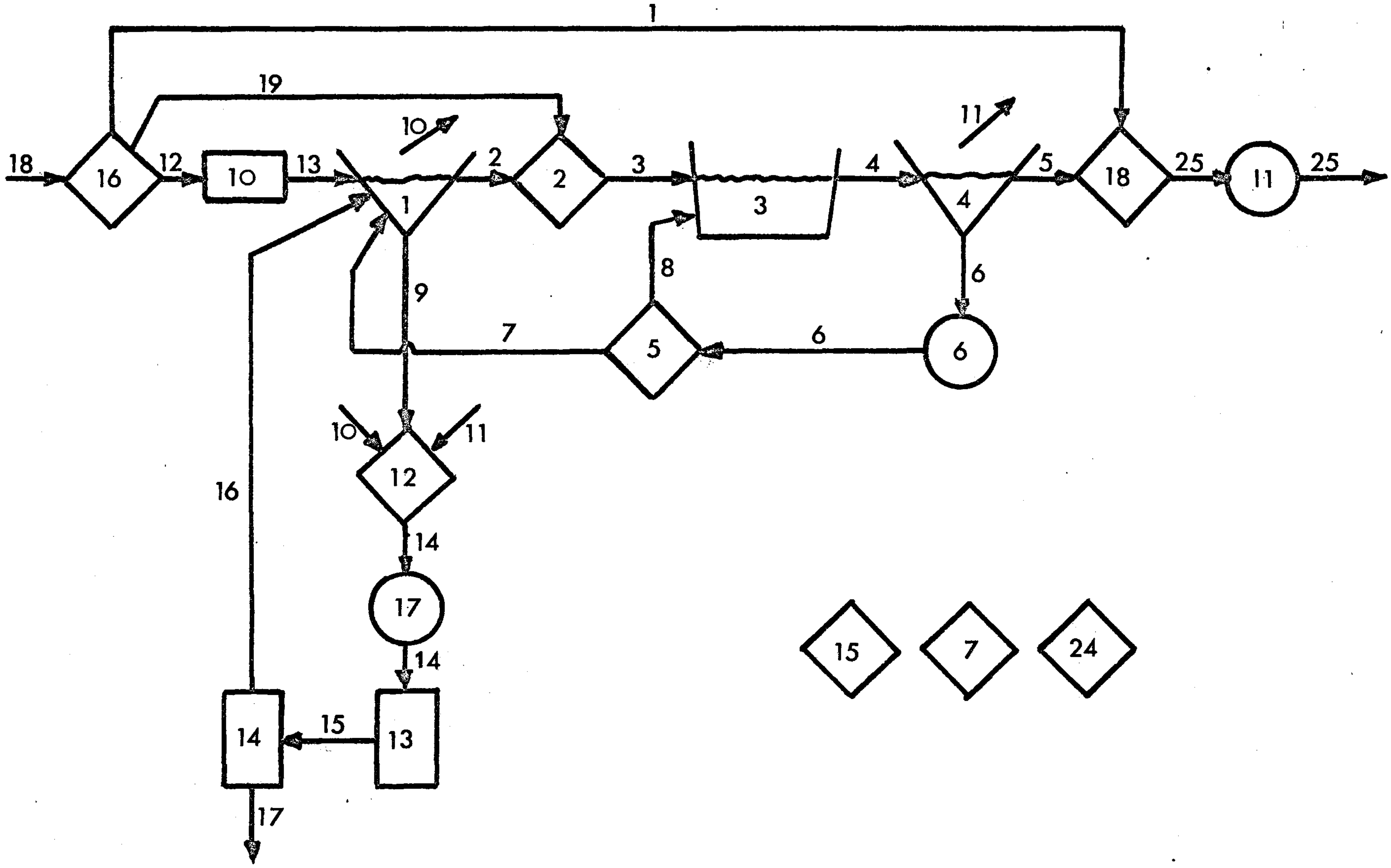


Figure 12.1.1. Process Flow Diagram of the Drury Lane Plant

Key to Figure 12.1.1.

Module Number	Equipment
1	PRISET1 - Primary clarifiers
2	MIXER1
3	ACTSL1 - Activated sludge tanks
4	SECLAR1 - Secondary clarifiers
5	CØNTO2 - Controls sludge wasting
6	SETSP1
7	CØNTL1
10	GRIT1 - Grit chambers
11	CHLØR1 - Chlorinator
12	MIXER1
13	ANDIG1 - First stage digestion
14	ANDIG1 - Second stage digestion
15	CØNTL1
16	MIXER1
17	SETSP1
18	MIXER1
24	REPTO1 - Report generator

It was originally designed for a flow of 2.5 migd. However, due to the expansion of the Skyway plant, part of the flow was diverted to the latter plant, and the actual flow received was 1.6 migd, in 1969. The average BOD and TSS for the raw sewage is 215 mg/l and 299 mg/l, respectively.

The pretreatment section consists of 1-inch bar screens and grit channels with a detention time of approximately one minutes. Primary treatment consists of two tanks with dimensions 29.3 ft. x 18 ft. x 12.25 ft. Secondary treatment is provided by two triple-pass activated sludge tanks, each with a total length of 321.5 ft., width of 18 ft. and depth of 10.7 ft. Total air blower capacity is 3000 scfm. Two circular secondary clarifiers are employed, each with a radius of 25 ft. and depth of 10.6 ft. A two-stage digestion system is used to handle the waste sludge generated. The first stage consists of two 40 ft. diameter tanks with a depth of 20 ft., and the second stage consists of one 40 ft. diameter tank with a depth of 18 ft. A summary of the operating conditions and the parameters used for the simulation is shown in Table 12.1.1.

The data set used for the simulation is shown in Appendix I. The computer printout for the case is also included in Appendix I. A summary of the results from the simulation, together with the plant data is shown in Table 12.1.2.

The removal of Total Suspended Solids by the primary clarifier was predicted to be 49% while the observed removal was 48%. The BOD removal predicted was 30% compared to the actual removal of 33%. Both removals were predicted very well by the primary clarifier model.

The Total Suspended Solids in the final effluent is identical with the value observed, which was 20 mg/l. The BOD of the final effluent was predicted to be 22 mg/l, while the observed value was lower at 15 mg/l. The agreement is quite good.

The predicted Total Suspended Solids of the return activated sludge was 11,700 mg/l with a volatile content of 57%. The observed values were 12,000 mg/l and 60% respectively.

The simulation predicted that a greater volume of sludge should be sent to the digester than was actually observed. A raw sludge flow of 7600 igpd was calculated, while the reported flow was much lower at 5300 igpd. This is reasonable since a considerable amount of solids is lost during a rain, but which is not accounted for. The figures imply that about 30% of the solids which should go to the digester was lost over the wiers of the secondary clarifiers, either during a storm or due to a plant upset.

The simulation predicted a digested sludge flow of 3000 igpd at a Total Suspended content of 5.8% as compared to the volumes of 2300 igpd hauled away for disposal. The anaerobic digester model predicted a much higher volatile solids destruction than was observed. This is reflected in the lower volatile solids concentration predicted for the digested sludge.

RAW SEWAGE:

average flow = 1.6 migd

average TSS = 299 mg/l

average VSS = 195 mg/l

percent of voltile solids settleable = (77%)

percent of inorganic solids settleable = (46%)

average BOD = 215 mg/l

average DOC = (61) mg/l

PRIMARY SETTLING TANKS: (using nomenclature of Chapter 4)

$$W_r = \emptyset \exp(-kt^{\alpha}/H^{\beta})$$

where $k = 0.23$

$\alpha = 0.5$

$\beta = 0.25$

and $\emptyset = 0.85$

average underflow solids concentration = 60,000 mg/l

ACTIVATED SLUDGE TANKS: (using nomenclature of Chapter 5)

$k_1 = 0.0028$ hr^{-1}

$k_2 = 0.0014$ hr^{-1}

$k_3 = 0.000002$ hr^{-1}

k_4 ,= 0.0010 hr^{-1}

$k_5 = 2.2$ hr^{-1}/(cu.ft.air/cu.ft.reactor)

$y = 0.54$

MLSS = 2200 mg/1

RTD model: 3 CSTR's in series.

SECONDARY SETTLING TANKS: (using nomenclature of Chapter 6)

$$XRSS = \frac{556\ (GSS^{0.494})\ \times 1.5}{(MLSS^{1.82})(TM^{1.5})}$$

$$SVI = 56.1 + 113\ (FM)\ (1.05^{T-20})$$

fraction of time return sludge pumps used = 0.3

ANAEROBIC DIGESTER: (using nomenclature of Chapter 7)

1st stage at high-rate, k = 0.082

2nd stage at conventional rate, k = 0.026 day^{-1}

fraction of flow to supernate = 0.6

Figure 12.1.1. Operating Conditions and Parameters Used In the Simulation of the Drury Lane Plant

Stream	Flow (migd)		BOD (mg/l)		TSS (mg/l)		VSS (mg/l)		DOC (mg/l)	
	Plant Data	Predicted	Plant Data	Predicted	Plant Data	Predicted	Plant Data	Predicted	Plant Data	Predicted
Raw Feed	1.6	-	215	-	299	-	191	-	(61)	-
Primary Effluent	1.6	1.6	145	151	155	153	80	76	-	60
Primary Clarifier Underflow	-	0.0069	-	-	-	63900	-	41500	-	60
Secondary Effluent	1.6	1.59	15	22	20	20	8	11	-	10
Return Activated Sludge	(0.32)	0.30	-	-	12000	11700	7200	6620	-	10
Raw Sludge to Digester	0.0053	0.0076	-	-	58000	65400	37000	45300	-	60
Digester Supernate	0.0028	0.0044	-	-	8000	4300	-	1600	-	82
Digested Sludge	0.0023	0.0030	-	-	57000	58600	22000	12100	-	82

Table 12.1.2. Simulation of the Drury Lane, Burlington, Water Pollution Control Plant

12.2 Simulation of the Skyway, Burlington, Sewage Treatment Plant

The process flow diagram for the plant is shown in Figure 12.2.1, and the design data is summarized in Appendix J. The average flow in 1969 was 3.3 migd, but due to an expansion completed in 1970, it is now receiving about 6.0 migd.

Pretreatment consists of a 2½ inch coarse screen followed by a 1 inch screen, both mechanically cleaned. Grit removal is achieved by an aerated grit chamber with a detention time of approximately 20 minutes. There are no primary tanks in the Skyway Plant. The activated sludge process employed is that of the extended aeration modification, and consists of six single-pass tanks with dimensions of 270 ft. x 27 ft. x 15 ft. The total blower capacity is 18000 scfm. Secondary clarification is provided by four settling tanks, 60 ft. square and 12 ft. deep. Waste sludge is thickened in a circular tank, 20 ft. in diameter and 9 ft. deep. A summary of the operating conditions and the parameters used in the simulation is shown in Table 12.2.1.

The data set for the simulation is shown in Appendix J, together with the computer printout for the case. A summary of the results from the simulation together with the plant data is shown in Table 12.2.2.

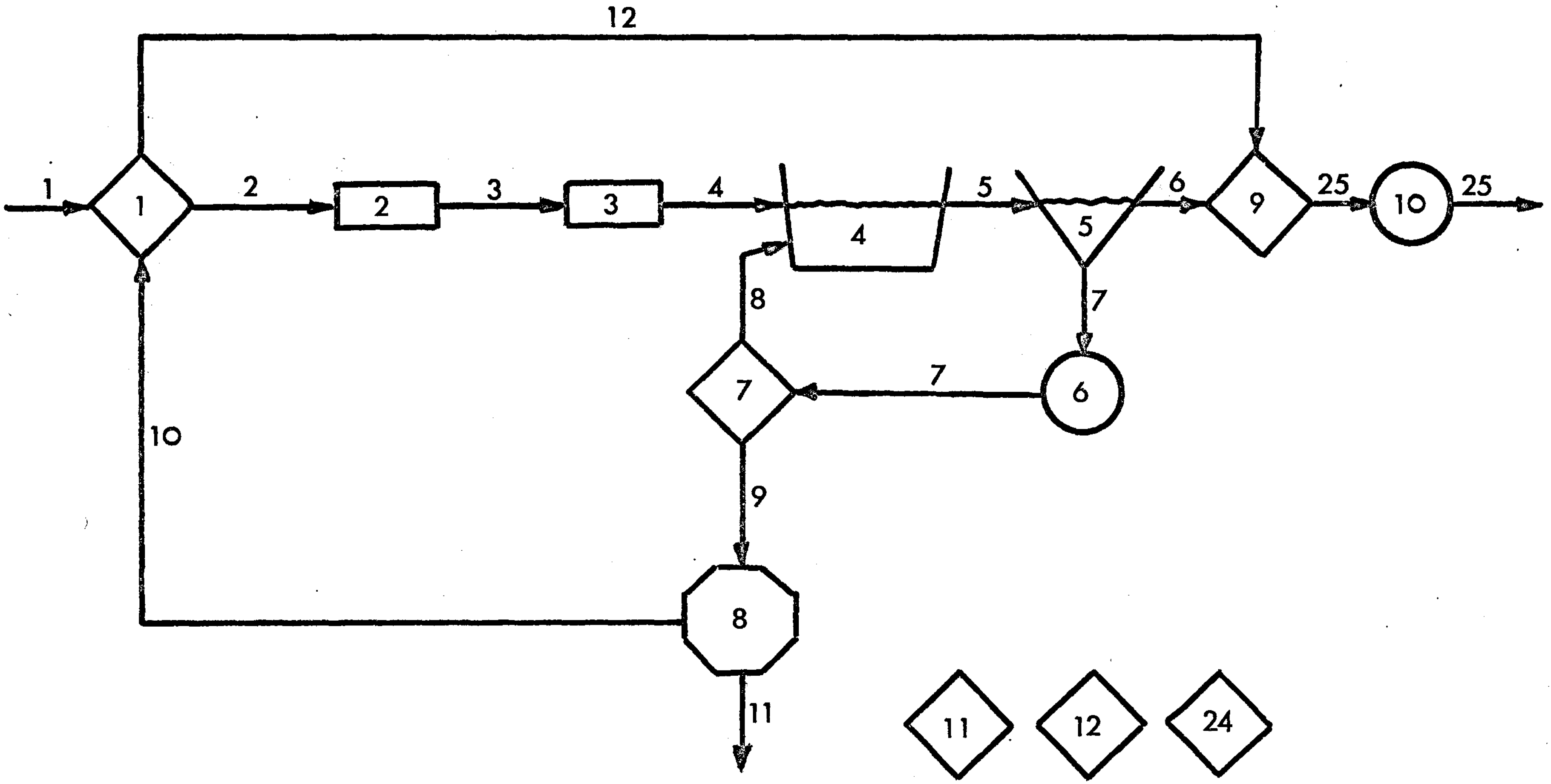


Figure 12.2.1. Process Flow Diagram of the Skyway Plant

Key to Figure 12.2.1.

Module Number	Equipment
1	MIXER1
2	SCREEN1 - Screens
3	GRIT1 - Grit chambers
4	ACTSL1 - Activated sludge tanks
5	SECLAR1 - Secondary clarifiers
6	SETSP1
7	C0NT02 - Controls sludge wasting
8	SEPA01 - (Thickener)
9	MIXER1
10	CHL0R1 - Chlorinator
11	C0NTL1
12	C0NTL1
24	REPT01 - Report generator

The simulation predicted a slightly better final effluent than was observed. The BOD and TSS predicted were 8 mg/l and 10 mg/l respectively, while the observed values were 12 mg/l and 12 mg/l respectively.

From plant data, the average suspended solids concentration in the return sludge was 10,000 mg/l, while the simulation predicted a value of 9,500 mg/l. The agreement is very good. However, the average volatile content of the sludge observed was 60% while the simulation gave a value of 42%.

A greater discrepancy occured here than was with the case of the Drury Lane Plant, in the volume of sludge hauled away. The simulation predicted that a volume of 22,000 igpd at a solids content of 2.1% should be hauled away, but actual plant figures indicated that only 4000 igpd at 2.0% solids were hauled away. Although upsets are frequent in a plant this size, the almost five-fold difference in the thickened sludge for disposal is unexpected. From a rough balance on the solids over the entire plant, the volume of sludge produced should be approximately

$$\frac{3.3 \times 10^6 \times (185 - 12)}{20,000}$$

$$= 28,000 \text{ igpd, at } 2.0\% \text{ solids}$$

This figure is in better agreement with the predicted value. Continuous sampling of the final effluent will probably show up the difference.

RAW SEWAGE:

average flow = 3.3 migd

average TSS = 185 mg/l

average VSS = 85 mg/l

average BOD = 155 mg/l

average DOC = (62) mg/l

ACTIVATED SLUDGE Tanks: (using nomenclature of Chapter 5)

$k_1 = 0.0028\ hr^{-1}$

$k_2 = 0.0014\ hr^{-1}$

$k_3 = 0.000002\ hr^{-1}$

$k_4 = 0.0010\ hr^{-1}$

$k_5 = 2.2\ hr^{-1}$

$Y = 0.54$

MLSS = 4000 mg/l

RTD model: 3 CSTR's in series

SECONDARY SETTLING DATA: (using nomenclature of Chapter 6)

$$XRSS = \frac{556\ (GSS^{0.494}) \times 1.5}{(MLSS^{1.82})\ (TM^{1.5})}$$

$$SVI = 56.1 + 113\ (FM)\ (1.05^{T-20})$$

Fraction of time return sludge pumps used = 0.4

THICKENER: Fraction of liquid to overflow = 0.6

Fraction of solids to overflow = 0.1

Table 12.2.1. Operating Conditions and Parameters Used in the Simulation of the Skyway Plant

Stream	Flow (migd)		BOD (mg/l)		TSS (mg/l)		VSS (mg/l)		DOC (mg/l)	
	Plant Data	Predicted	Plant Data	Predicted	Plant Data	Predicted	Plant Data	Predicted	Plant Data	Predicted
Raw Feed	3.3	-	155	-	185	-	84	-	(62)	-
Secondary Effluent	3.3	3.3	12	8	12	10	3	4	-	4
Return Activated Sludge	2.1	2.35	-	-	10000	9500	6000	4000	-	4
Thickened Sludge	0.004	0.022	-	-	20000	21000	12000	9000	-	-

Table 12.2.2. Simulation of the Skyway, Burlington, Water Pollution Control Plant

CHAPTER 13

13. DISCUSSION OF RESULTS

13.1 Discussion of Experimental Data

13.1.1 Primary Settling Data

Our settling curve analysis is based on the settleable solids present in the raw waste. The same analysis when applied to the total suspended solids gave less consistent results between the runs, as can be seen from Table 13.1.1.

Run Number	Source	k	α	β
A-1	Dundas (1971)	0.164	0.372	0.216
A-2	Drury Lane (1971)	0.202	0.403	0.285
A-3	Dundas (1970)	0.211	0.410	0.311
A-4	Dundas (1969)	0.150	0.397	0.252

Table 13.1.1. Correlations for the Batch Settling Data, Based on Total Solids

An assumption made in our model is that the removal obtained is the same for all classes of settleable solids. The validity of the assumption, although not tested, can be checked by taking volatile suspended solids measurements, together with the usual suspended solids readings.

A shortcoming of our data is the fact that our batch settling column is only 8 ft. tall. This means that an effective liquid depth of only 6 ft. may be used. Most primary settling tanks have liquid depths between 8 ft. and 12 ft., thereby necessitating the extrapolation of our data, to predict their performance.

13.1.2 Tracer Studies of Primary Sedimentation Tanks

In an attempt to evaluate the level of turbulence existing in the primary settling tanks, tracer studies were performed. The results were discouraging. Tracer recoveries were of the order of 80% and consequently the detention times estimated from the exit age distributions were much lower than the hydraulic detention times. The loss of the tail end of the exit age distribution also affects whatever model we try to fit to the flow pattern. Another tracer system should have been used where the recovery obtained is much higher.

The use of a pulse input is also a poor choice as it generates a tail end in the exit age distribution, which is very important but where the accuracy of measurement is poor. Time Series Analysis, using a series of random pulse inputs would largely remove this source of error.

We had to revert to a simplified treatment to correct for the effects of turbulence by defining the efficiency factor. The fact that a fairly constant efficiency factor exists for the primary tanks in both the Dundas and Drury Lane plants seem to suggest that a correlation is possible, relating the efficiency factor with a parameter that represents the level of turbulence in the tanks.

13.1.3 Data From the Chemostat Experiments

Our Chemostat set-up is rather simple and lacks a good control over the operating conditions. A closer control should have been kept on the temperature in the reactor. With proper temperature control, the experiments could be repeated at other temperature levels. The flow rate from the constant head tank was found to vary and had to be adjusted about twice a day.

We have assumed in our calculations that the original solids in the feed are not significantly solubilized during the experiment, and that the increase in solids in the effluent is mainly due to synthesis of microbial cells. There will be a slight solubilization of the feed solids, and hence our calculated value for M, the synthesized microbial cell mass, will be low. This problems can be corrected by filtering the raw waste through a filter press or by using a "synthetic" raw sewage, having only the soluble components.

Another assumption made was that the effluent soluble organic carbon was entirely degradable. This was not checked by taking the Biochemical Oxygen Demands of the filtered effluent. However, the least squares fit of the data points gave a correlation $u = 1.04 \times 10^{-3} (C + 0.55)$. The intercept on the horizontal axis is not significantly different from zero (but is in fact even negative). A significant positive intercept of say 5 mg/l or greater will indicate that not all of the effluent soluble carbon is degradable.

13.1.4 Data on the Aeration Studies of Activated Sludge

Since some of the biological rates in the kinetic scheme proposed in Chapter 5 are expected to be very slow, we had to aerate the return activated sludge for at least two weeks. No raw sewage was added to the return sludge. The reason is that the soluble degradable carbon in the raw sewage will have a very rapid rate of assimilation and hence creating a "stiff" condition in the solution of the differential equation describing its rate of reaction.

Several assumptions were made in the analysis of the results. The conversion factors obtained in Section 9.2, were used in calculating the soluble degradable carbon and in calculating the carbon equivalent of the volatile solids. Equation 5.1.12, relating the oxygen uptake rate to the rate of carbon loss due to respiration, and hence to the concentration of microorganisms, was assumed to hold. The above assumptions can be tested by integrating the area under the oxygen uptake rate curve (which is the total oxygen consumption), and comparing with the amount of carbon loss. for Run No. D-1,

$$\frac{\Delta O_2}{\Delta C} = \frac{6200}{1700} = 3.65$$

and for Run No. D-2,

$$\frac{\Delta O_2}{\Delta C} = \frac{5800}{1500} = 3.86$$

Both values are close to the factor of 3.73 obtained in Section 5.1.

A comparison of the results from the chemostat experiments and the extended aeration studies showed that the unit growth rate factor, k_4, was much lower in the latter case. The value of k_4 obtained in the chemostat experiments was 0.0010 hr^{-1} $(mg/l)^{-1}$ whilst that obtained from the extended aeration studies was 0.0006 hr^{-1} $(mg/l)^{-1}$. The former experiments were run under conditions where the substrate concentrations were high, whilst the latter experiments were made under food-deficient conditions. This suggests that an extended food-deficient condition could lead to decreased microbial activity, in what is commonly known as a "lag-phase". This implies then that k_4 is not actually a constant but could depend on the length of substrate privation. However, in activated sludge processes, the former condition normally occurs. The food-deficient condition would occur if we use the aerobic biological reaction in a solids digestion process.

Only a few readings were taken of the soluble degradable organic carbon throughout the duration of the runs. This was because the BOD measurements required a fairly large volume of sample. A larger reactor should have been used.

13.2 Discussion of Plant Simulations

13.2.1 Simulation of Drury Lane, Burlington, Sewage Treatment Plant

The agreement between the predicted and observed values for the primary and final effluents were very good. The results show that primary sedimentation tanks can be modelled quite successfully if a sufficiently accurate and detailed breakdown of the feed solids are provided. But normally a complete solids analysis, as required by our stream list is never performed, and the simulation may require the use of a less detailed model.

The activated sludge process was also modelled very successfully. The kinetic rates, measured experimentally, predicted the final effluent very well. An examination of the converged values for the return sludge stream showed that 42% of the volatile solids is composed of microorganisms. This is in agreement with the value of approximately 50% obtained in Section 5.3, for the return sludge from the Skyway Plant,

Several other case studies were made under different operating and flow conditions. Table 13.2.1 shows the individual effects of increasing capacities in the primary clarifiers, aeration tanks, secondary clarifiers and of just increasing the mixed liquor suspended solids in the aeration tanks to 3000 mg/l.

The effect of adding an extra primary clarifier was merely to improve the primary effluent to a BOD of 146 mg/l and a TSS of 141 mg/l. There was no significant improvement in the final effluent.

The effect of adding an extra aeration tank improved the final effluent to a BOD of 15 m/gl and a TSS of 17 mg/l. No improvements were expected to occur in the primary effluent.

Stream	BOD	TSS	DOC
Raw Sewage	215	299	61
CASE STUDY WITH NORMAL OPERATING CONDITIONS			
Primary Effluent	151	153	61
Secondary Effluent	22	20	10
CASE STUDY WITH A THIRD PRIMARY CLARIFIER			
Primary Effluent	146	141	61
Secondary Effluent	21	20	9
CASE STUDY WITH A THIRD AERATION TANK			
Primary Effluent	150	153	61
Secondary Effluent	15	17	8
CASE STUDY WITH A THIRD SECONDARY CLARIFIER			
Primary Effluent	150	153	61
Secondary Effluent	21	17	9
CASE STUDY WITH MLSS INCREASED TO 3000 mg/l			
Primary Effluent	151	153	61
Secondary Effluent	16	16	7

Table 13.2.1. Effect of Plant Alterations, at the Same Flow.

The extra secondary clarifier reduced the TSS in the final effluent to 17 mg/l, with not much improvement in the BOD.

The results of merely increasing the mixed liquor suspended solids in the aeration tanks to 3000 mg/l were quite surprising. The final effluent improved to a BOD of 16 mg/l and a TSS of 16 mg/l. This is just like having an extra aeration tank! This is quite logical since about 50% more solids will be carried in the aeration tanks at 3000 mg/l as compared to the operating value of 2200 mg/l.

Table 13.2.2 shows the effect of increasing the raw waste flow to 2.0 and 2.4 migd., with the same influent BOD and TSS, and with no change in equipment capacity. It should be noted that the plant was originally designed for a flow of 2.5 migd with an influent BOD of 200 and an influent TSS of 180 mg/l. However, both the influent BOD and TSS have increased over the years. The reported influent BOD and TSS In 1969 were, as mentioned before, 215 mg/l and 299 mg/l respectively.

At the operating conditions of 1969, with a feed flow of 1.6 migd, the final effluent BOD and TSS were predicted to be 22 mg/l and 20 mg/l respectively. This is just bordering on the limits set by the Ontario Water

Resources Commission. At a feed flow of 2.0 migd, the primary effluent deteriorated slightly to a BOD of 153 mg/l and a TSS of 160 mg/l, while the final effluent BOD and TSS rose to 28 mg/l and 25 mg/l respectively. At a feed flow of 2.4 migd, the primary effluent deteriorated further to a BOD of 156 mg/l and a TSS of 166 mg/l while the final effluent BOD and TSS predicted were 34 mg/l and 30 mg/l respectively, which is completely unsatisfactory.

The limiting equipment was found to be in the aeration tanks. If expansion is to be contemplated at the Drury Lane Plant to handle a higher flow, top priority should be given to expand the aeration tank capacity. The problem can be alleviated by maintaining a higher mixed liquor suspended solids in the activated sludge process.

Stream	BOD	TSS	DOC
Raw Sewage	215	299	61
CASE STUDY WITH 1.6 migd FEED FLOW			
Primary Effluent	151	153	61
Secondary Effluent	22	20	10
CASE STUDY WITH 2.0 migd FEED FLOW			
Primary Effluent	153	160	61
Secondary Effluent	28	25	12
CASE STUDY WITH 2.4 migd FEED FLOW			
Primary Effluent	156	166	61
Secondary Effluent	34	30	15

Table 13.2.2. Effect of Increased Plant Flows, with no Change in Present Equipment Capacities

13.2.2 Simulation of the Skyway, Burlington, Plant

In this case the activated sludge process model predicted a slightly better final effluent than was observed. However, the results show that the extended aeration process is not something special, but is merely the same activated sludge process, under a different name. The results also suggest that the 18 hour detention time required by the Ontario Water Resources Commission and other public agencies for a treatment plant without a primary clarifier is not necessary.

To show the effects of decreased detention time, or increased feed flow, on the final effluent, case studies were made at 6, 8 and 10 migd using the same feed composition. The two new final clarifiers, which are now completed, are added to the process flow diagram, together with the new (third) sludge return pump. The resulting detention times are 16, 12, and 10 hours respectively, all excluding sludge recycle.

The results are shown in Table 13.2.3. The final effluent at 10 migd feed flow, is predicted to have a BOD of 15 mg/l and a TSS of 20 mg/l, which is still acceptable. It should be pointed out that the feed to the plant (based on 1969 values) which has a BOD of 155 mg/l and a TSS of 185 mg/l is approximately equivalent to the primary effluent of many conventional activated sludge plants, and hence a detention time of 8-12 hours, which is sufficient for a conventional activated sludge plant, should also be sufficient for the "extended aeration" modification. The only justification for requiring more aeration time in a "extended aeration" plant is when the influent BOD and TSS are both higher than say 200 mg/l.

Stream	BOD	TSS	DOC
Raw Sewage	155	185	62
CASE STUDY WITH 6.0 migd FEED FLOW			
Final Effluent	11	13	5
CASE STUDY WITH 8.0 migd FEED FLOW			
Final Effluent	13	17	6
CASE STUDY WITH 10.0 migd FEED FLOW			
Final Effluent	15	20	7

Table 13.2.3. Effect of Increased Feed Flows, at the Skyway Plant.

CHAPTER 14

14. CONCLUSION

Simulation models for primary sedimentation, the activated sludge process, secondary sedimentation, anaerobic digestion and several other unit processes have been developed. The models were based on known and developed theories, supported by laboratory and plant data.

The primary clarifier was modelled on correlations obtained from batch column settling studies. It was found that if settleable suspended solids were used rather than the total suspended solids, better correlations resulted. This is to be expected as the total suspended solids include the non-settleable solids as well.

For the modelling of the activated sludge process, a new reaction scheme, based on the physiological activities of the bacterial and the bacterial cell mass, was proposed. Batch aeration studies of activated sludge were used to obtain estimates of the parameters used in the reaction scheme. This is an improvement over the use of mixed liquor suspended solids, as the fraction of "active mass" in the sludge is dependent on feed compositions and operating conditions in the plant.

For the secondary clarifier model, use was made of correlations developed by Villiers and the Rex Chainbelt

Company, for the fraction of solids escaping over the wiers and the Sludge Volume Index of the sludge produced, respectively. The anaerobic digester model assumed a first order rate for the liquefaction of organic solids, the rate constants being obtained from experimental data published in the literature.

Two plants were used in the simulation studies. The first is a conventional activated sludge plant, while the second is an extended aeration plant. The results from the simulation studies were in very good agreement with plant data for the liquid streams. The actual sludge volumes produced from both plants were lower than those predicted by the simulation. The loss of solids over the wiers of the secondary clarifiers, during plant upsets or storm flows, probably accounted for the lower production of sludge from both plants.

An inter-active version of the computer simulation was also developed and tested under varying conditions. This can be used as an effective teaching aid for operators and students in the wastewater treatment area.

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APPENDIX A

PRIMARY SETTLING DATA ON BATCH COLUMN

RUN #A.1	Raw Sewage from Dundas W.P.C.P.
RUN #A.2	Raw Sewage from Drury Lane, Burlington W.P.C.P.
RUN #A.3	Raw Sewage from Dundas W.P.C.P., 1970 Data.
RUN #A.4	Raw Sewage from Dundas W.P.C.P., 1969 Data.

RUN #A.1.

Raw Sewage from Dundas W.P.C.P.

Settling Data: Original suspended solids - average of duplicates.

Time (min) Depth (ft)	0	15	30	60	90	120	24 Hrs.
1.5	252	106	156	132	124	116	82
2.5	247	210	164	146	129	122	82
3.5	253	210	179	152	137	129	83
4.5	248	209	180	156	147	151	82
5.5	248	220	188	159	152	151	84
Depth Correction (ft)	0	0.1	0.2	0.3	0.4	0.5	

Average of initial solids = 250 mg/l (rounded up)

Average of final non-settleable solids = 82 mg/l (rounded up)

Hence total settleable solids = 168 mg/l

% of settleable solids = 100 (SS - 82)/168

Weight % settleable solids as a function of time and depth:

Time (min) Depth (ft)	0	15	30	60	90	120	24 Hrs.
1.5	100	62	44	30	25	20	0
2.5	100	77	49	38	28	24	0
3.5	100	77	58	42	33	28	0
4.5	100	77	58	44	39	35	0
5.5	100	82	63	46	42	35	0
Depth Correction (ft)	0	0.1	0.2	0.3	0.4	0.5	

Fraction of settleable solids removed, as a function of time and depth, using Equation 4.1.6:

Depth (ft)	Time (min)	Fraction Settleable Solids Removed
2.0	16	0.47
	21	0.57
	28	0.61
	35	0.65
	48	0.69
	65	0.73
3.0	20	0.46
	28	0.57
	35	0.61
	45	0.65
	62	0.69
	84	0.74
4.0	23	0.46
	31	0.57
	41	0.61
	53	0.65
	74	0.69
	101	0.74

(Con't.)

Depth (ft)	Time (min)	Fraction Settleable Solids Removed
5.0	25	0.45
	34	0.56
	46	0.60
	60	0.64
	85	0.69
	116	0.73
6.0	26	0.44
	37	0.56
	51	0.60
	66	0.64
	95	0.70
	130	0.74

RUN #A.2.

Raw Sewage from Drury Lane, Burlington W.P.C.P.
Settling Data: Original suspended solids - average of duplicates

Time (min) Depth (ft)	0	10	20	30	45	60	75	90	120	24 Hrs.
2.0	282	208	178	157	142	135	131	128	120	88
3.0	272	225	181	167	161	154	144	128	124	88
4.0	276	244	204	176	169	152	137	138	133	86
5.0	278	251	203	176	168	154	140	135	132	89
6.0	273	238	208	189	175	169	156	146	132	88
Depth Correction (ft)	0	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	

Average total initial suspended solids = 275 mg/l

Average final suspended solids = 88 mg/l

Total settleable solids = 187 mg/l

Weight % settleable solids = 100 (SS - 88)/187

Temperature = 20°C

Weight % settleable solids as a function of time and depth:

Time (min) Depth (ft)	0	10	20	30	45	60	75	90	120	24 Hrs.
2.0	100	66	48	37	29	25	23	21	17	0
3.0	100	73	50	42	39	35	30	21	19	0
4.0	100	83	62	47	43	34	26	26	23	0
5.0	100	88	62	47	42	35	28	25	23	0
6.0	100	81	64	54	47	43	37	31	23	0
Depth Correction (ft)	0	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	

Weight fraction of settleable solids removed, as a function fo time and depth, using Equation 4.1.6:

Depth (ft)	Time (min)	Weight Fraction Settleable Solids Removed
2.0	8	0.50
	13	0.59
	17	0.64
	22	0.67
	30	0.71
	38	0.75
	50	0.78
3.0	12	0.49
	18	0.58
	24	0.63
	31	0.67
	42	0.72
	54	0.75
	68	0.78
4.0	15	0.49
	23	0.57
	30	0.64
	39	0.67
	53	0.72

(Con't.)

Depth (ft)	Time (min)	Weight Fraction Settleable Solids Removed
4.0	68	0.75
	85	0.78
5.0	17	0.49
	26	0.57
	35	0.63
	46	0.67
	62	0.71
	80	0.75
	100	0.78
6.0	19	0.47
	29	0.57
	40	0.63
	53	0.67
	70	0.72
	92	0.75
	114	0.78

RUN #A.3.

Raw Sewage from Dundas W.P.C.P., data of 1970.

Settling Data: Original suspended solids - average of duplicates.

Time (min) Depth (ft)	0	15	30	45	60	75	90	105	120	24 Hrs.
2.1	234	164	138	130	123	115	111	110	106	66
3.1	243	186	151	140	132	126	120	116	112	74
4.1	246	193	162	147	139	133	127	122	118	80
5.1	262	198	172	153	143	138	133	129	123	72
6.1	264	200	175	158	143	141	136	132	128	68
Depth Correction (ft)	0	0.1	0.2	0.3	0.5	0.6	0.7	0.8	0.9	

Average total initial suspended solids = 250 mg/l

Average final suspended solids = 73 mg/l

Total settleable solids = 177 mg/l

Weight % settleable solids = 100 (SS - 72)/177

Weight % settleable solids as a function of time and depth:

Time (min) Depth (ft)	0	15	30	45	60	75	90	105	120	24 Hrs.
2.1	100	50	37	32	28	24	21	21	18	0
3.1	100	64	44	38	33	30	27	24	21	0
4.1	100	68	50	42	37	34	30	28	25	0
5.1	100	71	56	45	40	37	34	32	28	0
6.1	100	72	58	48	40	38	35	33	30	0
Depth Correction (ft)	0	0.1	0.2	0.3	0.5	0.6	0.7	0.8	0.9	

Weight fraction of settleable solids removed, as a function of time and depth, using Equation 4.1.6:

Depth (ft)	Time (min)	Weight Fraction Settleable Solids Removed
2.0	9	0.50
	13	0.58
	18	0.63
	23	0.66
	31	0.70
	44	0.74
3.0	13	0.50
	18	0.57
	24	0.62
	32	0.66
	43	0.70
	60	0.74
4.0	16	0.49
	22	0.57
	30	0.62
	39	0.66
	53	0.70
	75	0.75

Depth (ft)	Time (min)	Weight Fraction settleable Solids Removed
5.0	18	0.49
	26	0.52
	34	0.62
	46	0.66
	63	0.70
	88	0.75
6.0	21	0.48
	29	0.56
	39	0.61
	53	0.66
	73	0.70
	100	0.75

RUN #A.4.

Raw Sewage from Dundas W.P.C.P.

Settling Data: Original suspended solids - average of duplicates

- data of Hudspith et al, 1969

Time (min) Depth (ft)	0	15	30	45	60	75	90	105	120	24 Hrs.
1.0	(218)*	192	158	145	133	152	160	144	140	88
2.0	(232)*	187	166	165	167	160	146	150	145	93
3.0	248	204	178	163	156	158	157	188	145	95
4.0	244	208	176	174	162	162	138	168	157	93
5.0	246	202	176	172	164	164	144	156	158	(158)

Average of initial solids = 246 mg/l

Average of final non-settleable solids = 92 mg/l

Hence total settleable solids = 154 mg/l

% settleable solids = 100 (SS - 92)/154

*Insufficient mixing?

Weight % settleable solids as a function of time and depth:

Time (min) Depth (ft)	0	15	30	45	60	75	90	105	120	24 Hrs.
2.2	100	66	43	34	27	39	44	34	31	0
3.2	100	62	48	47	49	44	37	38	34	0
4.2	100	73	56	47	42	43	42	62	34	0
5.2	100	72	55	53	45	45	30	49	42	0
6.2	100	71	55	52	47	47	34	42	43	0
Depth Correction (ft)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	

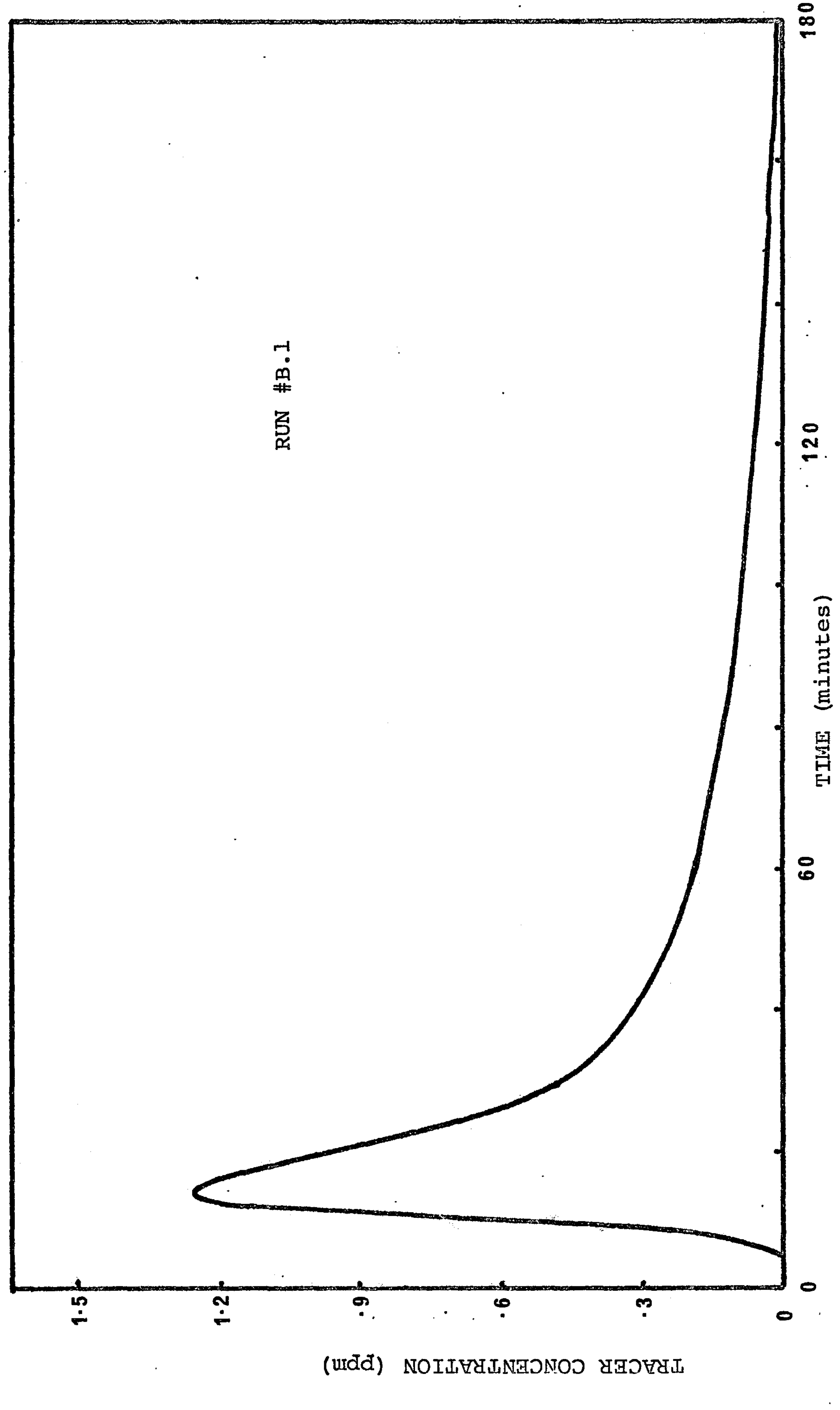
Weight fraction of settleable solids removed as a function of time and depth, using Equation 4.1.6:

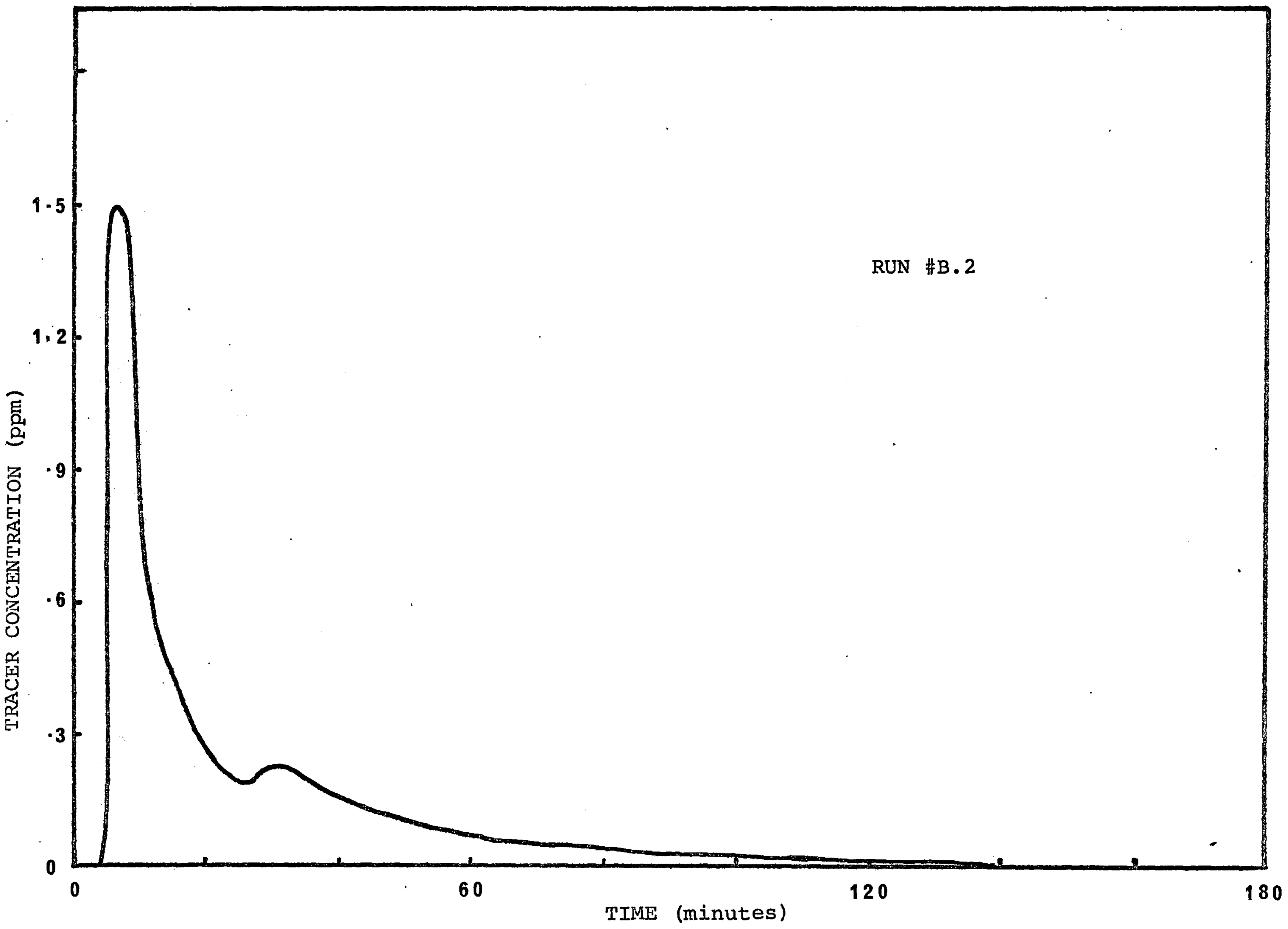
Depth (ft)	Time (min)	Weight Fraction settleable Solids Removed
2.0	10	0.46
	15	0.52
	20	0.58
	27	0.60
	38	0.67
	60	0.74
3.0	13	0.45
	20	0.52
	27	0.56
	37	0.60
	53	0.67
	80	0.73
4.0	16	0.44
	24	0.52
	34	0.56
	46	0.59
	65	0.66
	97	0.72

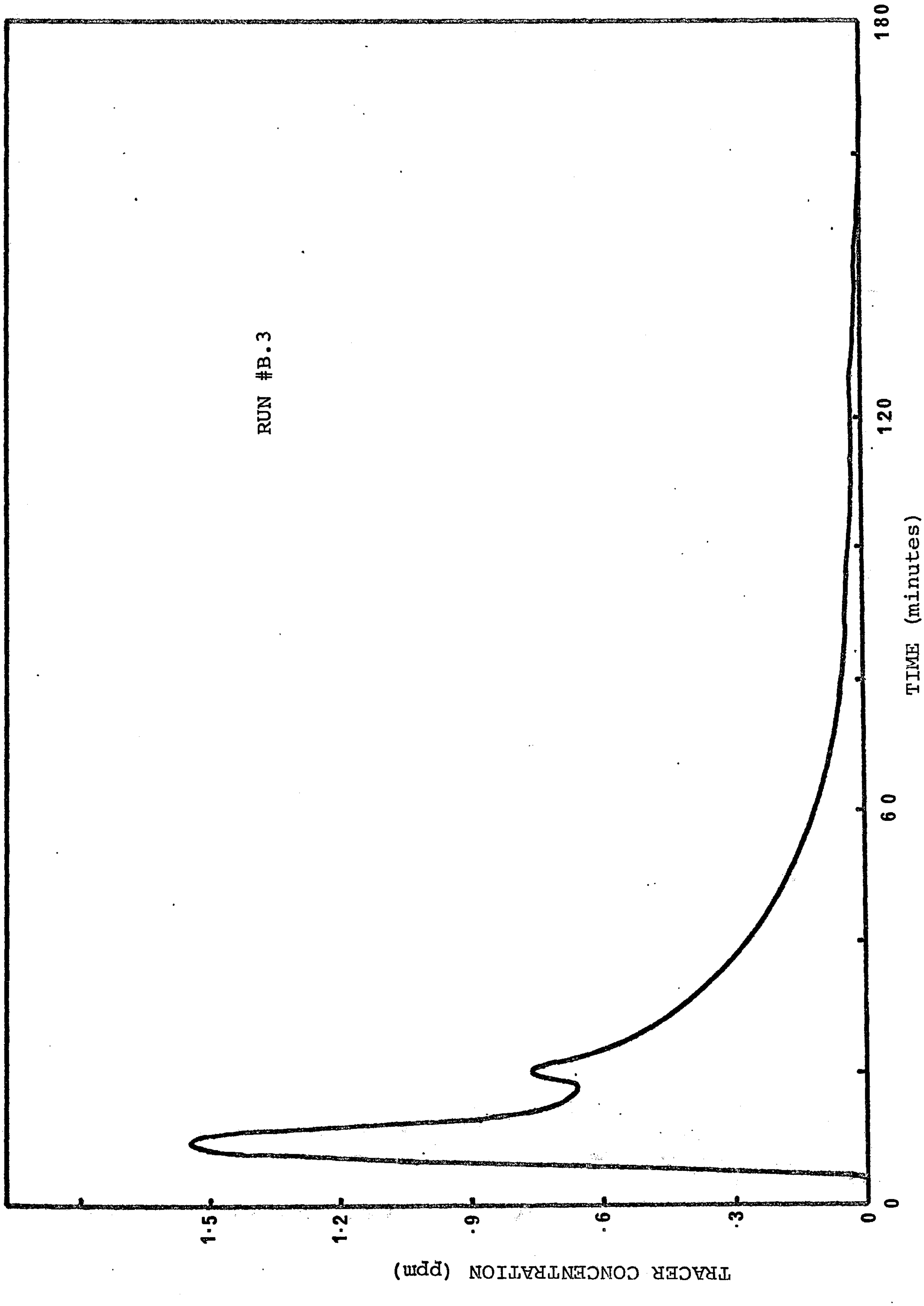
Depth (ft)	Time (min)	Weight Fraction Settleable Solids Removed
5.0	18	0.44
	27	0.53
	39	0.57
	53	0.61
	76	0.66
	111	0.74
6.0	20	0.44
	29	0.50
	43	0.55
	60	0.60
	85	0.66
	123	0.75

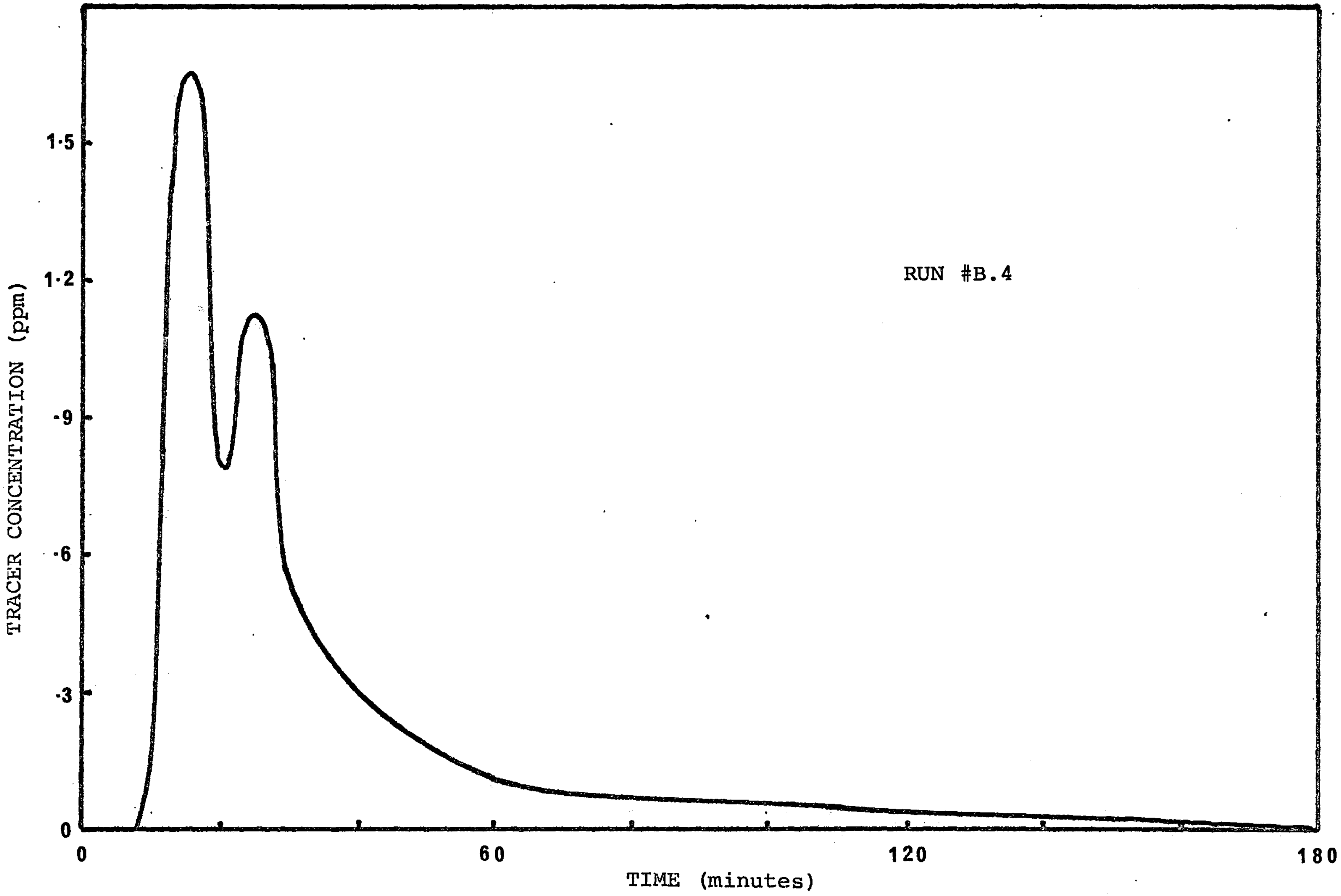
APPENDIX B

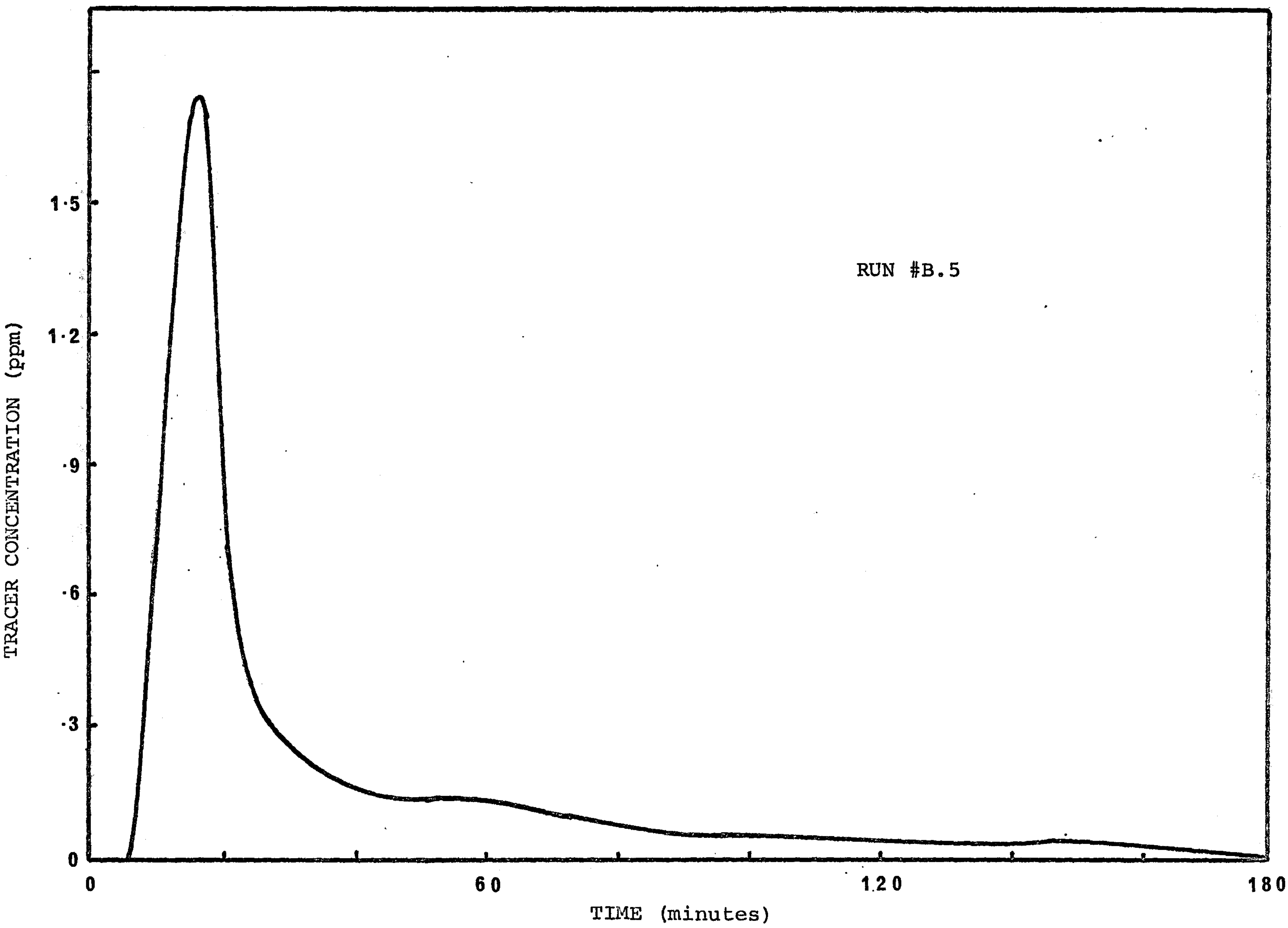
Exit Age Distributions of Primary Tanks
RUN #B.1-3 Dundas Plant
RUN #B.4-6 Drury Lane Plant
SETTLEABLE SOLIDS REMOVAL DATA

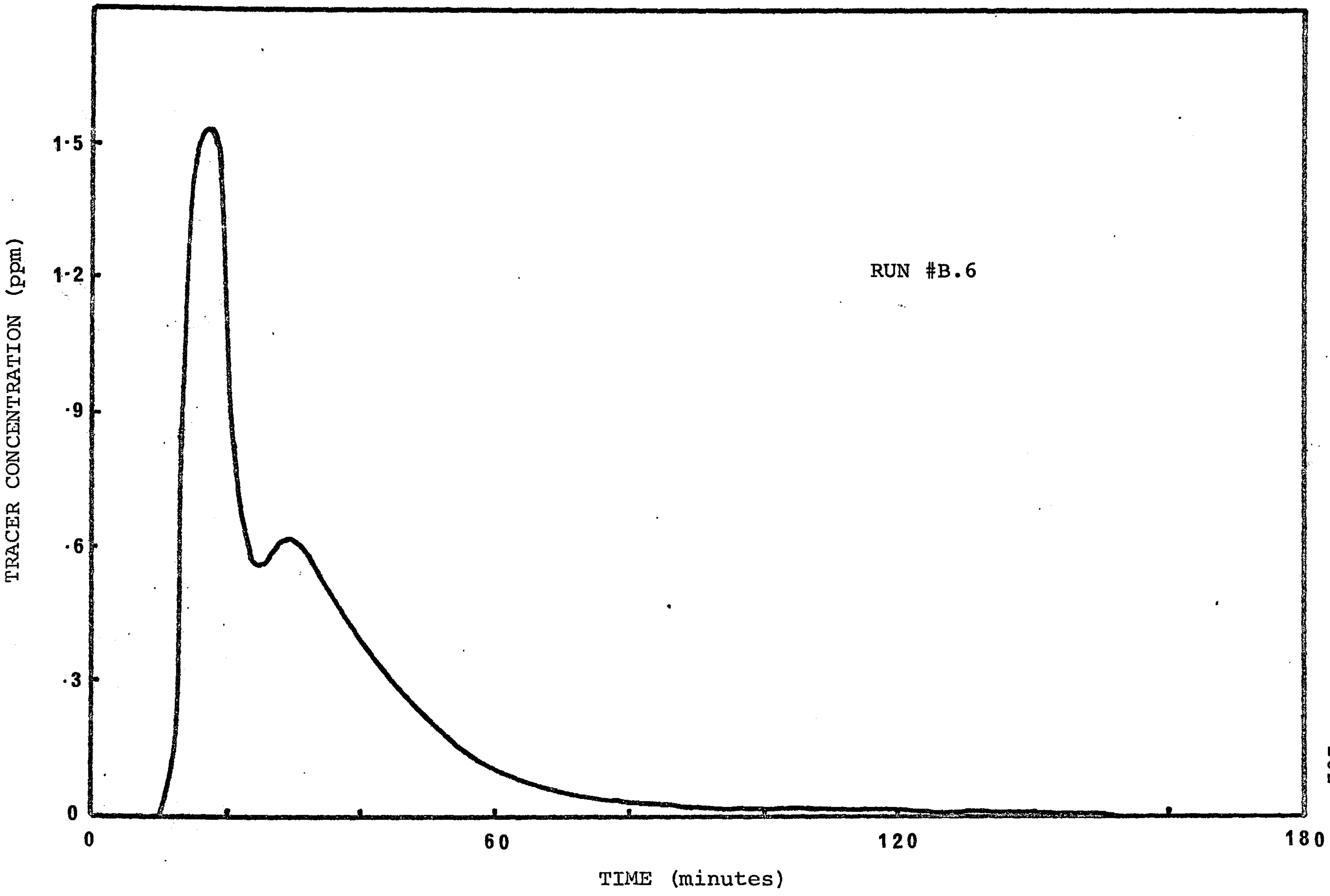

RUN #B.1
TRACER CONCENTRATION (ppm)
0
·3
·6
·9
1·2
1·5
TIME (minutes)
0
60
120
180


RUN #B.2
TRACER CONCENTRATION (ppm)
1·5
1·2
·9
·6
·3
0
0
60
120
180
TIME (minutes)


RUN #B.3
TRACER CONCENTRATION (ppm)
0
·3
·6
·9
1·2
1·5
TIME (minutes)
0
60
120
180


RUN #B.4
TRACER CONCENTRATION (ppm)
1·5
1·2
·9
·6
·3
0
0
60
120
180
TIME (minutes)


RUN #B.5
TRACER CONCENTRATION (ppm)
1·5
1·2
·9
·6
·3
0
0
60
120
180
TIME (minutes)


RUN #B.6
TRACER CONCENTRATION (ppm)
1·5
1·2
·9
·6
·3
0
0
60
120
180
TIME (minutes)

Run Number	Raw Flow (migd)	Settleable Suspended Solids		% Removal
		Influent	Effluent	
B.1	2.1	285	171	0.40
B.2	2.3	240	155	0.34
B.3	1.8	252	159	0.37
B.4	2.2	244	100	0.59
B.5	2.0	207	75	0.64
B.6	1.6	210	71	0.66

Table B.1. Settleable Solids Removal Data

APPENDIX C

DATA FROM THE CHEMOSTAT EXPERIMENTS

RUN #C.1. Detention Time = 40 hours

RUN #C.2. Detention Time = 45 hours

RUN #C.3. Detention Time = 60 hours

RUN #C.4. Detention Time = 30 hours

RUN #C.5. Detention Time = 45 hours

RUN #C.6. Detention Time = 70 hours

RUN #C.7. Detention Time = 50 hours

Run Number	Detention Time (Hrs.)	FEED		EFFLUENT		$M = \frac{\Delta SS}{2.1}$ (mg/l)	$U = k_4 C$ $(mg/l)^{-1}$ $(hr)^{-1}$	Y
		C_o (mg/l)	SS_o (mg/l)	C (mg/l)	SS (mg/l)			
1	40	69	26	45	54	14	4.9×10^{-2}	0.58
2	45	70	22	43	56	17	3.6×10^{-2}	0.62
3	60	65	25	35	59	16	3.2×10^{-2}	0.52
4	30	65	28	50	47	9	5.5×10^{-2}	0.60
5	45	62	30	35	64	16	3.8×10^{-2}	0.59
6	70	60	24	25	64	19	2.6×10^{-2}	0.54
7	50	72	25	30	73	23	3.6×10^{-2}	0.53

Average value of Y = 0.57

Standard deviation = 0.037

Temperature = 25°C ± 3°C

Source: Filtered raw sewage from Skyway, Burlington

(NOTE: M is obtained from the increase in suspended solids by the conversion factor of 2.1. Both C and M are expressed in terms of carbon).

APPENDIX D

EXTENDED AERATION STUDIES ON ACTIVATED SLUDGE

(a) Two runs using return sludge from the Skyway, Burlington W.P.C.P.

(b) Replicates analyses using five simulaneously-drawn samples.

RUN #D.1

Aeration of return activated sludge from the Skyway, Burlington W.P.C.P.

Original Data:

Aeration Time (days)	Suspended Solids (mg/l)	Oxygen Uptake Rate (mgO_2/l/hr)	Soluble Organic Carbon (mgC/l)	BOD_5 (filtrate) (mg/l)
0	6970	30.0	24	16
1	6710	21.6	25	
2	6260	18.6	29	10
3	6040	16.2	35	
7	5550	15.0	39	
8	5200	10.2	45	
9	4710	12.0	52	12
10	4880	10.8	46	
11	4560	9.6	50	
14	4670	9.0	53	
15	3960	6.6	55	
16	4250	6.0	53	8
17	3940	6.6	60	
23	3840	3.6	67	
24	3520	3.0	65	
25	3660	2.4	67	14

Temperature = 23 ± 2°C

pH = 7.5 ± 0.3

Air Rate = 1.0 litre/hr/litre reactor volume

Ash content of sludge:

initial = 1650 mg/l

final = 1480 mg/l

average = 1520 mg/l

Converted Data:

Aeration Time (days)	VSS (mgC/l)	OUR (mgO_2/l/hr)	SNDOC (mgC/l)	SDOC (mgC/l)
0	2600	20.0	16	8
1	2470	21.6	19	
2	2260	18,6	23	5
3	2150	16.2	30	
7	1920	15.0	34	
8	1750	10.2	40	
9	1520	12.0	46	6
10	1600	10.8	41	
11	1450	9.6	45	
14	1500	9.0	48	
15	1160	6.6	50	
16	1300	6.0	49	4
17	1150	6.6	55	
23	1120	3.6	62	
24	950	3.0	60	
25	1020	2.4	60	7

VSS = Volatile suspended solids (mg/ 1) (see Section 9.1)
= (Total Suspended Solids - 1520)/2.1

SDOC = Soluble degradable organic carbon (mgC/l)
= BOD_5 (filtrate)/1.9

SNDOC = Soluble non-degradable organic carbon (mhC/l)
= soluble organic carbon - SDOC

RUN #D.2

Aeration of return activated sludge from the Skyway, Burlington W.P.C.P.

Original Data:

Aeration Time (days)	Suspended Solids (mg/l)	Oxygen Uptake Rate (mgO_2/l/hr)	Soluble Organic Carbon (mgC/l)	BOD_5(filtrate) (mg/l)
0	7900	30.6	21	16
1	7370	25.2	23	
2	7260	21.6	29	
3	7100	21.6	33	10
4	6530	18.6	37	
7	5800	15.0	43	
8	5900	15.6	48	8
9	5290	13.8	50	
10	5380	11.4	55	
11	5290	10.8	57	
14	4700	7.8	59	12
15	4950	6.6	64	
16	4850	6.6	59	
17	4910	5.4	61	12

Temperature = 23 ± 2°C
pH = 7.4 ± 0.4
Air Rate = 1.0 litre air/hr/litre reactor volume

Ash content of sludge:
initial = 1700 mg/l
final = 1890 mg/l
average = 1800 mg/l

Converted Data:

Aeration Time (days)	VSS (mgC/l)	OUR (mgO_2/l/hr)	SNDOC (mgC/l)	SDOC (mgC/l)
0	2900	30.6	13	8
1	2650	25.2	18	
2	2600	21.6	24	
3	2520	21.6	28	5
4	2250	18.6	32	
7	1900	15.0	38	
8	1950	15.6	44	4
9	1660	13.8	45	
10	1700	11.4	50	
11	1660	10.8	52	
14	1380	7.8	53	6
15	1500	6.6	59	
6	1450	6.6	54	
17	1480	5.4	55	6

VSS = volatile suspended solids (mgC/l) (see Section 9.1)

SDOC = soluble degradable organic carbon (mgC/l)
= BOD_5 (filtrate)/1.9

SNDOC = soluble non-degradable organic carbon (mgC/l)
= soluble organic carbon - SDOC

(b) Replicate Analyses on Five Simultaneously-drawn Samples:

Original Data:

Sample Number	Volatile Suspended Solids (mg/l)	Oxygen Uptake Rate (mgO_2/l/hr)	Soluble Organic Carbon (mgC/l)	BOD_5 (mg/l)
1	3820	12.6	47	10.4
2	3550	9.6	51	7.6
3	3890	9.6	45	8.4
4	3920	10.2	44	11.6
5	3610	12.0	51	6.4

NOTE: (a) 10 ml samples were used for VSS

(b) dilution for BOD_5 is 25%. Filtrate is close to saturation. Hence no need for O_2 correction.

The above data is converted to the similar values used in the four responses for the objective function:

Sample Number	P+M (mgC/l)	OUR (mgO_2/l/hr)	SNDOC (mgC/l)	SDOC (mgC/l)
1	1820	12.6	41	5.5
2	1690	9.6	47	4.0
3	1850	9.6	41	4.4
4	1870	10.2	38	6.0
5	1720	12.0	48	3.3

NOTE: (a) P+M = volatile suspended solids/2.1

(b) SDOC = BOD_5/1.9

(c) SNDOC = soluble organic carbon - SDOC

Variance - Covariance Matrix (18)

Component 1 = volatile suspended solids (mgC/l)

Component 2 = oxygen uptake rate ($mgO_2/hr/l$)

Component 3 = soluble non-degradable carbon (mgC/l)

Component 4 = soluble degradable carbon (mgC/l)

$$\begin{bmatrix} 6450.0 & 7.5 & -332.5 & 69.5 \\ -7.5 & 1.98 & 0.75 & 0.045 \\ -332.5 & 0.75 & 18.5 & -4.325 \\ 69.5 & 0.045 & -4.325 & 1.213 \end{bmatrix}$$

Inverse of Variance - Covariance Matrix

$$\begin{bmatrix} 0.139 & -1.22 & 4.19 & 7.00 \\ -1.22 & 11.2 & -36.8 & -61.9 \\ 4.19 & -36.8 & 126.3 & 212.0 \\ 7.00 & -61.9 & 212.0 & 358.0 \end{bmatrix}$$

APPENDIX E

DATA FOR THE STRIPPING RATE OF PURGEABLE SOLUBLE ORGANIC CARBON BY AERATION WITH AIR

RUN #E.1 Air Rate = 2.1 cu.ft.air/hr/cu.ft. reactor

RUN #E.2 Air Rate = 1.0 cu.ft.air/hr/cu.ft. reactor

RUN #E.3 Air Rate = 0.5 cu.ft.air/hr/cu.ft. reactor

RUN #E.4 Air Rate = 1.5 cu.ft.air/hr/cu.ft. reactor

RUN #E.1.

Air Rate = 2.1 cu.ft.air/hr/cu.ft. reactor

Time (minutes)	SOC (mg/l)	SPOC (mg/l)
0	123	24
1	118	19
3	116	17
5	115	16
7	110	11
10	113	14
13	106	7
17	106	7
20	103	4
25	102	3
30	101	2
40	99	0
50	99	0

Soluble non-purgeable organic carbon assumed to be = 99 mg/l

SOC = total soluble organic carbon

SPOC = soluble purgeable organic carbon

SPOC = SOC - 99

RUN #E.2.

Air Rate = 1.0 cu.ft.air/hr/cu.ft. reactor

Time (minutes)	SOC (mg/l)	SPOC (mg/l)
0	126	20
2	124	18
5	121	15
10	124	18
15	118	12
20	116	10
25	118	12
30	114	8
40	112	6
50	110	4
60	109	3
70	108	2
80	106	0
90	106	0

Soluble non-purgeable organic carbon assumed to be = 106 mg/l

SOC = total soluble organic carbon

SPOC = soluble purgeable organic carbon

SPOC = SOC - 106

RUN #E.3.

Air Rate = 0.5 cu.ft.air/hr/cu.ft. reactor

Time (minutes)	SOC (mg/l)	SPOC (mg/l)
0	131	20
5	129	18
10	128	17
15	127	16
20	126	15
30	124	13
40	122	11
50	120	9
60	119	8
80	117	6
100	115	4
120	111	0
140	111	0

Soluble non-purgeable organic carbon assumed to be = 111 mg/l

SOC = total soluble organic carbon

SPOC = soluble purgeable organic carbon

SPOC = SOC - 111

RUN #E.4.

Air Rate = 1.5 cu.ft.air/hr/cu.ft. reactor

Time (minutes)	SOC (mg/l)	SPOC (mg/l)
0	130	32
2	126	28
5	121	23
10	116	18
15	113	15
20	109	11
25	106	8
30	105	7
40	102	4
50	100	2
60	98	0
70	98	0

Soluble non-purgeable carbon assumed to be = 98 mg/l

SOC = total soluble organic carbon

SPOC = soluble purgeable organic carbon

SPOC = SOC - 98

APPENDIX F

DATA OF ACTIVATED SLUDGE SETTLING FROM P. LEUNG

Aeration Time (Hrs.)	MLSS (mg/l)	Effluent SS (mg/l)	SVI	Prediction Effluent SS (mg/l)
0.5	2100	35	101.3	38
1.0	600	74	83.0	68
1.0	3800	20	156	23
3.0	220	93	91.3	96
3.0	2100	34	97.9	26
3.0	4000	9.5	171	18
5.0	600	50	82.7	49
5.0	3800	14.5	153	17
5.5	2100	30	99.4	23

Data of Peter Leung

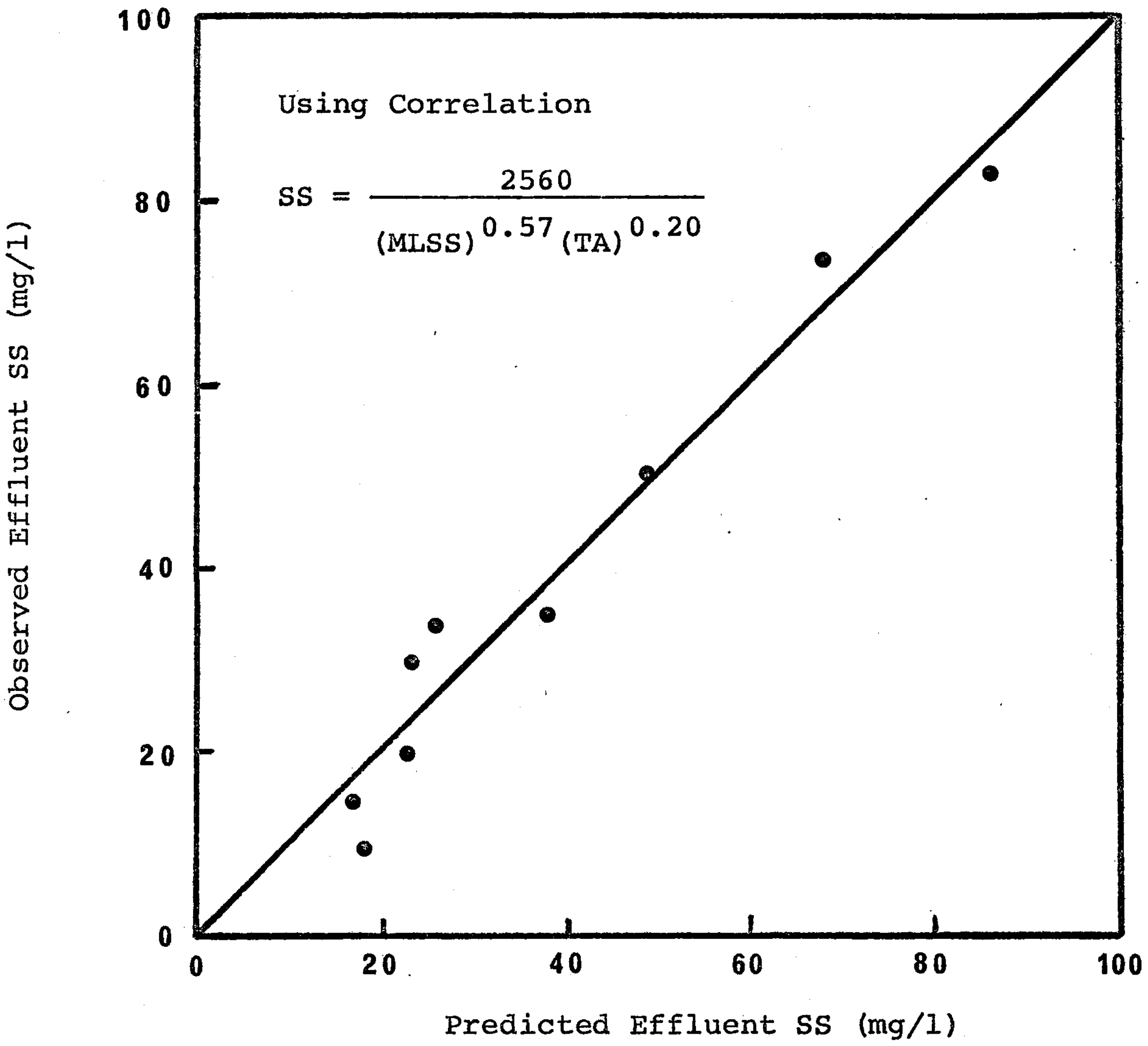
The predicted effluent SS_e was found to be

$$SS_e = \frac{2560}{(MLSS)^{0.57}\ (TA)^{0.20}}$$

or $$XRSS = \frac{SS_e}{(MLSS)} = \frac{2560}{(MLSS)^{1.57}\ (TA)^{0.20}}.$$

The SVI was not found to correlate well.

Figure F.1. Comparison of Observed Effluent Solids with Correlation (Data of P. Leung)



APPENDIX G

ANAEROBIC DIGESTION DATA

(a) Conventional Digester -
Data of Rankine (32).

(b) High Rate Digester -
Data of Torpey (50), Roy and Sawyer (34) and Estrada (12).

(a) Conventional Digester

Data of Rankine (32).

Detention Time (days)	Fraction Reduction of Volatile Solids =(1-R)	(1-R)/R
17	0.42	0.71
26	0.39	0.64
27	0.50	1.00
29	0.37	0.59
35	0.45	0.82
35	0.63	1.70
37	0.44	0.78
39	0.52	1.09
50	0.52	1.09
53	0.55	1.22
55	0.56	1.27
65	0.64	1.77
67	0.70	2.33
75	0.57	1.33
62	0.53	1.13

(b) <u>High Rate Digester</u>

Source	Detention Time (days)	Fraction Reduction of Volatile Solids =(1-R)/R	(1-R)/R
Torpey (50)	14.0	0.56	1.27
	10.3	0.45	0.82
	8.3	0.47	0.70
	6.4	0.45	0.82
	3.7	0.37	0.59
Roy (34)	20.0	0.58	1.38
	15.0	0.57	1.33
	10.0	0.56	1.27
	8.0	0.54	1.17
	6.0	0.52	1.09
Estrada(12)	22.5	0.61	1.58
	22.0	0.54	1.17
	19.8	0.64	1.77
	18.8	0.61	1.58
	18.0	0.63	1.70
	15.9	0.68	2.12
	15.7	0.57	1.33
	14.8	0.48	0.92
	13.9	0.40	0.67
	13.3	0.52	1.09
	12.0	0.66	1.94
	10.1	0.42	0.71

APPENDIX H

INTER-RELATIONSHIPS BETWEEN ORGANIC CARBON, BIOCHEMICAL OXYGEN DEMAND AND VOLATILE SUSPENDED SOLIDS

Sample	Raw Sewage		VSS	Filtrate		$\frac{DBOD}{SOC}$	$\frac{TBOD-DBOD}{TOC-SOC}$	$\frac{VSS}{TOC-SOC}$
	TBOD	TOC		DBOD	SOC			
1	220	160	230	114	60	1.90	1.06	2.30
2	300	226	320	110	58	1.96	1.13	1.90
3	260	177	224	110	68	1.62	1.37	2.05
4	289	192	236	145	72	2.02	1.20	1.98
5	315	218	286	149	85	1.75	1.23	2.14
6	310	187	244	149	74	2.01	1.42	2.15
7	308	196	272	151	70	2.15	1.25	2.15
Average =						1.91	1.24	2.09
Standard Deviation =						0.17	0.12	0.11

TBOD = total BOD_5 (mg/l)

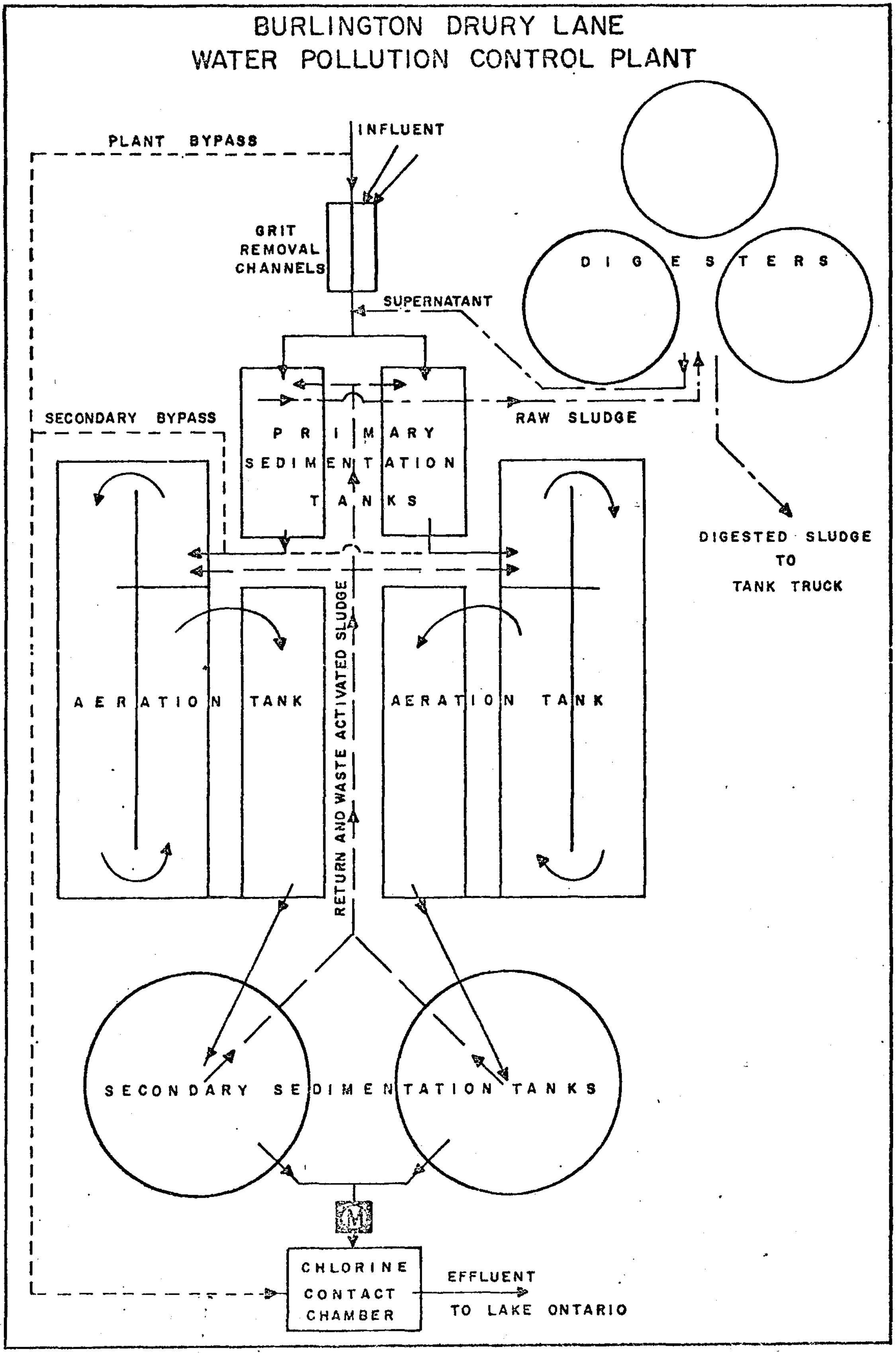
DBOD = BOD_5 of soluble organics (mg/l)

TOC = total organic carbon (mg/l)

SOC = soluble organic carbon (mg/l)

APPENDIX I

SIMULATION DATA AND RESULTS FOR THE DRURY LANE, BURLINGTON, SEWAGE TREATMENT PLANT



BURLINGTON DRURY LANE
WATER POLLUTION CONTROL PLANT

DESIGN DATA

PROJECT NO.	2-0051-60	TREATMENT	Activated Sludge
DESIGN FLOW	2.5 mgd	DESIGN POPULATION	30,000
BOD - Raw Sewage - Removal	200 mg/l 90%	SS - Raw Sewage - Removal	180 mg/l 90%

PRIMARY TREATMENT

Screening

1" bar screens

Grit Removal

Type: Grit channels
Retention: 0.8 min

Primary Sedimentation

Type: Walker Process
Size: Two 49.3' x 18' x 12.25'
(135,700 gal)
Retention: 1.3 hr
Loading: Surface, 1400 gal/ft^2/day
Weir, 17,100 gal/ft/day

SECONDARY TREATMENT

Aeration Tanks

Type: Diffused air; triple-pass
Size: Two tanks, each with
2 passes 118' x 18' x 10.7'
1 pass 85.5' x 18' x 10.7'
(833,000 gal. total)
Retention: 8.0 hours

Air Supply

One Sutorbilt - 1500 cfm
Two Roots-Connerville - 750 cfm

Diffusers - (each tank)

1) 132 Schumacher Brandel tubes in first two passes
2) 41 Spargers on 2' centres in third pass

Secondary Sedimentation

Type: Rex Unitube Tow-Bro
Size: Two 50' dia x 10.6' swd
(260,000 gal)
Retention: 2.5 hr
Loading: Surface, 1000 gal/ft^2/day
Weir, 8500 gal/ft/day

CHLORINATION

Type: Kent

Chlorine Contact Chamber

- in outfall

OUTFALL

- to Lake Ontario

SLUDGE HANDLING

Digestion System

Type: Two-stage

Primary --
Size: Two 40' dia tanks (313,000 gal total) , depth = 20'
Loading: 2.7 lb/ft^3/mo

Secondary --
Size: One 40' dia tank (143,000 gal)
Loading Total: 1.9 lb/ft^3/mo
depth = 18'

DATA SET FOR THE SIMULATION OF THE DRURY LANE PLANT

```
  DRURY LANE, BURLINGTON, STP
1.0             1.0             1.0             1.0             0.0
0.0             0.0             0.0             0.0             0.0
18.0            25.0            1.0
16.0            10.0            1.0             2.0             5.0
3.0             4.0             6.0             5.0             12.0
17.0            13.0            14.0            15.0            7.0
18.0            11.0            24.0
-25.0
1.0             1.0             1.0             1.0             1.0
1.0             1.0             1.0             1.0             1.0
1.0             1.0             1.0             1.0             1.0
1.0             1.0             1.0             1.0             1.0
1.0             1.0             1.0             1.0             1.0
4.0
18.0            7.0             66000.0         25.0            5.0
660000.0        4.0             0.0             0.0             0.0
0.0             0.0             48.0            56.0            10.0
62.0            0.0             18.0            3.0             6.0
55.0            0.0             100.0           0.0             0.0
0.0             23.0            0.5             6.0             0.0
16.0            9.0             186.7           40.0            6.5
1863.97         0.0             0.0             0.0             0.0
0.0             0.0             2751.5          14.5            163.9
451.5           0.0             131.2           0.0             28.4
54.1            0.0             15796.0         0.0             0.0
0.0             4499.4          0.0             979.1           0.0
6.0             8.74            15060.6         25.04           4.5
149860.6        0.0             0.0             0.0             0.0
0.0             0.0             5086.3          0.0             1306.4
1845.8          0.0             0.0             0.0             0.0
9.44            0.32            144.2           0.0             0.0
0.0             12.75           31.71           8.0             0.0
7.0             8.74            911.98          25.04           4.5
9074.6          0.0             0.0             0.0             0.0
0.0             0.0             5086.3          0.0             1306.4
1845.8          0.0             0.0             0.0             0.0
9.44            0.32            144.2           0.0             0.0
0.0             12.75           31.71           8.0             0.0
18.0
1.0             6.0             25.0            2.0             1.0
3.0             13.0            16.0            7.0             0.0
3.0             2.0             9.0             10.0            0.0
49.3            18.0            12.25           60000.0         80000.0
0.85            0.1             2.0             700.0           0.2
2.0             1.0             16.0            0.0             0.0
2.0             2.0             19.0            0.0             0.0
1.0             3.0             0.0             0.0             0.0
1.0
3.0             7.0             46.0            2.0             1.0
2.0             8.0             3.0             0.0             0.0
1.0             4.0             0.0             0.0             0.0
321.5           18.0            10.7            3.0             0.0014
0.0028          0.000002        2.2             0.54            0.45
0.08            90000.0         0.0010          0.005           0.23
0.07            250.0           0.0             3.0             1.0
0.0             0.0             0.0             0.0             0.0
0.0             0.0             0.0             0.0             3.0
60000.0
4.0             9.0             22.0            2.0             1.0
1.0             4.0             0.0             0.0             0.0
3.0             5.0             6.0             11.0            0.0
1.0             0.20            982.0           80000.0         2.0
25000.0         0.3
5.0             17.0            15.0            2.0             2200.0
1.0             6.0             0.0             0.0             0.0
2.0             8.0             7.0             0.0             0.0
6.0             4.0             15.0            0.0             3.0
1.0             6.0             0.0             0.0             0.0
1.0             6.0             0.0             0.0             0.0
7.0             2.0             50.0            101.0           5.0
0.0             0.0             0.0             0.0             0.0
0.0             0.0             0.0             0.0             0.0
```

```
12.0         5.0          16.0         0.001        101.0
101.0        0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
9.0          18.0         62.0         3.0          8.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
10.0         11.0         15.0         0.77         0.5
1.0          12.0         0.0          0.0          0.0
1.0          13.0         0.0          0.0          0.0
11.0         13.0         15.0         5.0          0.0
1.0          25.0         0.0          0.0          0.0
1.0          25.0         0.0          0.0          0.0
12.0         1.0          16.0         0.0          0.0
3.0          9.0          10.0         11.0         0.0
1.0          14.0         0.0          0.0          0.0
1.0
13.0         12.0         24.0         2.0          2.0
1.0          14.0         0.0          0.0          0.0
1.0          15.0         0.0          0.0          0.0
40.0         20.0         2.0          40.0         1.0
1.0          1.0          0.0          1.0
14.0         12.0         24.0         1.0          2.0
1.0          15.0         0.0          0.0          0.0
2.0          16.0         17.0         0.0          0.0
40.0         18.0         1.0          40.0         0.60
0.16         0.08         0.0          1.0
15.0         2.0          50.0         101.0        5.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
11.0         10.0         4.0          0.001        1.0
1.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
16.0         1.0          18.0         0.0          0.0
1.0          18.0         0.0          0.0          0.0
3.0          12.0         1.0          19.0         0.0
1.0          0.0          0.0
17.0         4.0          15.0         0.0          9.0
1.0          14.0         0.0          0.0          0.0
1.0          14.0         0.0          0.0          0.0
18.0         1.0          16.0         0.0          0.0
2.0          5.0          1.0          0.0          0.0
1.0          25.0         0.0          0.0          0.0
1.0
24.0         16.0         35.0         0.0          0.0
0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0
18.0         13.0         2.0          9.0          0.0
4.0          0.0          5.0          6.0          8.0
7.0          14.0         16.0         17.0         0.0
0.0          0.0          0.0          0.0          0.0
      RUN WITH AVERAGE FLOW CONDITIONS -1969
```

```
$$$$$$$$$$$$$    CASE  1    $$$$$$$$$$$$$


      RUN WITH AVERAGE FLOW CONDITIONS -1969

END OF LOOP      1

END OF LOOP      2

END OF LOOP      3

END OF LOOP      4

END OF LOOP      5
..J.......VALUE.......FRAC
   3     80940.35    -.000034
   4        25.04     .000000
   5         2.50    0.000000
   6    808651.26    -.000034
   7         3.79     .000759
   8       487.11    -.000158
   9         7.87    -.000537
  10       351.11    -.000526
  11      1779.03    -.000034
  12      1006.39    -.000151
  13       772.64     .000120
  15       198.70     .000375
  16       279.32    -.000527
  18         1.21    -.000003
  21         7.61    -.000566
  23       117.30    -.003348
  27        10.32    -.007073
  28        25.65    -.001444
  29         6.47    -.003722

END OF LOOP      6
***CONVERGED

END OF LOOP    101

END OF LOOP      1

END OF LOOP      2
***CONVERGED

END OF LOOP    102
***CONVERGED

$$$$$   FINAL OUTPUT STREAMS FOR MODULE    18   -   MIXER1    $$$$$

       25.000          8.746   65876.308          25.042        1.500
   658757.355          0.000      10.050           6.406       14.324
       13.547          7.653       5.894           0.000        1.517
        2.127          0.000       0.000           0.000         .002
        6.194           .211      95.515           0.000        0.000
        0.000          8.401      20.892           5.269        0.000

$$$$$   FINAL OUTPUT STREAMS FOR MODULE    11   -   CHLOR1    $$$$$

       25.000          8.746   65876.308          25.042        1.500
```

```
  658757.355          0.000         10.050          6.406         14.324
      13.547          7.653          5.894          0.000          1.517
       2.127          0.000          0.000          0.000           .002
       6.194           .211         95.515          0.000          0.000
       0.000          8.401         20.892          5.269          0.000

$$$$$  FINAL OUTPUT STREAMS FOR MODULE   16  -  MIXER1    $$$$$

      12.000          7.000      66008.582         25.000          5.000
  660000.000          2.640        101.640         40.260        142.230
     197.538        128.898         31.680         36.960          6.600
      40.920          0.000         11.880          1.980          3.960
      36.300          0.000         66.000          0.000          0.000
       0.000         15.180           .330          3.960          0.000

       1.000          7.000          0.000         25.000          5.000
       0.000          0.000          0.000          0.000          0.000
       0.000          0.000          0.000          0.000          0.000
       0.000          0.000          0.000          0.000          0.000
       0.000          0.000          0.000          0.000          0.000
       0.000          0.000          0.000          0.000          0.000

      19.000          7.000          0.000         25.000          5.000
       0.000          0.000          0.000          0.000          0.000
       0.000          0.000          0.000          0.000          0.000
       0.000          0.000          0.000          0.000          0.000
       0.000          0.000          0.000          0.000          0.000
       0.000          0.000          0.000          0.000          0.000

$$$$$  FINAL OUTPUT STREAMS FOR MODULE   10  -  GRIT1     $$$$$

      13.000          7.000      66008.582         25.000          4.500
  660000.000          2.640        101.640         40.260        142.230
     194.176        128.898         28.318         36.960          6.600
      40.920          0.000         11.880          1.980          3.960
      36.300          0.000         66.000          0.000          0.000
       0.000         15.180           .330          3.960          0.000

$$$$$  FINAL OUTPUT STREAMS FOR MODULE    1  -  PRISET1   $$$$$

       2.000          8.992      66790.415         25.042          3.500
  667861.462          0.000         64.035         40.316        100.662
     102.242         49.809         15.615         36.818          3.663
      16.872          0.000          1.212          1.971          3.995
      36.319           .003         96.833          0.000          0.000
       0.000         23.570           .617          5.830          0.000

       9.000          8.992        287.893         25.042          3.500
    2800.000          0.000         57.015           .169         50.303
     183.813        119.376         64.283           .154         15.194
      41.644          0.000          0.000           .008           .017
        .152           .000           .406          0.000          0.000
       0.000           .099           .003           .024          0.000

      10.000          8.992         28.745         25.042          3.500
     276.080          0.000         10.938           .017         13.136
      22.957         22.935           .006           .015           .002
        .007          0.000         10.912           .001           .002
        .015           .000           .040          0.000          0.000
       0.000           .010           .000           .002          0.000
```

```
$$$$$   FINAL  OUTPUT  STREAMS  FOR  MODULE      2   -   MIXER1     $$$$$

        3.000          8.988     66790.415        25.042         3.500
   667861.462          0.000        64.035        40.316       100.662
      102.242         49.809        15.615        36.818         3.663
       16.872          0.000         1.212         1.971         3.995
       36.319           .003        96.833         0.000         0.000
        0.000         23.570          .617         5.830         0.000

$$$$$   FINAL  OUTPUT  STREAMS  FOR  MODULE      5   -   CCNT02     $$$$$

        8.000          8.746     14148.710        25.042         4.500
   140787.010          0.000       446.883         1.369       314.603
     1656.203        935.580       720.623         0.000       185.441
      260.073          0.000         0.000         0.000          .000
        1.324           .045        20.413         0.000         0.000
        0.000          1.796         4.465         1.126         0.000

        7.000          8.746       911.871        25.042         4.500
     9073.592          0.000        28.801          .088        20.276
      106.741         60.297        46.443         0.000        11.952
       16.761          0.000         0.000         0.000          .000
         .085           .003         1.316         0.000         0.000
        0.000           .116          .288          .073         0.000

$$$$$   FINAL  OUTPUT  STREAMS  FOR  MODULE      3   -   ACTSL1     $$$$$

        4.000          8.746     80940.066        25.042         2.500
   808648.472          3.790       486.895         7.861       350.522
     1779.025       1005.970       773.055         0.000       198.969
      278.858          0.000         1.207         0.000          .002
        7.600           .259       117.246         0.000         0.000
        0.000         10.313        25.646         6.468         0.000

$$$$$   FINAL  OUTPUT  STREAMS  FOR  MODULE      4   -   SECLAR1    $$$$$

        5.000          8.746     65876.306        25.042         1.500
   658757.336          0.000        10.048         6.404        14.319
       13.547          7.652         5.895         0.000         1.517
        2.126          0.000         0.000         0.000          .002
        6.191           .211        95.513         0.000         0.000
        0.000          8.402        20.892         5.269         0.000

        6.000          8.746     15060.581        25.042         1.500
   149860.604          0.000       475.640         1.457       334.754
     1762.944        995.784       767.160         0.000       197.452
      276.731          0.000         0.000         0.000          .000
        1.408           .048        21.728         0.000         0.000
        0.000          1.911         4.753         1.199         0.000

       11.000          8.746         3.179        25.042         1.500
       30.533          0.000         1.207          .000         1.449
        2.535          2.535          .000         0.000          .000
         .000          0.000         1.207         0.000          .000
         .000           .000          .004         0.000         0.000
        0.000           .000          .001          .000         0.000

$$$$$   FINAL  OUTPUT  STREAMS  FOR  MODULE      6   -   SETSP1     $$$$$

        6.000          8.746     15060.581        25.042         4.500
   149860.604          0.000       475.640         1.457       334.754
```

```
      1762.944        995.784         767.160          0.000        197.452
       276.731          0.000           0.000          0.000           .000
         1.408           .048          21.728          0.000          0.000
         0.000          1.911           4.753          1.199          0.000

$$$$$  FINAL  OUTPUT  STREAMS  FOR  MODULE      5  -  CCNT02     $$$$$

         8.000          8.746       14148.721         25.042          4.500
    140787.128          0.000         446.841          1.369        314.486
      1656.204        935.493         720.711          0.000        185.497
       259.976          0.000           0.000          0.000           .000
         1.323           .045          20.413          0.000          0.000
         0.000          1.796           4.465          1.126          0.000

         7.000          8.746         911.859         25.042          4.500
      9073.475          0.000          28.798           .088         20.268
       106.739         60.291          46.449          0.000         11.955
        16.755          0.000           0.000          0.000           .000
          .085           .003           1.316          0.000          0.000
         0.000           .116            .288           .073          0.000

$$$$$  FINAL  OUTPUT  STREAMS  FOR  MODULE     12  -  MIXER1     $$$$$

        14.000          8.945         319.816         25.042          1.500
      3106.613          0.000          69.160           .186         64.888
       209.305        144.846          64.290           .170         15.196
        41.651          0.000          12.119           .009           .018
          .168           .000            .450          0.000          0.000
         0.000           .109            .004           .027          0.000

$$$$$  FINAL  OUTPUT  STREAMS  FOR  MODULE     17  -  SETSP1     $$$$$

        14.000          8.945         319.816         25.042         10.500
      3106.613          0.000          69.160           .186         64.888
       209.305        144.846          64.290           .170         15.196
        41.651          0.000          12.119           .009           .018
          .168           .000            .450          0.000          0.000
         0.000           .109            .004           .027          0.000

$$$$$  FINAL  OUTPUT  STREAMS  FOR  MODULE     13  -  ANDIG1     $$$$$

        15.000          9.000         314.448         40.000          8.500
      3106.613          0.000          14.065           .209         13.362
        93.557         29.098          64.290           .170          3.053
         8.367          0.000           2.435           .002           .042
          .168           .000          45.717          0.000          0.000
         0.000         12.786            .004          2.783          0.000

$$$$$  FINAL  OUTPUT  STREAMS  FOR  MODULE     14  -  ANDIG1     $$$$$

        16.000          9.000         186.728         40.000          6.500
      1863.968          0.000           1.546           .154          1.595
         8.095          2.925           5.143           .027           .307
          .841          0.000            .245           .000           .053
          .101           .000          29.962          0.000          0.000
         0.000          8.383            .002          1.824          0.000

        17.000          9.000         127.218         40.000          6.500
      1242.645          0.000           7.415           .102          7.036
        74.645         15.356          59.146           .142          1.611
         4.416          0.000           1.285           .001           .035
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```
         .067          .000        19.975          0.000          0.000
        0.000         5.588          .002          1.216          0.000

$$$$$  FINAL  OUTPUT  STREAMS  FOR  MODULE     18   -   MIXER1     $$$$$

       25.000         8.746     65876.306         25.042          1.500
   658757.336         0.000        10.048          6.404         14.319
       13.547         7.652         5.895          0.000          1.517
        2.126         0.000         0.000          0.000           .002
        6.191          .211        95.513          0.000          0.000
        0.000         8.402        20.892          5.269          0.000

$$$$$  FINAL  OUTPUT  STREAMS  FOR  MODULE     11   -   CHLOR1     $$$$$

       25.000         8.746     65876.306         25.042          1.500
   658757.336         0.000        10.048          6.404         14.319
       13.547         7.652         5.895          0.000          1.517
        2.126         0.000         0.000          0.000           .002
        6.191          .211        95.513          0.000          0.000
        0.000         8.402        20.892          5.269          0.000
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$                     SUMMARY REPORT ON PLANT OPERATIONS - CASE     1
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

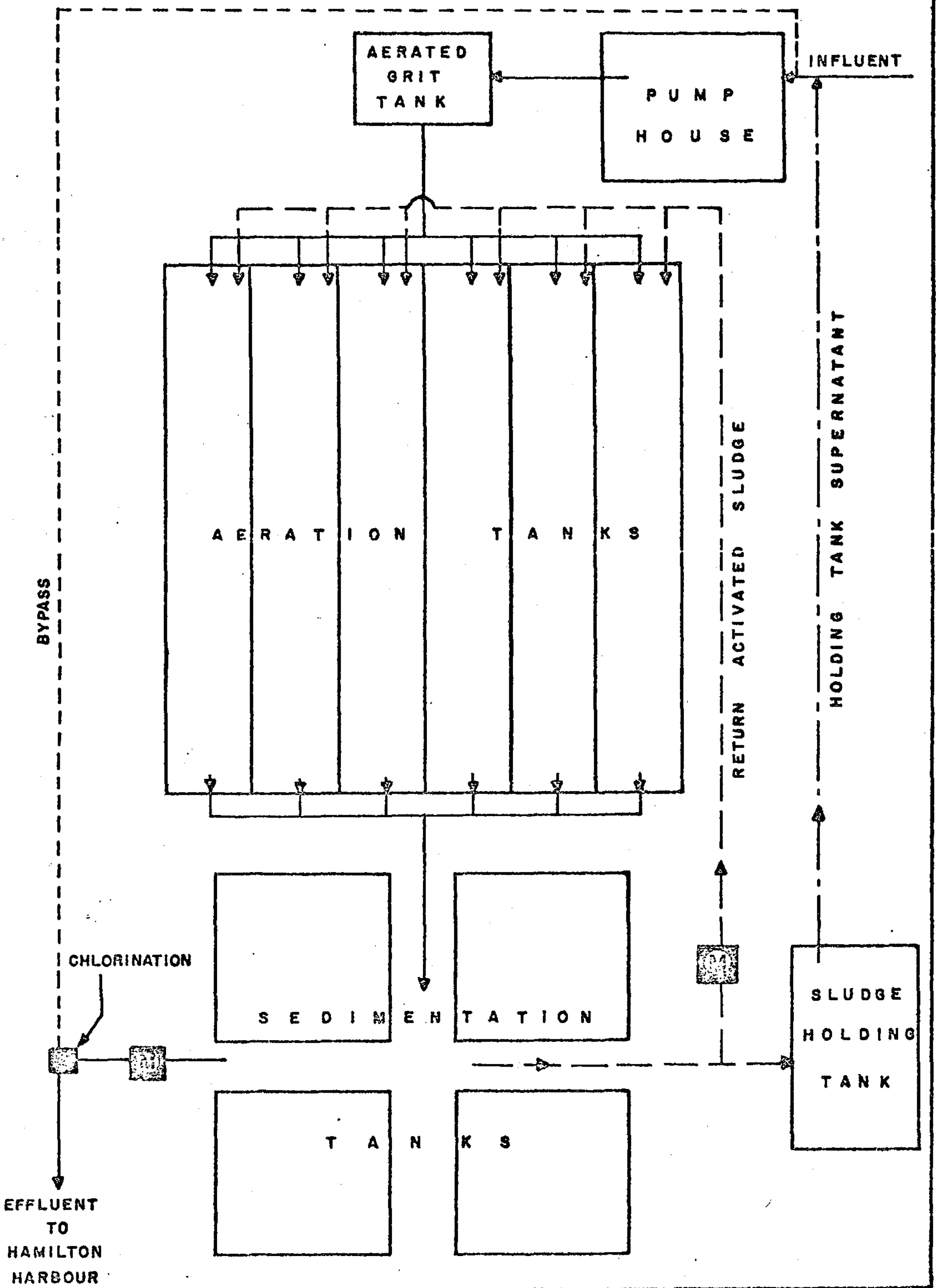
      STREAM            NUMBER     FLOW        DO        TOC        DOC        BOD        SS         VSS


RAW FEED                  18   66008.58      4.00     153.98      61.00     215.47     299.26     195.27
INPUT TO PRI. CLAR.       13   66008.58      4.00     153.98      61.00     215.47     294.17     195.27
EFF. OF PRI. CLAR.         2   66790.41      0.00      95.87      60.37     150.71     153.08      74.58
UNDERFLOW PRI CLAR         9     287.89      0.00   19804.14      60.37   17472.90   63847.75   41465.40
OUTPUT OF AER TANKS        4   80940.07      4.69     601.55       9.72     433.06    2197.95    1242.86
EFF. OF SEC. CLAR.         5   65876.31      0.00      15.25       9.72      21.74      20.56      11.62
UNDERFLOW SEC CLAR         6   15060.58      0.00    3158.18       9.72    2222.72   11705.68    6611.85
RETURN ACT. SLUDGE         8   14148.72      0.00    3158.18       9.72    2222.72   11705.68    6611.85
WASTE ACT. SLUDGE          7     911.86      0.00    3158.18       9.72    2222.72   11705.68    6611.85
INPUT TO DIGESTER         14     319.82      0.00   21624.99      59.87   20289.09   65445.39   45290.35
DIGESTER SUPERNATE        16     186.73      0.00     828.20      82.43     854.23    4335.31    1566.42
DIGESTED SLUDGE           17     127.22      0.00    5828.41      82.43    5530.88   58674.73   12070.57
```

APPENDIX J

SIMULATION DATA AND RESULTS FOR THE SKYWAY, BURLINGTON, SEWAGE TREATMENT PLANT

BURLINGTON SKYWAY
WATER POLLUTION CONTROL PLANT



DESIGN DATA

PROJECT NO.	2-0105-62	DESIGN FLOW	6 mgd
BOD - Raw Sewage	200 mg/l	SS - Raw Sewage	200 mg/l

PRETREATMENT

Coarse Screening

Type: Link Belt, mechanically-cleaned
Size: 2½" space

Lift Station Pumps (@ 30' tdh)

2 @ 6 mgd each; 2 @ 5 mgd each

Screening

Type: Link Belt, mechanically-cleaned
Size: 1" space

Grit Removal

Type: Air degritter
Size: One 20.3' x 25' x 14.2'
Retention: 20.8 min

SECONDARY TREATMENT

Aeration Tanks

Type: Diffused air, single pass
Size: Six 270' x 27' x 15'
(660,300 ft. or 4.12 mil gal)
Retention: 16.5 hr
Loading: 9.5 lb BOD/1000 ft^3

Air Supply

Type: Hoffman multi-stage
centrifugal blowers
Size: 3 - 4000 cfm (max); 1-6000 cfm (max)

Diffusers

Type: Saran-covered flexofusers
Spacing: 250 tubes per tank

Secondary Sedimentation

Type: Eimco
Size: Four 60' x 60' x 12' swd
(538,000 gal) (only two completed)
Retention: 4.1 hours
Loading: Surface, 434 gal/ft^2/day
Weir, 7,100 gal/ft/day

CHLORINATION

Type: Fischer & Porter
Size: Two 2000 lb/day

Chlorine Contact Chamber

- nil
- chlorination in outfall

OUTFALL

- to Hamilton Harbour

SLUDGE HANDLING

Type: Thickening tank, decanted
Size: One 20' dia x 9' depth
(2830 ft^3 or 1760 gal)

DATA SET FOR THE SIMULATION OF THE SKYWAY PLANT

```
   BURLINGTON SKYWAY STP
1.0         1.0         1.0         1.0         0.0
0.0         0.0         0.0         0.0         0.0
14.0        25.0        1.0
1.0         2.0         3.0         7.0         4.0
5.0         6.0         7.0         8.0         11.0
12.0        9.0         10.0        24.0
-25.0
1.0         1.0         1.0         1.0         1.0
1.0         1.0         1.0         1.0         1.0
1.0         1.0         1.0         1.0         1.0
1.0         1.0         1.0         1.0         1.0
1.0         1.0         1.0         1.0         1.0
3.0
1.0         7.4         140000.0    25.0        5.0
1400000.0   4.0         0.0         0.0         0.0
0.0         0.0         40.0        60.0        9.0
18.0        0.0         5.0         8.0         7.0
55.0        0.0         100.0       0.0         0.0
0.0         20.0        1.0         6.0         0.0
7.0         8.585       100227.0    25.0        5.5
998359.7    0.0         0.0         0.0         0.0
0.0         0.0         5602.0      0.0         654.7
1214.9      0.0         0.0         0.0         0.0
3.47        0.92        99.84       0.0         0.0
0.0         0.054       34.54       6.15        0.0
10.0        8.585       1371.4      25.0        5.5
13704.9     0.0         0.0         0.0         0.0
0.0         0.0         900.0       0.0         12.0
20.0        0.0         0.0         0.0         0.0
4.0         1.0         11.0        0.0         0.0
0.0         0.0         60.0        10.0        0.0
13.0
1.0         1.0         17.0        0.0         0.0
2.0         1.0         10.0        0.0         0.0
2.0         2.0         12.0        0.0         0.0
1.0         0.0
2.0         15.0        15.0        3.0         0.5
1.0         2.0         0.0         0.0         0.0
1.0         3.0         0.0         0.0         0.0
3.0         11.0        15.0        1.6         0.5
1.0         3.0         0.0         0.0         0.0
1.0         4.0         0.0         0.0         0.0
4.0         7.0         46.0        6.0         1.5
2.0         8.0         4.0         0.0         0.0
1.0         5.0         0.0         0.0         0.0
270.0       27.0        15.2        3.0         0.0014
0.0028      0.000002    2.2         0.54        0.45
0.08        120000.0    0.0010      0.005       0.23
0.07        250.0       0.0         3.0         1.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         3.0
240000.0
5.0         9.0         22.0        2.0         1.0
1.0         5.0         0.0         0.0         0.0
3.0         6.0         7.0         13.0        0.0
1.0         0.3         3600.0      80000.0     2.0
125000.0    0.4
6.0         4.0         15.0        0.0         4.0
1.0         7.0         0.0         0.0         0.0
1.0         7.0         0.0         0.0         0.0
7.0         17.0        15.0        4.0         4000.0
1.0         7.0         0.0         0.0         0.0
2.0         8.0         9.0         0.0         0.0
8.0         5.0         15.0        0.6         0.10
1.0         9.0         0.0         0.0         0.0
2.0         10.0        11.0        0.0         0.0
9.0         1.0         16.0        0.0         0.0
2.0         6.0         12.0        0.0         0.0
1.0         25.0        0.0         0.0         0.0
1.0
10.0        13.0        15.0        5.0         0.0
1.0         25.0        0.0         0.0         0.0
```

```
1.0         25.0        0.0         0.0         0.0
11.0        2.0         50.0        101.0       10.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
9.0         10.0        5.0         0.001       1.0
1.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
12.0        2.0         50.0        101.0       5.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
10.0        10.0        10.0        0.001       101.0
101.0       0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
24.0        16.0        35.0        0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
1.0         0.0         0.0         0.0         0.0
5.0         0.0         6.0         7.0         8.0
9.0         0.0         0.0         0.0         0.0
11.0        0.0         0.0         12.0        0.0
      RUN WITH AVERAGE FLOW CONDITIONS IN 1969
```

```
$$$$$$$$$$$$    CASE  1    $$$$$$$$$$$$

      RUN WITH AVERAGE FLOW CONDITIONS IN 1969

END OF LOOP     1

END OF LOOP     2

END OF LOOP     3

END OF LOOP     4

END OF LOOP     5
***CONVERGED

END OF LOOP   101

END OF LOOP     1

END OF LOOP     2
***CONVERGED

END OF LOOP   102

END OF LOOP     1

END OF LOOP     2
***CONVERGED

END OF LOOP   103

END OF LOOP     1

END OF LOOP     2
***CONVERGED

END OF LOOP   104
***CONVERGED
$$$$$  FINAL  OUTPUT STREAMS FOR MODULE    9  -  MIXER1   $$$$$

      25.000           8.582   139076.568       25.000        1.500
 1390759.785           0.000        8.922        6.117       11.394
      14.364           5.890        8.474        0.000         .983
       1.822           0.000        0.000        0.000         .001
       4.845           1.271      139.076        0.000        0.000
       0.000            .075       48.069        8.550        0.000
$$$$$  FINAL  OUTPUT STREAMS FOR MODULE   10  -  CHLOR1   $$$$$

      25.000           8.582   139076.568       25.000        1.500
 1390759.785           0.000        8.922        6.117       11.394
      14.364           5.890        8.474        0.000         .983
       1.822           0.000        0.000        0.000         .001
       4.845           1.271      139.076        0.000        0.000
       0.000            .075       48.069        8.550        0.000
$$$$$  FINAL  OUTPUT STREAMS FOR MODULE    1  -  MIXER1   $$$$$
```

```
      2.000         7.703     141384.741        25.000         5.000
1413731.237         5.600        147.109        86.860       220.403
    279.356       126.522         68.835        84.000        14.089
     27.960         0.000          7.000        11.200         9.800
     77.048          .013        141.373         0.000         0.000
      0.000        28.001          1.875         8.484         0.000

     12.000         7.703          0.000        25.000         5.000
      0.000         0.000          0.000         0.000         0.000
      0.000         0.000          0.000         0.000         0.000
      0.000         0.000          0.000         0.000         0.000
      0.000         0.000          0.000         0.000         0.000
      0.000         0.000          0.000         0.000         0.000

$$$$$  FINAL OUTPUT STREAMS FOR MODULE     2  -  SCREEN1   $$$$$

      3.000         7.703     141384.159        25.000         4.500
1413731.237         5.600        141.050        86.860       213.131
    266.632       113.797         68.835        84.000        14.089
     21.900         0.000          7.000        11.200         9.800
     77.048          .013        141.373         0.000         0.000
      0.000        28.001          1.875         8.484         0.000

$$$$$  FINAL OUTPUT STREAMS FOR MODULE     3  -  GRIT1     $$$$$

      4.000         7.703     141384.159        25.000         4.000
1413731.237         5.600        141.050        86.860       213.131
    251.669       113.797         53.872        84.000        14.089
     21.900         0.000          7.000        11.200         9.800
     77.048          .013        141.373         0.000         0.000
      0.000        28.001          1.875         8.484         0.000

$$$$$  FINAL OUTPUT STREAMS FOR MODULE     7  -  CCNT02    $$$$$

      8.000         8.585      97938.673        25.000         5.500
 975565.103         0.000       1822.428         4.291      1423.737
   9310.721      3818.087       5492.634         0.000       637.072
   1181.065         0.000          0.000         0.000          .001
      3.398          .892         97.556         0.000         0.000
      0.000          .053         33.719         5.997         0.000

      9.000         8.585       2288.455        25.000         5.500
  22795.252         0.000         42.583          .100        33.267
    217.556        89.214        128.342         0.000        14.886
     27.597         0.000          0.000         0.000          .000
       .079          .021          2.280         0.000         0.000
      0.000          .001           .788          .140         0.000

$$$$$  FINAL OUTPUT STREAMS FOR MODULE     4  -  ACTSL1    $$$$$

      5.000         8.585     239322.029        25.000         2.500
2389296.340        17.105       1880.367        10.510      1476.276
   9557.206      3926.700       5630.506         0.000       652.810
   1210.113         0.000          6.934         0.000          .002
      8.324         2.183        238.930         0.000         0.000
      0.000          .129         82.578        14.687         0.000

$$$$$  FINAL OUTPUT STREAMS FOR MODULE     5  -  SECLAR1   $$$$$

      6.000         8.585     139076.643        25.000         1.500
1390760.532         0.000          8.922         6.117        11.395
```

```
      14.364        5.889        8.475        0.000         .983
       1.822        0.000        0.000        0.000         .001
       4.845        1.271      139.076        0.000        0.000
       0.000         .075       48.067        8.549        0.000

       7.000        8.585   100227.123       25.000        1.500
  998360.390        0.000     1864.510        4.391     1456.560
    9528.279     3906.250     5622.030        0.000      651.828
    1208.291        0.000        0.000        0.000         .001
       3.478         .912       99.836        0.000        0.000
       0.000         .054       34.505        6.137        0.000

      13.000        8.585       18.263       25.000        1.500
     175.418        0.000        6.935         .001        8.322
      14.562       14.561         .001        0.000         .000
        .000        0.000        6.934        0.000         .000
        .001         .000         .018        0.000        0.000
       0.000         .000         .006         .001        0.000

$$$$$  FINAL OUTPUT STREAMS FOR MODULE     6  -  SETSP1   $$$$$

       7.000        8.585   100227.123       25.000        5.500
  998360.390        0.000     1864.510        4.391     1456.560
    9528.279     3906.250     5622.030        0.000      651.828
    1208.291        0.000        0.000        0.000         .001
       3.478         .912       99.836        0.000        0.000
       0.000         .054       34.505        6.137        0.000

$$$$$  FINAL OUTPUT STREAMS FOR MODULE     7  -  CCNT02   $$$$$

       8.000        8.585    97938.264       25.000        5.500
  975561.112        0.000     1821.931        4.291     1423.297
    9310.685     3817.044     5493.641        0.000      636.942
    1180.698        0.000        0.000        0.000         .001
       3.399         .891       97.556        0.000        0.000
       0.000         .053       33.717        5.997        0.000

       9.000        8.585     2288.859       25.000        5.500
   22799.278        0.000       42.579         .100       33.263
     217.595       89.206      128.389        0.000       14.886
      27.593        0.000        0.000        0.000         .000
        .079         .021        2.280        0.000        0.000
       0.000         .001         .788         .140        0.000

$$$$$  FINAL OUTPUT STREAMS FOR MODULE     8  -  SEPA01   $$$$$

      10.000        8.585     1374.208       25.000        5.500
   13733.153        0.000        4.308         .060        3.402
      21.759        8.921       12.839        0.000        1.489
       2.759        0.000        0.000        0.000         .000
        .048         .013        1.373        0.000        0.000
       0.000         .001         .475         .084        0.000

      11.000        8.585      914.650       25.000        5.500
    9066.125        0.000       38.271         .040       29.861
     195.835       80.285      115.550        0.000       13.397
      24.834        0.000        0.000        0.000         .000
        .032         .008         .907        0.000        0.000
       0.000         .000         .313         .056        0.000
```

```
      25.000         8.582    139076.643        25.000         1.500
 1390760.532         0.000         8.922         6.117        11.395
      14.364         5.889         8.475         0.000          .983
       1.822         0.000         0.000         0.000          .001
       4.845         1.271       139.076         0.000         0.000
       0.000          .075        48.067         8.549         0.000

$$$$$  FINAL OUTPUT STREAMS FOR MODULE   10  -  CHLOR1   $$$$$

      25.000         8.582    139076.643        25.000         1.500
 1390760.532         0.000         8.922         6.117        11.395
      14.364         5.889         8.475         0.000          .983
       1.822         0.000         0.000         0.000          .001
       4.845         1.271       139.076         0.000         0.000
       0.000          .075        48.067         8.549         0.000
```

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$                     SUMMARY REPORT CN PLANT OPERATIONS - CASE     1
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$


      STREAM           NUMBER     FLOW         DO         TOC         DOC         EOC          SS         VSS


RAW FEED                    1 140010.72       4.00      101.99       62.00      154.99      183.99       83.99
OUTPUT OF AER TANKS         5 239322.03       7.16      785.71        4.40      616.86     3993.45     1640.76
EFF. OF SEC. CLAR.          6 139076.64       0.00        6.41        4.40        8.19       10.33        4.23
UNDERFLOW SEC CLAR          7 100227.12       0.00     1860.29        4.40     1453.26     9506.69     3897.40
RETURN ACT. SLUDGE          8  97938.26       0.00     1860.29        4.40     1453.26     9506.69     3897.40
WASTE ACT. SLUDGE           9   2288.86       0.00     1860.29        4.40     1453.26     9506.69     3897.40
THICKENED SLUDGE           11    914.65       0.00     4184.22        4.40     3264.73    21410.93     8777.71
PLANT BYPASS               12      0.00       0.00        0.00        0.00        0.00        0.00        0.00
```

APPENDIX K

Computer Listings

```
      PROGRAM TST (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C
C     GEMCS/6400
C
C
C     ***** PRINTING CONTROL CHARACTERS *****
C
C     KPRNT(1)=1  CAUSES PRINTING OF NCONT,LLST,NS
C     KPRNT(1)=0  SUPPRESSES ABOVE PRINTING
C     KPRNT(2)=1  CAUSES PRINTING OF INITIAL STREAMS
C     KPRNT(2)=0  SUPPRESSES ABOVE PRINTING
C     KPRNT(3)=1  CAUSES PRINTING OF MODULES SETS
C     KPRNT(3)=0  SUPPRESSES ABOVE PRINTING
C     KPRNT(4)=1 CAUSES PRINTING OF NPOINT
C     KPRNT(4)=0  SUPPRESSES ABOVE PRINTING
C     KPRNT(5)=1 CAUSES PRINTING OF SN TABLE ON ENTERING LOOP
C     KPRNT(5)=0 SUPPRESSES ABOVE PRINTING
C     ISP =1 PRINTS BOTH THE INPUT STREAMS AND OUTPUT STREAMS LEAVING
C     A MODULE - CAN BE SET BY HAVINGMSN NEGATIVE IN DATA SET
C     ISP=0 SUPPRESSES ABOVE PRINTING - DONE AUTOMATICALLY BY GEMCS
C     AFTER TWO LOOPS
C
C     ***** COMMON DECLARATIONS - JUNE 8 *****
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
      DIMENSION NAME(20)
      NAME(1)=8H MIXER1
      NAME(2)=8H CONTL1
      NAME(3)=8H SETST1
      NAME(4)=8H SETSP1
      NAME(5)=8H SEPA01
      NAME(6)=8H PRISET1
      NAME(7)=8H ACTSL1
      NAME(8)=8H DPTR1
      NAME(9)=8H SECLAR1
      NAME(10)=8H TRICK1
      NAME(11)=8H GRIT1
      NAME(12)=8H ANDIG1
      NAME(13)=8H CHLOR1
      NAME(14)=8H COST1
      NAME(15)=8H SCREEN1
      NAME(16)=8H REPT01
      NAME(17)=8H CONT02
      NAME(18)=8H CONV01
      NAME(19)=8H CASET
      NAME(20)=8H THICK1
C
C
      III=25
      CALL DLOAD1
      LOOPC=1
      WRITE(6,196) LOOPC
      READ(5,198) TITLE
      WRITE(6,200) TITLE
C
C     CALCULATING EQUIPMENT IN CALCULATION ORDER LIST
C
C     IK IS USED AS AN INDICATOR
C     IK=1 FOR A STRAIGHT THROUGH CALCULATION
C     IK=0 FOR A RECYCLE OPERATION
      IK=0
      IF(LOOP.EQ.999) IK=1
C
100   CONTINUE
      NC=1
      MODE=0
      KTEST=0
      LOOP=1
      IF(IK.EQ.0) GO TO 98
```

```
      MODE=1
      KTEST=1
      LOOP=999
98    CONTINUE
C
C     READ EN VECTOR
C
102   IF (KPRNT(5)) 108,108,104
104   CONTINUE
      WRITE (6,182) LOOP
      DO 106 IKE=1,III
      IF (SN(IKE,1).LE.0.0) GO TO 106
      WRITE (6,194) (SN(IKE,J),J=1,JJ)
106   CONTINUE
C
108   NE=LLST(NC)
      MM=NE
      CALL DISKIO (1,MM)
      NN=EN(3)+.001
      NIN=EN(6)+.001
      NOUT=EN(11)+.001
      NTYPE=ABS(EN(2))+.001
      KSW=0
      IF (EN(2).LE.0.) KSW=1
      IF (LOOP.GT.2) ISP=0
      IF(LOOP.LE. 2) ISP=1
C
C     FINDING INPUT STREAMS
C
      IF(NIN.EQ.0) GO TO 128
      DO 122 I=1,NIN
      S=EN(I+6)
      CALL STREAM (S)
      IF (IS-III) 114,114,110
110   CONTINUE
      SI(I,1)=S
      DO 112 J=2,JJ
      SI(I,J)=0.
112   CONTINUE
      GO TO 122
114   DO 116 J=1,JJ
      SI(I,J)=SN(IS,J)
116   CONTINUE
      IF (INT(S+.001)) 122,122,118
118   CONTINUE
      M=S+.001
      IF (NS(M)-6) 122,120,120
120   CONTINUE
      SN(IS,1)=0.
122   CONTINUE
      IF (ISP) 128,128,124
124   WRITE (6,184) NE ,NAME(NTYPE)
      DO 126 IKE=1,NIN
      WRITE(6,194)
      WRITE (6,194) (SI(IKE,J),J=1,JJ)
126   CONTINUE
C
128   CONTINUE
C
C
      CALL MODULE (NTYPE)
C
C
C     STORING OUTPUT STREAMS AND PRINTING
C
      IF(NOUT) 166,166,136
136   CONTINUE
      DO 150 I=1,NOUT
      S=EN(I+11)
      SO(I,1)=S
      M=S+.001
      IF(NS(M)-6) 140,150,140
140   CALL STREAM (-S)
      IF (IS-III) 146,146,142
142   CALL STREAM (0.)
      IF (IS-III) 146,146,144
```

```
144   WRITE (6,190)
      GO TO 150
146   DO 148 J=1,JJ
      SN(IS,J)=SO(I,J)
148   CONTINUE
150   CONTINUE
C
      IF (ISP) 158,158,154
154   WRITE (6,186) NE , NAME(NTYPE)
      DO 156 IKE=1,NOUT
      WRITE(6,194)
      WRITE (6,194) (SO(IKE,J),J=1,JJ)
156   CONTINUE
C
158   IF (LOOP-999) 166,160,160
160   IF (KSW.NE.0) GO TO 166
      WRITE(6,188) NE, NAME(NTYPE)
      DO 164 IKE=1,NOUT
      WRITE(6,194)
      WRITE (6,194) (SO(IKE,J),J=1,JJ)
164   CONTINUE
C
166   NC=NC+1
      IF (NC-NCALC) 102,102,168
C
168   CONTINUE
      IF (LOOP-999) 170,172,172
170   CONTINUE
      NC=0
      GO TO 166
172   IF (KTEST) 174,174,176
174   NC=0
      KTEST=1
      MODE=1
      GO TO 166
176   LOOPC=LOOPC+1
      IF (LOOPC-NPLNT) 178,178,180
178   WRITE(6,196) LOOPC
      CALL DLOAD3
      GO TO 100
C
180   WRITE (6,192)
      STOP
C
182   FORMAT (1H0,32H$$$$$  SN TABLE ON ENTERING LOOP  ,I5,7H  $$$$$ )
184   FORMAT (1H0,31H$$$$$  INPUT STREAMS FOR MODULE ,I5,4H  - ,
     1A8,7H  $$$$$ )
186   FORMAT (1H0,32H$$$$$  OUTPUT STREAMS FOR MODULE ,I5,4H  - ,A8,
     2 7H  $$$$$ )
188   FORMAT (1H0,38H$$$$$  FINAL OUTPUT STREAMS FOR MODULE ,I5,4H  - ,
     3 A8,7H  $$$$$ )
190   FORMAT (1H0,25H*****  ERROR IN SN  *****  )
192   FORMAT (1H0,38H**********  END OF EXECUTION  **********  )
194   FORMAT (1H ,10F12.3)
196   FORMAT(1H1,28H$$$$$$$$$$$$$$$$$$$$   CASE  ,I4,24H    $$$$$$$$$$$$
     1$$$$$$$$  ,//)
198   FORMAT(10A8)
200   FORMAT(1H0,10A8)
      END


                          CD TOT   0212
```

```
      SUBROUTINE STREAM (S)
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
      DO 2 IS=1,III
      IF (ABS(SN(IS,1)-ABS(S))-.001) 4,2,2
2     CONTINUE
      IS=IS+1
4     RETURN
      END




      SUBROUTINE DISKIO (IPNT,MM)
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     THIS SUBROUTINE SIMULATES DISKIO ON360/30
C     IF IPNT=1.  READS FROM MODULE SETS TABLE
C     IF IPN=2. WRITES ONTO MODULE SETS TABLE
      MQ=NPOINT(MM,1)
      ML=NPOINT(MM,2)
      IF (IPNT-1) 6,2,6
2     DO 4 I=1,ML
      EN(I)=EEN(MQ+I)
4     CONTINUE
      GO TO 14
6     IF (IPNT-2) 12,8,12
8     DO 10 I=1,ML
      EEN(MQ+I)=EN(I)
10    CONTINUE
      GO TO 14
12    WRITE (6,16) IPNT,MM
14    RETURN
C
16    FORMAT (1H0,22H DISKIO ERROR-IPNT,MM=,I5,1X,I5)
      END




      SUBROUTINE DLOAD1
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
      DIMENSION TITLE (10)
      DIMENSION AKPRNT(10), ALLST(10)
      DIMENSION ANS(100)
C
      DO 2 I=1,100
      EN(I)=0.
2     CONTINUE
      DO 6 I=1,30
      DO 4 J=1,4
      SI(J,I)=0.
      SO(J,I)=0.
4     CONTINUE
      DO 6 IK=1,III
      SN(IK,I)=0.
6     CONTINUE
      DO 7 I=1,25
      NPOINT(I,1)=0.0
7     NPOINT(I,2)=0.0
      NCOUNT=0
C
      WRITE(6,79)
```

```
      WRITE(6,81)
      READ (5,80) TITLE
      WRITE(6,82) TITLE
      WRITE(6,81)
      READ (5,100) AKPRNT
      DO 8 I=1,10
      KPRNT(I)=AKPRNT(I)
8     CONTINUE
C
C     REPORT ON PRINTING EXPECTED
C
      IF (KPRNT(1)-1) 12,10,12
10    WRITE (6,84)
12    IF (KPRNT(2)-1) 16,14,16
14    WRITE (6,86)
16    IF (KPRNT(3)-1) 20,18,20
18    WRITE (6,88)
20    CONTINUE
C
C     READ NO. OF MODULES IN CALCULATION ORDER, AND NO. OF CONPOMENTS
C
      READ (5,100) ANCALC,ANOCOM,ANPLNT
      NCALC=ANCALC
      NOCOMP=ANOCOM
      NPLNT=ANPLNT
      IF (NPLNT.GT.0) WRITE (6,108) NPLNT
      IF (KPRNT(1)-1) 24,22,24
22    WRITE(6,95) NOCOMP
      WRITE(6,92) NCALC
24    CONTINUE
      IF (-NCALC) 28,26,26
26    NCALC=-NCALC
      LOOP=999
      GO TO 30
28    LOOP=1
C
C     READ CALCULATION ORDER
C
30    READ (5,100) (ALLST(I),I=1,NCALC)
      DO 32 I=1,NCALC
      LLST(I)=ALLST(I)
32    CONTINUE
      IF (KPRNT(1)-1) 36,34,36
34    WRITE(6,93)
      WRITE (6,94) (LLST(I),I=1,NCALC)
36    CONTINUE
C
C     READ STREAM CODES,MSN IS THE MAXIMUM STREAM NUMBER, IF NEGATIVE
C     OUTPUT STREAMS WILL BE PRINTED DURING EXECUTION
C
      READ (5,100) AMSN
      MSN=AMSN
      IF (-MSN) 40,38,38
38    MSN=-MSN
      ISP=1
40    IF (KPRNT(1)-1) 44,42,44
42    WRITE (6,96) MSN
44    READ (5,100) (ANS(I),I=1,MSN)
      DO 46 I=1,MSN
      NS(I)=ANS(I)
46    CONTINUE
      IF (KPRNT(1)-1) 50,48,50
48    WRITE (6,94) (NS(I),I=1,MSN)
50    JJ=NOCOMP+5
      READ (5,100) ANSR
      NSR=ANSR
      IF (KPRNT(2)-1) 54,52,54
52    WRITE (6,98) NSR
54    DO 60 I=1,NSR
      READ (5,100) (SN(I,J),J=1,JJ)
      CALL CONVERT(2,1,I,1,I)
      CALL BALNCE(1,I)
      IF (KPRNT(2)-1) 58,56,58
56    WRITE (6,102) (SN(I,J),J=1,JJ)
      WRITE(6,102)
58    CONTINUE
```

```
60    CONTINUE
C
C     READING MODULE SETS,NOE IN NUMBER
C
      READ (5,100) ANOE
      NOE=ANOE
      IF (KPRNT(3)-1) 64,62,64
62    WRITE (6,104) NOE
64    DO 72 I=1,NOE
      DO 66 IZ=1,100
      EN(IZ)=0.
66    CONTINUE
      READ (5,100) (EN(N),N=1,5)
      NN=EN(3)
      NCOUNT=NCOUNT+NN
      READ (5,100) (EN(N),N=6,NN)
      IF (KPRNT(3)-1) 70,68,70
68    WRITE (6,102) (EN(N),N=1,NN)
      WRITE(6,102)
70    MM=EN(1)+.001
      NPOINT(MM,1)=NCOUNT-NN
      NPOINT(MM,2)=NN
      CALL DISKIO (2,MM)
72    CONTINUE
      IF (KPRNT(4).GT.0) GO TO 74
      GO TO 78
74    WRITE (6,106)
      DO 76 I=1,25
      WRITE (6,90) I,NPOINT(I,1),NPOINT(I,2)
76    CONTINUE
78    CONTINUE
C     FORMAT STATEMENTS FOR DLOAD
C
      RETURN
C
79    FORMAT(1H1)
80    FORMAT(10A8)
81    FORMAT(1H0,120H$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
     1$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
     2$$$      )
82    FORMAT(1H0,1H$,19X,10A8,19X,1H$)
84    FORMAT (1H0,22HPRINTING NCONT,LLST,NS)
86    FORMAT (1H0,24HPRINTING INITIAL STREAMS)
88    FORMAT (1H0,20HPRINTING MODULE SETS)
90    FORMAT (1X,3I6)
92    FORMAT(1H0,41HNUMBER OF MODULES IN CALCULATION ORDER =    ,I5)
93    FORMAT(1H0,27HCALCULATION ORDER LIST IS-   ,/)
94    FORMAT (1X,20I5)
95    FORMAT(1H0,23HNUMBER OF COMPONENTS =  ,I5)
96    FORMAT(1H0,30HNUMBER OF STREAM CODES READ =  ,I5,/)
98    FORMAT(1H0,33HNUMBER OF INITIAL STREAMS READ =  ,I5,/)
100   FORMAT(5F12.2)
102   FORMAT (1X,10F12.4)
104   FORMAT(1H0,29HNUMBER OF MODULE SETS READ =  ,I5,/)
106   FORMAT(1H0,//,20H MODULE  EEN  LENGTH   ,/)
108   FORMAT((1H0,25HNUMBER OF PLANT CASES =  ,I5)
      END
```

```
      SUBROUTINE MODULE(NT)
C
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20),NT
C
1     CALL MIXER1
      GO TO 50
2     CALL CONTL1
      GO TO 50
3     CALL SETST1
      GO TO 50
4     CALL SETSP1
      GO TO 50
5     CALL SEPA01
      GO TO 50
6     CALL PRISET1
      GO TO 50
7     CALL ACTSL1
      GO TO 50
8     CALL DPTR1
      GO TO 50
9     CALL SECLAR1
      GO TO 50
10    CALL TRICK1
      GO TO 50
11    CALL GRIT1
      GO TO 50
12    CALL ANDIG1
      GO TO 50
13    CALL CHLOR1
      GO TO 50
14    CALL COST1
      GO TO 50
15    CALL SCREEN1
      GO TO 50
16    CALL REPT01
      GO TO 50
17    CALL CONT02
      GO TO 50
18    CALL CONV01
      GO TO 50
19    CALL CASET
      GO TO 50
20    CALL THICK1
C
50    RETURN
      END
```

```
      SUBROUTINE DLOAD3
C
C
C     WRITTEN BY P. TAN  1971
C     MODULE TO RUN NEW CASES
C     READS IN NEW STREAMS AND MODULE SETS
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
      DIMENSION TITLE(10)
C
C
      READ(5,100) TITLE
100   FORMAT(10A8)
      WRITE(6,101) TITLE
101   FORMAT(1H0,10A8)
C
C     READ NUMBER OF STREAM CHANGES
      READ(5,112) ANSR
112   FORMAT(5F12.4)
      NSR=ANSR+0.001
      IF(NSR.LE. 0) GO TO 300
      WRITE(6,111) NSR
  111 FORMAT(1H0,I5,25HINITIAL STREAMS ARE READ    )
C
C     READ STREAMS
      DO 530 I=1,NSR
C     BORROWS VECTOR FROM SO(4,J), J=1,JJ
      READ(5,112) (SO(4,J),J=1,JJ)
      CALL CONVERT(2,2,4,2,4)
      CALL BALNCE(2,4)
      WRITE(6,113)
      WRITE(6,113) (SO(4,J),J=1,JJ)
  113 FORMAT(1X,10F12.4)
      S=SO(4,1)
      CALL STREAM(S)
      IF(III-IS) 400,401,401
  400 CALL STREAM(0.0)
      IF(III-IS) 403,401,401
  401 DO 402 J=1,JJ
  402 SN(IS,J)=SO(4,J)
  530 CONTINUE
C
C     READ NUMBER OF MODULE CHANGES
  300 READ(5,112) ANOE
      NOE=ANOE+0.001
      IF(NOE.LE. 0) GO TO 301
      WRITE(6,114) NOE
  114 FORMAT(1H0,I5,21HMODULE SETS ARE READ     )
C
C     READ MODULES
      DO 540 I=1,NOE
      DO 541 IZ=1,100
  541 EN(IZ)=0.0
      READ(5,112) (EN(N),N=1,5)
      NN=EN(3)+0.001
      MM=EN(1)+0.001
      READ(5,112) (EN(N),N=6,NN)
      WRITE(6,113)
      WRITE(6,113)(EN(N),N=1,NN)
      CALL DISKIO(2,MM)
  540 CONTINUE
  301 CONTINUE
      RETURN
C
  403 WRITE(6,405)
  405 FORMAT(1H0,* ERROR IN SN - VECTOR SPACE INSUFFICIENT *,//)
C
      RETURN
      END
```

```
      SUBROUTINE SETST1
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     ALTERS THE TEMPERATURE IN ANY STREAM
C     EN(4)= CHANGE IN TEMP (+VE FOR INCREASE AND -VE FOR DROP)
C     WRITTEN BY P. TAN
C     FOR WWTP SIMULATION
C
C
      DO 1 I=2,JJ
1     SO(1,I)=SI(1,I)
      SO(1,4)=SI(1,4)+EN(4)
C
      RETURN
      END



      SUBROUTINE SETSP1
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     WRITTEN BY P. TAN
C     FOR WWTP SIMULATION
C     ALTERS THE HEAD IN ANY STREAM
C     EN(5)= CHANGE IN HEAD (+VE FOR GAIN, -VE FOR LOSS)
C
C
      DO 1 I=2,JJ
1     SO(1,I)=SI(1,I)
      SO(1,5)=SI(1,5)+EN(5)
C
      RETURN
      END



      SUBROUTINE CONTL1
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     WRITTEN BY A.I.JOHNSON AND T.TOONG  MAY 1968
C
C     EN LIST
C     1. EQUIPMENT NUMBER
C     2. EQUIPMENT TYPE -2
C     3. LENGTH OF EN LIST-21
C     4. LARGEST LOOP IDENTIFICATION NUMBER IN PROCESS FLOW DIAGRAM
C     5. PRINTING CONTROL-NUMBER OF LOOPS BETWEEN PRINTING OF THE STREAM
C         UNDER TEST )ONLY NON ZERO COMPONENTS* AND THEIR FRACTIONAL
C         CHANGES
C     6.-15.  TEN ZEROES
C     16. NO. OF MODULES IN CALC ORDER LIST CONTROLLED BY CONTL1
C     17. MAXIMUM NO. OF LOOPS
C     18. STREAM NUMBER OF STREAM TESTED
C     19. FRACTIONAL TOLERANCE
C     20. LOOP IDENTIFICATION NO.
C     21. LOOP IDENTIFICATION NO.
C     22.-(19+JJ) = 0.0
```

```
C
C
      IF(999-LOOP)13030,13030,13300
13300 NN=EN(3)+.001
      LOOP=EN(21)+.001
      ML=EN(20)+.001
      LL=LOOP-ML+1
      WRITE(6,13001) LOOP
13001 FORMAT(1H0,11HEND OF LOOP,I5)
      D=FLOAT(LL)/EN(5)
      C=FLOAT(INT(D))-D
      E=EN(18)
      IF(INT(E+.001))13011,13015,13011
13011 CALL STREAM (E)
      IF(LL-2)13015,13150,13150
13150 L=0
      DO 13013 J=3,JJ
      S=SN(IS,J)
      IF(INT(S+.001)) 13016,13013,13016
13016 TEST=(S-EN(J+19))/S
      IF(ABS(TEST)-EN(19)) 13017,13017,13170
13170 L=L+1
13017 IF(J-3)13024,13019,13024
13019 WRITE(6,13004) E,TEST
      IF(C)13013,13130,13130
13130 WRITE(6,13077)
13077 FORMAT(1X,30H...J......VALUE........FRAC          )
13024 IF(ABS(C)-.001)13135,13135,13013
13135 WRITE(6,13005) J,S,TEST
13005 FORMAT(1X,I3,F12.2,F12.6)
13004 FORMAT(1H0,36HFRACTIONAL CHANGE IN TOTAL OF STREAM,F5.0,2HIS,F10.8
     1)
13013 CONTINUE
      IF(L) 13022,13020,13022
13020 WRITE(6,13301)
13301 FORMAT(1H ,12H***CONVERGED)
      EN(21)=EN(20)
      IF(FLOAT(LOOP).GE.EN(4)) LOOP=999
      GO TO 13023
13022 IF(LL-INT(EN(17)+.001)) 13015,13025,13015
13025 WRITE(6,13302)
13302 FORMAT(1H ,16H***NOT CONVERGED)
      EN(21)=EN(20)
      IF(FLOAT(LOOP).GE.EN(4)) LOOP=999
      GO TO 13023
13015 EN(21)=LOOP+1
      LOOP=LOOP+1
      NC=NC-INT(EN(16))-1
      IF(INT(E+.001)) 13023,13030,13023
13023 DO13021 J=3,JJ
13021 EN(J+19)=SN(IS,J)
      MM=NE
      CALL DISKIO(2,MM)
 3000 CONTINUE
C
13030 RETURN
      END
```

CD TOT   0133

```
      SUBROUTINE CONV01
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     WRITTEN BY P. TAN           25/6/71
C     FOR WWTP SIMULATION
C
C     CONVERGENCE PROMOTION ON A STREAM
C
C     EN VECTOR
C     *********
C     1. = MODULE NUMBER
C     2. MODULE TYPE (18)
C     3. MODULE LENGTH    (   16 + (JJ-2)*2    )
C     4. = LOOP AT WHICH MODULE IS EFFECTIVE
C     5. = STREAM NUMBER OF STREAM TO BE CONVERGENCE-PROMOTED
C     6.-15. = TEN ZEROES
C     16. LOOP COUNTER - INITIALLY SET AT ZERO
C     17. - (16+(JJ-2)*2)     STORAGE SPACE FOR STREAM
C
C
      NLOOP = EN(4)+0.01
      IF(LOOP.LT.NLOOP) RETURN
      KOUNT=EN(16)+0.01
      KOUNT=KOUNT+1
      S=EN(5)
      CALL STREAM(S)
      GO TO (1,2,3), KOUNT
C
1     DO 600 J=3,JJ
600   EN(14+J)=SN(IS,J)
      EN(16)=KOUNT
      RETURN
C
2     DO 610 J=3,JJ
610   EN(12+JJ+J)=SN(IS,J)
      EN(16)=KOUNT
      RETURN
C
3     DO 630 J=13,JJ
      DENOM=2.0*EN(12+JJ+J)-EN(14+J)-SN(IS,J)
      IF(DENOM.EQ. 0.0) GO TO 630
      SN(IS,J)=(EN(12+JJ+J)*EN(12+JJ+J)-SN(IS,J)*EN(14+J))/DENOM
      EN(14+J)=SN(IS,J)
630   CONTINUE
      EN(16)=1.0
      I=S+0.01
      CALL BALNCE(1,I)
C
      RETURN
      END
```

```
      SUBROUTINE PRISET1
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     SIMULATES A PRIMARY SETTLING TANK
C     WRITTEN BY P. TAN
C     FOR WWTP SIMULATION
C     FOR REVISED STREAM LIST    2/9/71
C
C
C     EN VECTOR
C     *********
C     1.-15. STANDARD FORMAT
C     4.     NUMBER OF TANKS IN PARALLEL
C     5.     HEAD LOSS THROUGH TANKS (FT OF WATER)
C     7.     FIRST INPUT STREAM (RAW WASTE STREAM)
C     8.     SECOND INPUT STREAM (SUPERNATE FROM THE DIGESTERS - IF ANY)
C     9.     THIRD INPUT STREAM (WASTE ACTIVATED SLUDGE - IF ANY )
C     12.    FIRST OUTPUT STREAM (EFFLUENT)
C     13.    SECOND OUTPUT STREAM (UNDERFLOW)
C     14.    THIRD OUTPUT STREAM (SCUM TROUGH FLOW)
C     16.    LENGTH OF TANK (FEET)
C            = 0.0 IF TANK IS CIRCULAR
C     17.    WIDTH OF TANK (FEET)
C            = RADIUS OF TANK IF CIRCULAR (FEET)
C     18.    DEPTH OF TANK (FEET)
C     19.    NOT CURRENTLY USED
C     20.    SOLIDS CONCENTRATION OF SCUM FLOW (MG/L)
C     21.    EFFICIENCY FACTOR FOR TANKS
C     22.    FRACTION OF FLOCCULATED SOLIDS FROM WASTE ACTIVATED
C            SLUDGE AND DIGESTER SUPERNATE THAT IS RESUSPENDED
C     23.    NUMBER OF UNDERFLOW SLUDGE PUMPS
C     24.    CAPACITY OF PUMPS IGPH EACH
C     25.    FRACTION OF CAPACITY AT WHICH PUMPS ARE RUN
C
C
      CALL ALKMIX(PH)
C
      DO 700 J=2,JJ
      SO(1,J)=0.0
      SO(2,J)=0.0
700   SO(3,J)=0.0
C
      IF(NIN.EQ.1) GO TO 40
C
C     INPUT STREAMS 2 AND 3 ARE SLUDGE STREAMS - HENCE SETTLE MUCH
C     FASTER THAN SOLIDS IN RAW WASTE. DISP IS THE FRACTION OF SOLIDS
C     FROM INPUT STREAMS 2 AND 3 WHICH ARE RESUSPENDED.
C
      DISP=EN(22)
      DISP1=1.0-DISP
C
      DO 620 J=13,19
      DO 620 I=2,NIN
      SO(2,J)=SO(2,J)+SI(I,J)*DISP1
620   SO(1,J)=SO(1,J)+SI(I,J)*DISP
C
      DO 610 J=20,JJ
      DO 610 I=2,NIN
610   SI(1,J)=SI(1,J)+SI(I,J)
C
      SI(1,4)=SI(1,4)*SI(1,3)
      DO 630 I=2,NIN
      SI(1,3)=SI(1,3)+SI(I,3)
      SI(1,4)=SI(1,4)+SI(I,4)*SI(I,3)
      SI(1,6)=SI(1,6)+SI(I,6)
630   IF(SI(I,5).LT.SI(1,5)) SI(1,5)=SI(I,5)
      SI(1,4)=SI(1,4)/SI(1,3)
C
```

```
C
40    CONTINUE
C
C     CALCULATE EXIT HEAD
      SO(1,5)=SI(1,5)-EN(5)
      SO(2,5)=SI(1,5)-EN(5)
      SO(3,5)=SI(1,5)-EN(5)
C
      SO(1,2)=PH
      SO(2,2)=PH
      SO(3,2)=PH
      SO(1,4)=SI(1,4)
      SO(2,4)=SI(1,4)
      SO(3,4)=SI(1,4)
C
C     CALCULATE SURFACE AREA
      IF(EN(16).LE. 0.0) GO TO 730
      AREA=EN(16)*EN(17)*EN(4)
      GO TO 720
730   AREA=3.142*EN(17)*EN(17)*EN(4)/4.0
720   CONTINUE
C
C     CALCULATING RESIDENCE TIME TBAR (MINUTES)
      TBAR=AREA*EN(18)/SI(1,3)*374.4
C
C     CALCULATING OVERFLOW RATE OR (IGPD/SQ.FT.)
      OR=SI(1,3)*24.0/AREA
C
C     CALCULATE THE THEORETICAL REMOVAL FROM BATCH TEST DATA
      REMOVAL=1.0-EXP(-0.23*TBAR**0.5/EN(18)**0.25)
C
C     ACCOUNT FOR THE DECREASE IN EFFICIENCY DUE TO TURBULENCE
      REMOVAL=REMOVAL*EN(21)
C
C     MATERIAL BALANCE
      SO(2,13)=SO(2,13)+SI(1,13)*REMOVAL
      SO(2,15)=SO(2,15)+SI(1,15)*REMOVAL
      SO(2,16)=SO(2,16)+SI(1,16)*REMOVAL
      SO(2,17)=SO(2,17)+SI(1,17)*REMOVAL
      REM1=1.0-REMOVAL
      SO(1,13)=SO(1,13)+SI(1,13)*REM1
      SO(1,15)=SO(1,15)+SI(1,15)*REM1
      SO(1,16)=SO(1,16)+SI(1,16)*REM1
      SO(1,17)=SO(1,17)+SI(1,17)*REM1
C
C     CALCULATE UNDERFLOW FLOW
      SO(2,6)=EN(25)*EN(23)*EN(24)*10.0
      SSF=(SO(2,13)+SO(2,15)+SO(2,16)+SO(2,17))/SO(2,6)
C     ASSUME THAT THE MAXIMUM UNDERFLOW CONCENTRATION IS 60000 MG/L
      IF(SSF.LE.0.06) GO TO 19
C     INSUFFICIENT WITHDRAWAL OF SLUDGE LEADS TO CARRY-OVER OF SOLIDS
      SO(1,13)=SO(1,13)+SO(2,13)*(1.0-0.06/SSF)
      SO(1,15)=SO(1,15)+SO(2,15)*(1.0-0.06/SSF)
      SO(1,16)=SO(1,16)+SO(2,16)*(1.0-0.06/SSF)
      SO(1,17)=SO(1,17)+SO(2,17)*(1.0-0.06/SSF)
      SO(2,13)=SO(2,13)*0.06/SSF
      SO(2,15)=SO(2,15)*0.06/SSF
      SO(2,16)=SO(2,16)*0.06/SSF
      SO(2,17)=SO(2,17)*0.06/SSF
19    CONTINUE
C
C     SET SCUM FLOW
      SO(3,18)=SI(1,18)*0.9
      SO(1,18)=SO(1,18)+SI(1,18)-SO(3,18)
      SO(2,18)=0.0
      SO(3,6)=SO(3,18)*(1.0-EN(20)*1.0E-6)/EN(20)*2.2E6
C
C     EFFLUENT FLOW
      SO(1,6)=SI(1,6)-SO(2,6)-SO(3,6)
C
C     SET SCUM VARIABLES (OTHER THAN SCUM) SIMILAR TO EFFLUENT
      F=SO(3,6)/(SO(1,6)+SO(3,6))
      SO(3,13)=SO(1,13)*F
      SO(1,13)=SO(1,13)-SO(3,13)
      SO(3,15)=SO(1,15)*F
      SO(1,15)=SO(1,15)-SO(3,15)
```

```
      SO(3,16)=SO(1,16)*F
      SO(1,16)=SO(1,16)-SO(3,16)
      SO(3,17)=SO(1,17)*F
      SO(1,17)=SO(1,17)-SO(3,17)
C
C     COMPONENTS IN SOLUTION SPLIT ACCORDING TO FLOW
      DO 600 I=20,JJ
      SO(1,I)=SI(1,I)*SO(1,6)/SI(1,6)
      SO(2,I)=SI(1,I)*SO(2,6)/SI(1,6)
      SO(3,I)=SI(1,I)-SO(1,I)-SO(2,I)
600   CONTINUE
      SO(1,14)=SI(1,14)*SO(1,6)/SI(1,6)+SO(1,14)
      SO(2,14)=SI(1,14)*SO(2,6)/SI(1,6)+SO(2,14)
      SO(3,14)=SI(1,14)*SO(3,6)/SI(1,6)+SO(3,14)
      SO(1,19)=SI(1,19)*SO(1,6)/SI(1,6)+SO(1,19)
      SO(2,19)=SI(1,19)*SO(2,6)/SI(1,6)+SO(2,19)
      SO(3,19)=SI(1,19)*SO(3,6)/SI(1,6)+SO(3,19)
C
C     SET ALL EXIT OXYGEN CONCENTRATIONS TO ZERO
      SO(1,7)=0.0
      SO(2,7)=0.0
      SO(3,7)=0.0
C
C
      CALL BALNCE(2,1)
      CALL BALNCE(2,2)
      CALL BALNCE(2,3)
C
C
      IF(ISP) 1,1,2
2     CONTINUE
      WRITE(6,300) REMOVAL
300   FORMAT(1H0,17HSOLIDS REMOVAL = ,F10.3)
      WRITE(6,400) OR
400   FORMAT(1X,17HOVERFLOW RATE   =  ,F10.3,12H  IGPD/SQFT  )
      WRITE(6,410) TBAR
410   FORMAT(1X,17HDETENTION TIME =  ,F10.3,10H  MINUTES  )
1     CONTINUE
C
C
      RETURN
      END
```

LISTING OF THE AEROBIC BIOLOGICAL SLUDGE MODEL

```
      SUBROUTINE ACTSL1
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
      COMMON /A/ TAER,TM,FM,DELS
C
C     SIMULATES THE ACTIVATED SLUDGE PROCESS
C     CAN ALSO BE USED TO SIMULATE THE STEP AERATION PROCESS
C     CALLS THE BASIC CSTR PROGRAM FOR AEROBIC BIOLOGICAL REACTIONS
C
C     EN VECTOR
C     *********
C     1.-15. STANDARD FORMAT
C     4.     NUMBER OF REACTORS IN PARALLEL
C     5.     TOTAL HEAD LOSS THROUGH ACT. SL. TANKS (FT OF WATER)
C     6.     NUMBER OF INPUT STREAMS (= 2.0)
C     7.     FIRST INPUT STREAM (= RETURN SLUDGE FLOW)
C     8.     SECOND INPUT STREAM (= FEED STREAM)
C     11.    NUMBER OF OUTPUT STREAMS (= 1.0)
C     12.    OUTPUT STREAM NUMBER
C
C            NOTE EN(16.-32.) ARE USED BY CSTR2
C     16.    LENGTH OF REACTOR  (FEET)
C     17.    WIDTH OF REACTOR  (FEET)
C     18.    DEPTH OF REACTOR  (FEET)
C     19.    = 1.0 IF NOT USING A RESIDENCE TIME DISTRIBUTION MODEL
C            = EN(34) IF USING A RTD MODEL
C     20.    LYSIS RATE  (K2 /HR)
C     21.    BASAL METAB. RATE  (K1 /HR)
C     22.    RATE OF SOLUBILIZATION OF DEGRADABLE SOLIDS  (K3 /HR)
C     23.    STRIPPING RATE OF VOLATILE ORGANICS  (K5 /HR)
C     24.    MICROORGANISMS YIELD FACTOR  (Y DIMENSIONLESS)
C     25.    FRACTION OF LYSIS PRODUCTS TO SOLUBLE DEGRADABLE CARBON
C     26.    FRACTION OF LYSIS PRODUCTS TO SOLUBLE NONDEGRADABLE CARBON
C     27.    RATE OF AIR ADDITION TO EACH REACTOR (SCF/HR)
C     28.    UNIT GROWTH RATE CONSTANT (K4 /HR)
C     29.    FRACTION OF MLSS THAT IS NITRIFIERS
C     30.    N/C RATIO IN RAW FEED
C     31.    P/C RATIO IN RAW FEED
C     32.    ABSORPTION NUMBER (FOR OXYGEN TRNSFER)
C
C     33.    NOT PRESENTLY USED
C     34.    NUMBER OF CSTR,S IN SERIES - EITHER AN RTD MODEL OR THE
C            ACTUAL NUMBER OF TANKS IN A STEP AERATION PROCESS
C            MAXIMUM OF TEN TANKS IN SERIES
C     35.    FRACTION OF FEED STREAM TO FIRST TANK
C     36.    FRACTION OF FEED STREAM TO SECOND TANK
C     37. -  ETC
C     44.    FRACTION OF FEED STREAM TO TENTH TANK (IF ANY)
C     45.    NUMBER OF BLOWERS USED
C     46.    CAPACITY OF EACH BLOWER  SCF/HR
C
      EN(27)=EN(45)*EN(46)/EN(4)/EN(34)
C
C
      SIN=SI(1,11)+SI(2,11)
C
C
C     STORE FEED STREAM IN SI(4,J)
      DO 600 J=2,JJ
600   SI(4,J)=SI(2,J)
C
C     CALCULATING THE VARIABLES FOR USE BY THE SECONDARY CLARIFIER
C     FM IS THE FOOD TO MICOORGANISM RATIO AND TAER IS THE AERATION TIME
      TANKS=EN(34)
      IF(EN(19).GT.1.0) TANKS=1.0
      TAER=EN(16)*EN(17)*EN(18)*TANKS *6.24/(SI(1,3)+SI(2,3))*EN(4)
      TM=TAER/EN(34)
      FM=SI(2,10)/SI(1,12)/TAER*24.0
```

```
C
C
      NCSTR=EN(34)+0.01
C
      DO 610 IJ=1,NCSTR
      IF(EN(34+IJ).LE. 0.0) GO TO 20
C
      SI(2,3)=SI(4,3)*EN(34+IJ)
      DO 900 KB=6,JJ
900   SI(2,KB)=SI(4,KB)*EN(34+IJ)
      CALL MIXER1
      EN(29)=EN(29)*SI(1,11)/SO(1,11)
      DO 910 KB=2,JJ
910   SI(1,KB)=SO(1,KB)
C
20    CONTINUE
C
      CALL CSTR2
C
      DO 620 J=2,JJ
620   SI(1,J)=SO(1,J)
C
610   CONTINUE
C
C
      SO(1,5)=SI(2,5)-EN(5)
      DELS=SO(1,11)-SIN
C
C
      RETURN
      END




      SUBROUTINE CSTR2
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
      COMMON /A/ TAER,TM,FM,DELS
C
C     THIS IS THE BASIC CSTR ROUTINE TO DESCRIBE THE AEROBIC
C     BIOLOGICAL PROCESSES AND IS CALLED BY ACTSL
C     WRITTEN BY P. TAN
C
C     EN VECTOR
C     *********
C           NOTE-CSTR2 USES ONLY EN(16.-32.)
C           EN(1.-15.) AND EN(33.- ) ARE USED BY ACTSL1
C           NOTE-CSTR2 HAS ONLY ONE INPUT STREAM,THE MIXED LIQUOR FLOW
C     16.   LENGTH OF REACTOR  (FEET)
C     17.   WIDTH OF REACTOR  (FEET)
C     18.   DEPTH OF REACTOR  (FEET)
C     19.   = 1.0 IF NOT USING A RESIDENCE TIME DISTRIBUTION MODEL
C           = EN(34) IF USING A RTD MODEL
C     20.   LYSIS RATE  (K2 /HR)
C     21.   BASAL METAB. RATE  (K1 /HR)
C     22.   RATE OF SOLUBILIZATION OF DEGRADABLE SOLIDS  (K3 /HR)
C     23.   STRIPPING RATE OF VOLATILE ORGANICS  (K5 /HR)
C     24.   MICROORGANISMS YIELD FACTOR  (Y DIMENSIONLESS)
C     25.   FRACTION OF LYSIS PRODUCTS TO SOLUBLE DEGRADABLE CARBON
C     26.   FRACTION OF LYSIS PRODUCTS TO SOLUBLE NONDEGRADABLE CARBON
C     27.   RATE OF AIR ADDITION TO EACH REACTOR (SCF/HR)
C     28.   UNIT RATE GROWTH CONSTANT (K4 /HR)
C     29.   FRACTION OF MLSS THAT IS NITRIFIERS
C     30.   N/C RATIO IN RAW FEED
C     31.   P/C RATIO IN RAW FEED
C     32.   ABSORPTION NUMBER (FOR OXYGEN TRANSFER )
C
C
```

```
      CALL CONVERT(1,3,1,3,1)
C
      DO 600 J=2,JJ
600   SO(1,J)=SI(1,J)
C
      SI15=SI(1,15)
      SI1619=SI(1,16)+SI(1,17)+SI(1,18)+SI(1,19)
C
C     CALCULATING OXYGEN SATURATION AT INLET TEMPERATURE
      CS=14.16-SI(1,4)*(0.3943-SI(1,4)*(0.007714-0.0000646*SI(1,4)))
C
C     CALCULATING VOLUME OF REACTOR
      V=EN(16)*EN(17)*EN(18)/EN(19)
C
C     CALCULATING OXYGEN TRANSFER COEFFICIENT  KLA
      AKL=EN(32)*((EN(27)/60.0)**0.85)*(EN(18)**0.7)/V
C
C
C     BACTIN IS THE CONCENTRATION OF NITROSOMONAS
      BACT=EN(29)*SI(1,11)
      BACTIN=BACT
C
      KOUNT=1
C
C     INITIAL GUESS OF DEGRADABLE CARBON IS HALF FEED VALUE
C     INITIAL GUESS OF OTHER VARIABLES ARE FEED VALUES
C
      SO(1,20)=0.5*SO(1,20)
      SO(1,21)=0.5*SO(1,21)
C
C     BEGIN ITERATION FOR EFFLUENT CONCENTRATIONS OF CSTR
10    CONTINUE
C
C     CALCULATING RATE OF SOLUBLE CARBON REMOVAL
      CC=SO(1,20)+SO(1,21)
      RFC=EN(28)*CC
C
      SO(1,20)=SI(1,20)/(1.0+TM*(RFC*SO(1,15)/CC+EN(23)*EN(27)/V))
      SO(1,21)=(SI(1,21)+TM*SO(1,15)*(EN(20)*EN(25)+EN(22)*(SO(1,16)+
     1 SO(1,18)+SO(1,19))))/(1.0+TM*RFC*SO(1,15)/CC)
C
      SO(1,22)=SI(1,22)+TM*EN(20)*EN(26)*SO(1,15)
C
C     CALCULATING EXIT SOLIDS
      SO(1,15)=SI(1,15)/(1.0-TM*(EN(24)*RFC-EN(20)-EN(21)))
      SO(1,16)=SI(1,16)/(1.0+TM*SO(1,15)*(EN(22)-EN(20)*(1.0-EN(25)-
     1EN(26))/SO(1,16)))
      SO(1,18)=SI(1,18)/(1.0+TM*EN(22)*SO(1,15))
      SO(1,19)=SI(1,19)/(1.0+TM*EN(22)*SO(1,15))
C
C     BALANCE ON NITROGEN
C     AVNIT IS THE AVAILABLE AMMONIACAL NITROGEN
      AVNIT=SI(1,27)+(SI(1,15)-SO(1,15))*0.23 +(SI(1,8)-SI(1,15)-
     1SO(1,16)-SO(1,17)-SO(1,18)-SO(1,19)-SO(1,20)-SO(1,21)-SO(1,22))*
     2EN(30)
C     CALCULATE CONVERSION OF AMMONIA TO NITRATES
      EFF=SO(1,7)
      IF(SO(1,7).GE.1.0) EFF=1.0
      SO(1,27)=AVNIT/(1.0+0.275*BACT*TM*EFF/(1.0+SO(1,27)))
      IF(SO(1,27).LT. 0.0) GO TO 40
      GO TO 41
40    CONTINUE
      SO(1,27)=0.0
      WRITE(6,410)
410   FORMAT(1H0,28HDEFICIENCY IN FEED NITROGEN   )
41    CONTINUE
      SO(1,28)=SI(1,28)+(AVNIT-SO(1,27))
      BACT=BACTIN+(AVNIT-SO(1,27))*0.05
C
C     CALCULATING EXIT OXYGEN CONCENTRATION
      SO(1,7)=(SI(1,7)-TM*((RFC*(1.0-EN(24))+EN(21))*SO(1,15)*2.66
     1+(AVNIT-SO(1,27))*4.57-AKL*CS))/(1.0+TM*AKL)
      IF(SO(1,7).LT. 0.0) SO(1,7)=0.0
C
```

```
      KOUNT=KOUNT+1
      IF(KOUNT.GT. 20) GO TO 20
      IF(ABS((CC-SO(1,20)-SO(1,21))/CC).GT. 0.005) GO TO 10
      GO TO 30
C
20    CONTINUE
      WRITE(6,400)
400   FORMAT(1H0,20HCSTR2 NOT CONVERGED      )
C
30    CONTINUE
C
C     PHOSPHORUS BALANCE
      SO(1,29)=SI(1,29)+(SI15-SO(1,15))*0.05 + (SI1619-SO(1,16)-SO(1,17)
     1-SO(1,18)-SO(1,19))*EN(31)
      IF(SO(1,29).LT.0.0) GO TO 50
      GO TO 51
50    CONTINUE
      SO(1,29)=0.0
      WRITE(6,420)
420   FORMAT(1H0,30HDEFICIENCY IN FEED PHOSPHORUS      )
51    CONTINUE
C
C     DUE TO THE HIGH DEGREE OF FLOCCULATION IN THE AERATION TANKS
C     COLLOIDAL COMPONENTS ARE CONVERTED TO SETTLEABLE
      SO(1,13)=SO(1,13)+SO(1,14)
      SO(1,14)=0.0
      SO(1,16)=SO(1,16)+SO(1,19)
      SO(1,19)=0.0
C
C     CALCULATING THE FRACTION OF NITRIFIERS IN THE EXIT SOLIDS
      EN(29)=BACT/SO(1,11)
C
C     CALCULATING EXIT PH
C     ASSUME CARBON DIOXIDE CONCENTRATION IS IN EQUILIBRIUM WITH AIR
      SO(1,2)=-ALOG10(2.6E-7/SI(1,23))
C
      CALL CONVERT(2,2,1,2,1)
      CALL BALNCE(2,1)
C
      RETURN
      END
```

```
      SUBROUTINE SECLAR1
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
      COMMON /A/ TAER,TM,FM,DELS
C
C     WRITTEN BY P. TAN
C     FOR WWTP SIMULATION
C     FOR REVISED STREAM LIST    2/9/71
C
C     SIMULATES A SECONDARY CLARIFIER
C
C     EN VECTOR
C     *********
C     1.-15. STANDARD FORMAT
C     4.     NUMBER OF CLARIFIERS IN PARALLEL
C     5.     HEAD LOSS THROUGH CLARIFIER (FEET OF WATER)
C     12.    FIRST OUTPUT STREAM (EFFLUENT)
C     13.    SECOND OUTPUT STREAM (UNDERFLOW)
C     14.    THIRD OUTPUT STREAM (SCUM TROUGH FLOW)
C     16.    MODE OF OPERATION
C            = 1.0 FOR FIXED FRACTION OF RECYCLE
C            = 2.0 FOR MAXIMUM CONCENTRATION OF UNDERFLOW
C     17.    FRACTION OF RECYCLE IF MODE=1
C     18.    SURFACE AREA OF CLARIFIER (PER TANK)    - SQ.FT.
C     19.    SCUM FLOW CONCENTRATION (MG/L)
C     20.    NUMBER OF UNDERFLOW SLUDGE PUMPS
C     21.    CAPACITY OF PUMPS IGPH EACH
C     22.    FRACTION OF CAPACITY USED
C
C
      EN(17)=EN(20)*EN(21)*EN(22)/SI(1,3)
C
      SO(1,2)=SI(1,2)
      SO(2,2)=SI(1,2)
      SO(3,2)=SI(1,2)
      SO(1,4)=SI(1,4)
      SO(2,4)=SI(1,4)
      SO(3,4)=SI(1,4)
C
C     CALCULATE EXIT HEADS
      SO(1,5)=SI(1,5)-EN(5)
      SO(2,5)=SI(1,5)-EN(5)
      SO(3,5)=SI(1,5)-EN(5)
C
C     CALCULATING THE SLUDGE VOLUME INDEX
      SVI=56.1+113.0*FM*(1.05**(SI(1,4)-20.0))
C
C     CALCULATING THE MAXIMUM UNDERFLOW CONCENTRATION  CU
      CU=1.0E+06/SVI
C
C     CALCULATING THE MIXED LIQUOR SUSPENDED SOLIDS XMLSS
      XMLSS=SI(1,11)/SI(1,6)*1.0E6
C
      METHOD=EN(16)+0.001
      GO TO (1,2),METHOD
C
1     CONTINUE
C     FOR FIXED FRACTION OF RECYCLE
      SO(2,6)=SI(1,6)*EN(17)
      SO(1,6)=SI(1,6)-SO(2,6)
C     CALCULATING THE OVERFLOW RATE GSS  (USGPD/SQFT)
      GSS=SO(1,6)*2.879/EN(18)/EN(4)
C     APPLY CORRELATION
C     THE FACTOR 1.5 IS SUGGESTED BY RICH TO ACCOUNT FOR
C     THE EXTRAPOLATION OF BATCH SETTLING TESTS TO ACTUAL TANKS
      XRSS=556.0*(GSS**0.494)/(XMLSS**1.82)/(TAER**0.439)*1.5
C     MATERIAL BALANCE
      SO(1,11)=SI(1,11)*XRSS
```

```
      SO(2,11)=SI(1,11)-SO(1,11)
C     UNDERFLOW CONCENTRATION CANNOT BE GREATER THAN CU
      IF((SO(2,11)/SO(2,6)*1.0E6) .LT. CU) GO TO 10
      SO(2,11)=CU*1.0E-6*SO(2,6)
      SO(1,11)=SI(1,11)-SO(2,11)
      GO TO 10
C
2     CONTINUE
C     FOR MAXIMUM CONCENTRATION OF UNDERFLOW
C     ROUGH ESTIMATE OF UNDERFLOW FLOW
      SO(2,6)=SI(1,11)*1.0E6/CU
      SO(1,6)=SI(1,6)-SO(2,6)
C     CALCULATING THE OVERFLOW RATE GSS  (USGPD/SQFT)
      GSS=SO(1,6)*2.879/EN(18)/EN(4)
C     APPLY CORRELATION
      XRSS=556.0*(GSS**0.494)/(XMLSS**1.82)/(TAER**0.439)*1.5
      SO(1,11)=SI(1,11)*XRSS
      SO(2,11)=SI(1,11)-SO(1,11)
C     CALCULATING CORRECTED UNDERFLOW FLOW
      SO(2,6)=SO(2,11)*1.0E6/CU
      SO(1,6)=SI(1,6)-SO(2,6)
C
10    CONTINUE
C
C
C     ASSUME THAT THE FLOCS ARE UNIFORM IN COMPOSITION
C     ALSO ASSUME THAT THE OVERFLOW AND UNDERFLOW SOLIDS HAVE THE
C     SAME COMPOSITION AS THE INCOMING FLOCS
      P1=SO(1,11)/SI(1,11)
      DO 600 I=13,19
      SO(1,I)=P1*SI(1,I)
      SO(2,I)=SI(1,I)-SO(1,I)
600   CONTINUE
C
C     SPLIT OVERFLOW INTO EFFLUENT AND SCUM FLOW
      SO(3,18)=SI(1,18)
      SO(1,18)=0.0
      SO(2,18)=0.0
      SO(3,6)=SO(3,18)*(1.0-EN(19)*1.0E-6)/EN(19)*2.2E6
      SO(1,6)=SO(1,6)-SO(3,6)
      P1=SO(3,6)/(SO(1,6)+SO(3,6))
      DO 610 I=13,17
      SO(3,I)=SO(1,I)*P1
      SO(1,I)=SO(1,I)-SO(3,I)
610   CONTINUE
      SO(3,19)=SO(1,19)*P1
      SO(1,19)=SO(1,19)-SO(3,19)
C
C     SPLIT SOLUBLE COMPONENTS ACCORDING TO FLOW
      P1=SO(1,6)/SI(1,6)
      P2=SO(2,6)/SI(1,6)
      DO 620 I=20,JJ
      SO(1,I)=SI(1,I)*P1
      SO(2,I)=SI(1,I)*P2
      SO(3,I)=SI(1,I)-SO(1,I)-SO(2,I)
620   CONTINUE
C
C
C     SET ALL EXIT OXYGEN CONCENTRATIONS AT ZERO
      SO(1,7)=0.0
      SO(2,7)=0.0
      SO(3,7)=0.0
C
      CALL BALNCE(2,1)
      CALL BALNCE(2,2)
      CALL BALNCE(2,3)
C
C
      IF(ISP) 30,30,31
31    WRITE(6,300) TAER
300   FORMAT(1H0,22HAERATION TIME          =  ,F10.3,7H  HOURS )
      WRITE(6,301) FM
301   FORMAT(1X,22HFOOD TO MICRO RATIO =  ,F10.3)
      WRITE(6,302) GSS
```

```
302     FORMAT(1X,22HOVERFLOW RATE        =  ,F10.3,12H  USGPD/SQFT )
        WRITE(6,303) SVI
303     FORMAT(1X,22HSLUDGE VOLUME INDEX =  ,F10.3)
30      CONTINUE
C
C
        RETURN
        END
```

LISTING OF THE ANAEROBIC DIGESTER MODEL

```
        SUBROUTINE ANDIG1
C
C
        COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
        COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
        COMMON MODE,NPLNT,LOOPC
        COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C       SIMULATES AN ANAEROBIC DIGESTER
C       WRITTEN BY P. TAN    AUG/71
C
C       EN VECTOR
C       *********
C       1.-15.  STANDARD FORMAT
C       4.      NUMBER OF DIGESTERS IN PARALLEL
C       5.      HEAD LOSS IN DIGESTERS (FT OF WATER)
C       16.     DIAMETER OF DIGESTER (FEET)
C       17.     DEPTH OF DIGESTER (FEET)
C       18.     = 1.0 FOR CONVENTIONAL DIGESTER OPERATION
C               = 2.0 FOR HIGH RATE DIGESTER OPERATION
C       19.     TEMPERATURE OF OPERATION
C       20.     FRACTION OF WATER TO FIRST OUTPUT STREAM (SUPERNATANT)
C               = 1.0 IF FIRST STAGE OF A TWO-STAGE SYSTEM
C       21.     FRACTION OF SOLIDS TO FIRST OUTPUT STREAM (SUPERNATANT)
C               (EXCLUDES SETTLEABLE INORGANIC SOLIDS)
C               = 1.0 IF FIRST STAGE OF A TWO-STAGE SYSTEM
C       22.     FRACTION OF SETTLEABLE INORGANIC SOLIDS TO SUPERNATE
C               = 1.0 IF FIRST STAGE OF A TWO-STAGE SYSTEM
C       23.     STORAGE SPACE FOR GAS PRODUCED
C       24.     FRACTION OF VOLUME THAT IS EFFICIENTLY USED IN DIGESTION
C
C
C       USING SO(4,JJ) AS TEMPORARY STORAGE OF INTERMEDIATE RESULTS

        DO 600 IK=2,JJ
        SO(4,IK)=SI(1,IK)
600     CONTINUE
C
        SO(1,4)=EN(19)
        SO(2,4)=EN(19)
        SO(4,4)=EN(19)
        SO(1,5)=SI(1,5)-EN(5)
        SO(2,5)=SI(1,5)-EN(5)
        SO(4,5)=SI(1,5)-EN(5)

C       CALCULATING VOLUME OF DIGESTER (CU FT)
        VOL=3.142*EN(16)*EN(16)*EN(17)/4.0*EN(4)
        VOL=VOL*EN(24)
C
C       CALCULATING DIGESTER RESIDENCE TIME (DAYS)
        RESTIME=VOL*6.24/SI(1,3)/24.0
C
C       CALCULATING VOLATILE SOLIDS LOADING ON DIGESTER LB/CUFT/DAY
        SSLOAD=SI(1,12)*24.0/VOL
C
C       ALKALINITY CALCULATIONS
        ALK=20.0*SI(1,23)/SI(1,6)
```

```
      CN=71.43*SI(1,27)/SI(1,6)
      PH=SI(1,2)
      CALL ALKPH(1,ALK,ACT,CN,PH)
      CT=ACT
C
C     SET REACTION CONSTANT FOR HIGH RATE OR CONVENTIONAL OPERATION
      NCOR=EN(18)+0.01
      GO TO (1,2),NCOR
1     AK1=0.026*1.04**(EN(19)-35.0)
      GO TO 10
2     AK1=0.080*1.04**(EN(19)-35.0)
10    CONTINUE
C
C     CALCULATE FRACTION OF VOLATILE SOLIDS DESTROYED
      FRAC=1.0-1.0/(1.0+AK1*RESTIME)
C
C     STORE RESULTING LIQUOR IN SO(4,J) - PRIOR TO SEPARATION
      DO 610 IK=15,19
610   SO(4,IK)=SI(1,IK)*(1.0-FRAC)

C     CALCULATE VOLUME OF GAS LIBERATED
      GAS=17.0*SI(1,12)*FRAC
      EN(23)=GAS

C     CALCULATE VOLATILE ACID CARBON IN EFFLUENT
      AKMAX=0.28*EXP(-0.036*(35.0-EN(19)))
      VAC=200.0*EXP(0.12*(35.0-EN(19)))/(1.0+AKMAX*RESTIME)
      SO(4,20)=SI(1,20)+SI(1,6)*VAC*1.0E-6
C
C     NUTRIENT BALANCE
      SO(4,27)=SI(1,27)+SI(1,12)/2.1*FRAC*0.23
      SO(4,29)=SI(1,29)+SI(1,12)/2.1*FRAC*0.05

      CALL BALNCE(2,4)

C     CALCULATE EFFLUENT PH
      ACID=(VAC-SI(1,20)/SI(1,6)*1.0E6)/24.0/1000.0
      CNNEW=71.43*SO(4,27)/SO(4,6)
      ALK=ALK+(CNNEW-CN)-ACID
      CALL ALKPH(2,ALK,CT,CNNEW,APH)
      SO(4,2)=APH
      SO(1,2)=APH
      SO(2,2)=APH
      SO(4,23)=ALK*SO(4,6)/20.0
C
C     CALCULATING EFFLUENT AND UNDERFLOW FLOWS
      IF( EN(20) .GE. 1.0 ) GO TO 31
C
C     SETTING THE SUPERNATANT FLOW
      SO(1,6)=SO(4,6)*EN(20)
      DO 620 IK=20,JJ
      SO(1,IK)=SO(4,IK)*EN(20)
620   CONTINUE
      SO(1,13)=SO(4,13)*EN(22)
      DO 640 IK=14,19
      SO(1,IK)=SO(4,IK)*EN(21)
640   CONTINUE
      CALL BALNCE(2,1)
C
C     CALCULATE DIGESTED SLUDGE FLOW BY MATERIAL BALANCE
      DO 650 IK=6,JJ
      SO(2,IK)=SO(4,IK)-SO(1,IK)
650   CONTINUE
      SO(2,3)=SO(4,3)-SO(1,3)
      GO TO 32
C
31    CONTINUE
C     ONLY ONE STREAM DRAWN OFF - THE FIRST OUTPUT STREAM
      DO 660 IK=2,JJ
      SO(1,IK)=SO(4,IK)
      SO(2,IK)=0.0
660   CONTINUE
C
32    CONTINUE
```

```
C     SET ALL EXIT OXYGEN CONCENTRATIONS TO ZERO
      SO(1,7)=0.0
      SO(2,7)=0.0
C
C
      IF(ISP) 20,20,21
21    CONTINUE
      WRITE(6,400) RESTIME
400   FORMAT(1H0,25HDETENTION TIME         =  ,F12.3,6H  DAYS )
      WRITE(6,410) SSLOAD
410   FORMAT(1X,25HSOLIDS LOADING         =  ,F12.3,15H  LBS/CUFT/DAY  )
      GAS=GAS*24.0
      WRITE(6,430) GAS
430   FORMAT(1X,25HGAS PRODUCED           =  ,F12.3,11H  CUFT/DAY     )
      WRITE(6,420) FRAC
420   FORMAT(1X,25HFRACTION VSS DESTROYED =  ,F12.3)
20    CONTINUE
C
C
      RETURN
      END
```

```
      SUBROUTINE TRICK1
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     SIMULATES A TRICKLING FILTER
C     UTILIZES THE EQUATION PROPOSED BY ECKENFELDER
C     WRITTEN BY P. TAN      SEPT/71
C
C     EN VECTOR
C     *********
C     1.-15. STANDARD FORMAT
C     4.     NUMBER OF TRICKLING FILTERS IN PARALLEL
C     5.     HEAD LOSS IN FILTER (FT OF WATER - GREATER THAN HEIGHT)
C     16.    DEPTH OF FILTER (FEET)
C     17.    DIAMETER OF FILTER (FEET)
C     18.    REACTION CONSTANT
C     19.    EXPONENT ON DEPTH
C     20.    EXPONENT ON LIQUID LOADING RATE
C
C
      DO 600 J=2,JJ
600   SO(1,J)=SI(1,J)
      SO(1,5)=SI(1,5)-EN(5)
C
C     CALCULATE SURFACE AREA
      AREA=3.142*EN(17)*EN(17)/4.0*EN(4)
C
C     CALCULATE THE LIQUID LOADING RATE (USGPD/SQFT)
      Q=SI(1,3)*28.79/AREA
C
C     CALCULATE REMOVAL OF BOD ACCORDING TO EQUATION
C     REM = FRACTION OF DEGRADABLE CARBON REMAINING
      REM=EXP(-EN(18)*EN(16)**EN(19)/Q**EN(20))
C
C     ASSUME THAT THE REMOVAL APLLIES TO ALL DEGRADABLE COMPONENTS
      SO(1,16)=SI(1,16)*REM
      DO 610 J=18,22
610   SO(1,J)=SI(1,J)*REM
C
C
C     ASSUME MICROORGANISM YIELD FACTOR IS 0.54
      SO(1,15)=0.54*(SI(1,16)+SI(1,18)+SI(1,19)+SI(1,20)+SI(1,21)
     1 +SI(1,22))*(1.0-REM)
C
      CALL BALNCE(2,1)
C
      RETURN
      END
```

LISTING OF THE SCREEN MODEL

```
      SUBROUTINE SCREEN1
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     EN VECTOR
C     *********
C     1.-15. STANDARD FORMAT
C     4.     = SCREENINGS, IF KNOWN FROM PLANT OPERATIONS  (CUFT/MIG)
C            = 0.0 IF USING BARMINUTER
C            = ANY NEGATIVE NUMBER IF WANT TO USE INTERNAL SCREENINGS
C              ESTIMATE
C     5.     HEAD LOSS ACROSS SCREEN (FT OF WATER)
C     16.    SCREEN SIZE, IF USING INTERNAL ESTIMATE OF SCREENINGS (IN)
C
C
      DO 600 J=2,JJ
600   SO(1,J)=SI(1,J)
      SO(1,5)=SI(1,5)-EN(5)
C
C     CALCULATE VOLUME OF SCREENINGS PER DAY
C
      IF(EN(4))1,2,3
1     SCR=19.0*10.0**(-0.8*EN(16))
      GO TO 4
2     RETURN
3     SCR=EN(4)
C
4     VOL=SI(1,3)*SCR*24.0*1.0E-6
C
C     ESTIMATED DRY WEIGHT OF SCREENINGS IS 30 LBS/CUFT
C     CALCULATING MASS OF SCREENINGS PER HOUR
      WRAGS=30.0*VOL/24.0
C     CONVERT TO EQUIV CARBON
      WRAGS=WRAGS/2.1
      SO(1,16)=SI(1,16)-WRAGS
      CALL BALNCE(2,1)
C
      IF(ISP) 10,10,11
11    WRITE(6,400) VOL
400   FORMAT(1H0,13HSCREENINGS =  ,F8.2,10H  CUFT/DAY )
10    CONTINUE
C
      RETURN
      END
```

LISTING OF THE GRIT REMOVAL MODEL

```
      SUBROUTINE GRIT1
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     WRITTEN BY P. TAN      27/8/71
C     DEGRITTER FOR SEWAGE TREATMENT
C     SIMPLE MODEL USING THE AVERAGE AMOUNT OF GRIT COLLECTED /MIG
C
C     EN VECTOR
C     *********
C     1.-15. STANDARD FORMAT
C     4.     CU.FT. OF GRIT PER MILLION GALLONS OF RAW FEED
C     5.     HEAD LOSS THROUGH CHAMBER (FT OF WATER)
C
C
      DO 600 J=2,JJ
600   SO(1,J)=SI(1,J)
      SO(1,5)=SI(1,5)-EN(5)
C
      CUFT=SI(1,3)*EN(4)*1.0E-6
C
      GRIT=CUFT*0.40*62.4*2.65
      SO(1,11)=SI(1,11)-GRIT
      SO(1,13)=SI(1,13)-GRIT
C
      IF (ISP) 1,1,2
2     CUFT=CUFT*24.0
      WRITE(6,400) CUFT
400   FORMAT(1H0,25HVOLUME OF GRIT REMOVED =  ,F8.2,11H  CU FT/DAY   )
1     CONTINUE
C
      RETURN
      END
```

LISTING OF THE CHLORINATOR MODEL

```
      SUBROUTINE CHLOR1
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
      DIMENSION CL(6)
C
C     EN VECTOR
C     *********
C     1.-15. STANDARD FORMAT
C     4.     DISPOSITION OF WASTE
C            = 1.0  FOR RAW SEWAGE
C            = 2.0  FOR SEPTIC RAW SEWAGE
C            = 3.0  FOR SETTLED RAW SEWAGE
C            = 4.0  FOR SEPTIC SETTLED RAW SEWAGE
C            = 5.0  FOR BIOLOGICAL TREATMENT EFFLUENT
C            = 6.0  FOR SAND FILTER EFFLUENT
C     5.     USED FOR STORING AMOUNT OF CHLORINE USED PER DAY
C
C
      CL(1)=10.0
      CL(2)=20.0
      CL(3)=8.0
      CL(4)=16.0
      CL(5)=6.0
      CL(6)=3.0
C
      DO 600 J=2,JJ
600   SO(1,J)=SI(1,J)
C
      I=EN(4)+0.01
      CL2=SI(1,3)*24.0*10.0*CL(I)*1.0E-6
      EN(5)=CL2
C
      IF(ISP) 10,10,11
11    WRITE(6,400) CL2
400   FORMAT(1H0,17HCHLORINE USAGE =   ,F8.2,10H  LBS/DAY    )
10    CONTINUE
C
      RETURN
      END
```

LISTING OF THE MIXER-SPLITTER MODEL

```
      SUBROUTINE MIXER1

      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     EN VECTOR
C     1.-15. STANDARD FORMAT
C     16.    FRACTION OF FLOW TO FIRST OUTPUT STREAM
C     17.    ETC

      IF(NIN.GT.1) GO TO 30
      DO 650 J=2,JJ
650   SO(NOUT,J)=SI(1,J)
      GO TO 40

30    CONTINUE
C
      CALL ALKMIX(PH)
C     SUM OF INPUT STREAMS IS TEMPORARILY STORED IN SO(NOUT,J)

      DO 600 J=6,JJ
      SO(NOUT,J)=0.
      DO 600 I=1,NIN
600   SO(NOUT,J)=SO(NOUT,J)+SI(I,J)
      SO(NOUT,2)=PH
      SO(NOUT,3)=0.0
      SO(NOUT,4)=0.0
      SO(NOUT,5)=SI(1,5)
      DO 610 I=1,NIN
      SO(NOUT,3)=SO(NOUT,3)+SI(I,3)
      SO(NOUT,4)=SO(NOUT,4)+SI(I,3)*SI(I,4)
      IF(SI(I,5).LT.SO(NOUT,5)) SO(NOUT,5)=SI(I,5)
610   CONTINUE
      SO(NOUT,4)=SO(NOUT,4)/SO(NOUT,3)
C
40    CONTINUE

C     OUTPUT

      IF(NOUT.EQ.1) RETURN
      DO 620 I=1,NOUT
      SO(I,2)=SO(NOUT,2)
      SO(I,3)=SO(NOUT,3)*EN(I+15)
      SO(I,4)=SO(NOUT,4)
      SO(I,5)=SO(NOUT,5)
      DO 620 J=6,JJ
      SO(I,J)=SO(NOUT,J)*EN(I+15)
620   CONTINUE
C
C
      RETURN
      END
```

LISTING OF THE SIMPLE PHASE SEPARATOR MODEL

```
      SUBROUTINE SEPA01
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     EN VECTOR
C     *********
C     1.-15. STANDARD FORMAT
C     4.     FRACTION OF FLOW TO FIRST OUTPUT STREAM (SUPERNATE)
C     5.     FRACTION OF SOLIDS TO FIRST OUTPUT STREAM (SUPERNATE)
C
C
      SO(1,2)=SI(1,2)
      SO(2,2)=SI(1,2)
      SO(1,4)=SI(1,4)
      SO(2,4)=SI(1,4)
      SO(1,5)=SI(1,5)
      SO(2,5)=SI(1,5)
C
      IF(SI(1,6).GT. 0.0) GO TO 10
      DO 650 J=6,JJ
      SO(1,J)=0.0
      SO(2,J)=0.0
650   CONTINUE
      SO(1,3)=0.0
      SO(2,3)=0.0
      RETURN
10    CONTINUE
C
C
      SO(1,6)=EN(4)*SI(1,3)*10.0
      SO(2,6)=SI(1,6)-SO(1,6)
C
C     SEPARATE SOLIDS
      DO 600 J=13,19
      SO(1,J)=SI(1,J)*EN(5)
      SO(2,J)=SI(1,J)-SO(1,J)
600   CONTINUE
C
C     SOLUBLE COMPONENTS ARE SPLIT ACCORDING TO FLOW
      P1=SO(1,6)/SI(1,6)
      DO 610 J=20,JJ
      SO(1,J)=SI(1,J)*P1
      SO(2,J)=SI(1,J)-SO(1,J)
610   CONTINUE
C
      CALL BALNCE(2,1)
      CALL BALNCE(2,2)
C
      RETURN
      END
```

LISTING OF THE PROGRAM TO CONTROL THE MLSS IN THE AERATION TANKS

```
      SUBROUTINE CONT02
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
      COMMON /A/ TAER,TM,FM,DELS
      DATA DELS/0.0/
C
C     WRITTEN BY P. TAN
C     FOR WWTP SIMULATION
C
C     CONTROLS THE MLSS IN THE AERATION TANKS
C
C     EN VECTOR
C     *********
C     1.-15. STANDARD FORMAT
C     4.     FEED STREAM TO AERATION TANKS (EXCLUDING RECYCLE FLOW)
C     5.     MLSS REQUIRED IN AERATION TANKS
C     12.    FIRST OUTPUT STREAM (RECYCLE STREAM)
C     13.    SECOND RECYCLE STREAM (WASTE SLUDGE FLOW)
C
C
      S=EN(4)
      CALL STREAM(S)
C
C     CALCULATE FRACTION OF INCOMING FLOW TO RECYCLE  - A
      A=(EN(5)*1.0E-6*SN(IS,6)-SN(IS,11)-DELS)/(SI(1,11)-EN(5)*SI(1,6)*
     1 1.0E-6)
C
      IF(A.LT.0.0) A=0.0
      IF(A.GT.1.0) A=1.0
      DO 600 I=3,JJ
      SO(1,I)=SI(1,I)*A
  600 SO(2,I)=SI(1,I)-SO(1,I)
C
      SO(1,2)=SI(1,2)
      SO(2,2)=SI(1,2)
      SO(1,4)=SI(1,4)
      SO(2,4)=SI(1,4)
      SO(1,5)=SI(1,5)
      SO(2,5)=SI(1,5)
      SO(1,7)=0.0
      SO(2,7)=0.0
C
C
      RETURN
      END
```

```
      SUBROUTINE BALNCE(NVECT,I)
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     WRITTEN BY P. TAN
C     FOR WASTE-WATER SIMULATION
C     BALANCES THE STREAM VARIABLES IN A STREAM (ELEMENTS 8-12)
C
C     NVECT=1 FOR SN VECTORS
C     NVECT=2 FOR SO VECTOR
C     C1 = RATIO OF BOD5 TO SOLUBLE DEGRAD ORGANICS (EQUIV CARBON)
C     C2 = RATIO OF BOD5 TO PARTICULATE DEGRAD ORGANICS (EQUIV CARBON)
C     C3 = RATIO OF VSS TO PARTICULATE ORGANICS (EQUIV CARBON)
C
C
      C1=1.9
      C2=1.2
      C3=2.1
C
      GO TO (1,2),NVECT
C
1     CONTINUE
      PC=SN(I,15)+SN(I,16)+SN(I,17)+SN(I,18)+SN(I,19)
      SN(I,12)=C3*PC
      SN(I,11)=SN(I,12)+SN(I,13)+SN(I,14)
      SN(I,9)=SN(I,20)+SN(I,21)+SN(I,22)
      SN(I,8)=SN(I,9)+PC
      SN(I,10)=C1*(SN(I,20)+SN(I,21))+C2*(SN(I,16)+SN(I,18)+SN(I,19))
      SN(I,3)=0.0378*(SN(I,13)+SN(I,14)) + 0.096*(SN(I,15)+SN(I,16)
     1 +SN(I,17)+SN(I,19)) + 0.104*SN(I,18) + 0.1*SN(I,6)
      RETURN
C
C
2     CONTINUE
      PC=SO(I,15)+SO(I,16)+SO(I,17)+SO(I,18)+SO(I,19)
      SO(I,12)=C3*PC
      SO(I,11)=SO(I,12)+SO(I,13)+SO(I,14)
      SO(I,9)=SO(I,20)+SO(I,21)+SO(I,22)
      SO(I,8)=SO(I,9)+PC
      SO(I,10)=C1*(SO(I,20)+SO(I,21))+C2*(SO(I,16)+SO(I,18)+SO(I,19))
      SO(I,3)=0.0378*(SO(I,13)+SO(I,14)) + 0.096*(SO(I,15)+SO(I,16)
     1 +SO(I,17)+SO(I,19)) + 0.104*SO(I,18) + 0.1*SO(I,6)
C
C
      RETURN
      END
```

```
      SUBROUTINE CONVERT(M,KIN,JIN,KOUT,JOUT)
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
      DIMENSION V(30)
C
C     CONVERTS STREAM VARIABLES FROM POUNDS PER HOUR TO PPM
C     OR VICE VERSA
C
C     INPUT VARIABLES
C     M = 1    FOR CONVERTING LBS/HR TO PPM
C     M = 2    FOR CONVERTING PPM TO LBS/HR
C     KIN = VECTOR TO BE READ FROM
C         = 1 FOR SN VECTOR
C         = 2 FOR SO VECTOR
C         = 3 FOR SI VECTOR
C     JIN = ROW NUMBER OF INPUT VECTOR
C     KOUT = VECTOR TO BE WRITTEN ON TO
C          = 1    FOR SN VECTOR
C          = 2    FOR SO VECTOR
C          =3    FOR SI VECTOR
C     JOUT = ROW NUMBER OF OUTPUT VECTOR
C
C     VARIABLES 2. TO 6. ARE NOT CHANGED
C
C
C     READ FROM INPUT VECTOR
C
      GO TO (1,2,3),KIN
C
1     DO 600 J=2,JJ
600   V(J)=SN(JIN,J)
      GO TO 10
2     DO 610 J=2,JJ
610   V(J)=SO(JIN,J)
      GO TO 10
3     DO 620 J=2,JJ
620   V(J)=SI(JIN,J)
C
10    CONTINUE
C
      IF(V(6).GT. 0.0 ) GO TO 40
      V(3)=0.0
      DO 700 J=6,JJ
700   V(J)=0.0
      GO TO 11
C
40    CONTINUE
C
C     CONVERSION
C
      GO TO (4,5),M
C
4     CONTINUE
C     CONVERTING FROM LBS/HR TO PPM
C     SOLUBLE COMPONENTS
      V(7)=V(7)/V(6)*1.0E6
      V(9)=V(9)/V(6)*1.0E6
      DO 630 J=20,JJ
630   V(J)=V(J)/V(6)*1.0E6
C
C     PARTICULATE COMPONENTS
      V(8)=V(8)/V(3)*1.0E5
      DO 640 J=10,19
640   V(J)=V(J)/V(3)*1.0E5
      GO TO 11
C
5     CONTINUE
C     CONVERTING FROM PPM TO LBS/HR
C     SOLUBLE COMPONENTS
      V(7)=V(7)*V(6)*1.0E-6
      V(9)=V(9)*V(6)*1.0E-6
      DO 650 J=20,JJ
```

```
650    V(J)=V(J)*V(6)*1.0E-6
C
C      PARTICULATE COMPONENTS
       V(8)=V(8)*V(3)*1.0E-5
       DO 660 J=10,19
660    V(J)=V(J)*V(3)*1.0E-5
C
11     CONTINUE
C
C      WRITING ON TO OUTPUT VECTOR
C
       GO TO (6,7,8),KOUT
C
6      DO 670 J=2,JJ
670    SN(JOUT,J)=V(J)
       GO TO 12
7      DO 680 J=2,JJ
680    SO(JOUT,J)=V(J)
       GO TO 12
8      DO 690 J=2,JJ
690    SI(JOUT,J)=V(J)
C
12     CONTINUE
C
       RETURN
       END
```

LISTING OF THE PROGRAM RELATING PH AND ALKALINITY

```
      SUBROUTINE ALKMIX(PH)
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     SUBROUTINE TO CALCULATE THE RESULTING PH  WHEN STREAMS ARE MIXED
C
      SUMALK=0.0
      SUMCN=0.0
      SUMCT=0.0
      DO 600 I=1,NIN
      IF(SI(I,6).LE.0.0) GO TO 600
      IF(SI(I,2).LE.0.0) SI(I,2)=7.0
      ALK=20.0*SI(I,23)/SI(I,6)
      CN=71.43*SI(I,27)/SI(I,6)
      PH=SI(I,2)
      CALL ALKPH(1,ALK,CT,CN,PH)
      SUMALK=SUMALK+ALK
      SUMCT=SUMCT+CT
      SUMCN=SUMCN+CN
600   CONTINUE
C
      CALL ALKPH(2,SUMALK,SUMCT,SUMCN,APH)
      PH=APH
C
      RETURN
      END
      SUBROUTINE  ALKPH(NZ,ALK,CT,CN,PH)
C
C
      DIMENSION XCOF(4)
C
C     SUBROUTINE TO CALCULATE CT OR PH GIVEN THE OTHER THREE VARIABLES
C
      PK1=6.3
      PK2=10.3
      PKN=9.3
      GO TO (1,2), NZ
C
C     CALCULATE CT
1     CONTINUE
      CT=(ALK-CN/(1.0+10.0**(PKN-PH)))*(10.0**(PK1-PH)+1.0+10.0**
     1(PH-PK2))/(1.0+10.0**(PH-PK2)*2.0)
C
      RETURN
C
C     CALCULATE PH
2     CONTINUE
      A1=ALK-CN
      A2=ALK-CT
      A3=ALK-CN-CT
      A4=ALK-2.0*CT
      A5=ALK-CN-2.0*CT
      XCOF(1)=10.0**(-PK1-PK2-PKN)*A5
      XCOF(2)=(A3*10.0**(-PK1-PKN) + A4*10.0**(-PK1-PK2))
      XCOF(3)=(A1*10.0**(-PKN) + A2*10.0**(-PK1))
      XCOF(4)=ALK
C
      CALL BISECT(XCOF,H)
C
      PH=-ALOG10(H)
C
      RETURN
      END
```

```
      SUBROUTINE BISECT(XCOF,H)
C
C
      DIMENSION XCOF(4)
C
      F(XCOF,H)= XCOF(1)+H*(XCOF(2)+H*(XCOF(3)+H*XCOF(4)))
C
      HL=1.0E-5
      HR=1.0E-9
C
      IF(F(XCOF,HL)*F(XCOF,HR)) 10,20,30
10    H=SQRT(HL*HR)
      IF(F(XCOF,HL)*F(XCOF,H).LT. 0.0) GO TO 2
      HL=H
      GO TO 4
2     HR=H
4     IF(ABS((HL-HR)/HL).GT.0.01) GO TO 10
      H=HL
      RETURN
C
20    H=HR
      IF(F(XCOF,HL).EQ. 0.0) H=HL
      RETURN
C
30    H=HR
      IF(ABS(F(XCOF,HL)).LT. ABS(F(XCOF,HR))) H=HL
C
      RETURN
      END
```

```
      SUBROUTINE REPT01
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     WRITTEN BY P. TAN
C     FOR WWTP SIMULATION
C
C     REPORTS ON THE VARIOUS STREAMS IN THE PLANT
C
C     EN VECTOR
C     *********
C     1.-3. STD FORMAT
C     EN VECTOR LENGTH = 35
C     4.-15. =0.0
C     EN(16) = RAW FEED TO PLANT (STREAM NUMBER)
C     EN(17) = INPUT TO PRIMARY CLARIFIER
C     EN(18) = EFFLUENT OF PRIMARY CLARIFIER
C     EN(19) = UNDERFLOW OF PRIMARY CLARIFIER
C     EN(20) = INPUT TO AERATION TANKS
C     EN(21) = OUTPUT OF AERATION TANKS
C     EN(22) = INPUT TO SECONDARY CLARIFIER
C     EN(23) = EFFLUENT OF SECONDARY CLARIFIER
C     EN(24) = UNDERFLOW OF SECONDARY CLARIFIER
C     EN(25) = RETURN ACTIVATED SLUDGE
C     EN(26) = WASTE ACTIVATED SLUDGE
C     EN(27) = INPUT TO DIGESTERS
C     EN(28) = DIGESTER SUPERNATANT
C     EN(29) = DIGESTED SLUDGE
C     EN(30) = INPUT TO THICKENER
C     EN(31) = THICKENED SLUDGE
C     EN(32) = INPUT TO TRICKLING FILTER
C     EN(33) = OUTPUT OF TRICKLING FILTER
C     EN(34) = PLANT BYPASS
C     EN(35) =
C
C     SET STREAM NUMBER TO 0.0 IF DO NOT WISH TO REPORT ON STREAM
C
      IF (MODE.EQ. 0) RETURN
C
C

      WRITE(6,79)
      WRITE(6,80)
      WRITE(6,82) LOOPC
      WRITE(6,80)
      WRITE(6,85)
C
      DO 50 I=1,20
      S=EN(I+15)
      IF( S.LE.0.0 ) GO TO 50
      CALL STREAM(S)
      IT=IS
      CALL CONVERT(1,1,IT,3,1)
      SI(1,1)=S
      IW=29+I
C
      WRITE(6,IW) SI(1,1),SI(1,3),(SI(1,J),J=7,12)
C
C
50    CONTINUE
      WRITE(6,79)
      MODE=0
C
C
30    FORMAT(1H0,20HRAW FEED            ,F5.0,7F10.2)
31    FORMAT(1H0,20HINPUT TO PRI. CLAR.  ,F5.0,7F10.2)
32    FORMAT(1H0,20HEFF. OF PRI. CLAR.  ,F5.0,7F10.2)
33    FORMAT(1H0,20HUNDERFLOW PRI CLAR  ,F5.0,7F10.2)
34    FORMAT(1H0,20HINPUT TO AER TANKS  ,F5.0,7F10.2)
35    FORMAT(1H0,20HOUTPUT OF AER TANKS  ,F5.0,7F10.2)
```

```
36    FORMAT(1H0,20HINPUT TO SEC. CLAR.   ,F5.0,7F10.2)
37    FORMAT(1H0,20HEFF. OF SEC. CLAR.    ,F5.0,7F10.2)
38    FORMAT(1H0,20HUNDERFLOW SEC CLAR    ,F5.0,7F10.2)
39    FORMAT(1H0,20HRETURN ACT. SLUDGE    ,F5.0,7F10.2)
40    FORMAT(1H0,20HWASTE ACT. SLUDGE     ,F5.0,7F10.2)
41    FORMAT(1H0,20HINPUT TO DIGESTER     ,F5.0,7F10.2)
42    FORMAT(1H0,20HDIGESTER SUPERNATE    ,F5.0,7F10.2)
43    FORMAT(1H0,20HDIGESTED SLUDGE       ,F5.0,7F10.2)
44    FORMAT(1H0,20HINPUT TO THICKENER    ,F5.0,7F10.2)
45    FORMAT(1H0,20HTHICKENED SLUDGE      ,F5.0,7F10.2)
46    FORMAT(1H0,20HTRICK. FILT. INPUT    ,F5.0,7F10.2)
47    FORMAT(1H0,20HTRICK. FILT. OUTPUT   ,F5.0,7F10.2)
48    FORMAT(1H0,20HPLANT BYPASS          ,F5.0,7F10.2)
49    FORMAT(1H0,20H                      ,F5.0,7F10.2)
79    FORMAT(1H1)
80    FORMAT(1H0,120H$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
     1$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
     2$$$     )
82    FORMAT(1H0,1H$,20X,42HSUMMARY REPORT ON PLANT OPERATIONS - CASE   ,
     1 I5,51X,1H$)
85    FORMAT(///,7X,6HSTREAM, 8X,6HNUMBER,5X,4HFLOW,6X,3H DO,7X,3HTOC,
     17X,3HDOC,7X,3HBOD,8X,2HSS,7X,3HVSS,//)
C
C
      RETURN
      END
```

```
      SUBROUTINE COST1
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
      DIMENSION TITLE (10),ELECT(3)
C
C     CALCULATES THE FIXED CAPITAL INVESTMENT, THE OPERATING AND
C     MAINTENANCE COSTS OF A WASTEWATER TREATMENT PLANT.
C     PLACES A SURTAX ON EFFLUENT IF THE EFFLUENT QUALITY IS POOR.
C     COSTS TAKEN FROM ECKENFELDER AND BARNHARDT, AND FROM SMITH.
C
C     EN VECTOR
C     *********
C     1.   MODULE NUMBER
C     2.   MODULE TYPE
C     3.   MODULE LENGTH
C     4.-15. = TWELVE ZEROES
C
C             UNIT PROCESS                             PARAMETER
C     16.  PRETREATMENT                      DESIGNED FLOW MIGPD
C     17.  NO. OF PRETREATMENT UNITS
C     18.  PRIMARY SEDIMENTATION             SURFACE AREA PER UNIT /1000 SQFT
C     19.  NO. OF PRI. SETTLING TANKS
C     20.  ACTIVATED SLUDGE TANKS            VOLUME PER UNIT MIGPD
C     21.  NO. OF AERATION TANKS
C     22.  AIR BLOWERS                       CAPACITY PER UNIT CPM/1000
C     23.  NO. OF AIR BLOWERS
C     24.  FINAL SEDIMENTATION               SURFACE AREA/1000 SQFT PER UNIT
C     25.  NO. OF FINAL TANKS
C     26.  SLUDGE RETURN PUMPS               CAPACITY MIGPD
C     27.  NO. OF SLUDGE RETURN PUMPS
C     28.  ANAEROBIC DIGESTION               VOLUME PER UNIT /1000 CUFT
C     29.  NO. OF ANAEROBIC DIGESTERS
C     30.  CHLORINATION                      DESIGNED FLOW MIGPD
C     31.  NO. OF CHLORINATION UNITS
C     32.  VACUUM FILTRATION                 SURFACE AREA PER UNIT/100 SQFT
C     33.  NO. OF VACUUM FILTERS
C     34.  SLUDGE INCINERATION               LBS SOLIDS/DAY PER UNIT
C     35.  NO. OF SLUDGE INCINERATERS
C     36.  SLUDGE DRYING BEDS                SURFACE AREA SQFT
C     37.  NO. OF DRYING BEDS
C     38.  SLUDGE THICKENING                 SURFACE AREA PER UNIT SQFT
C     39.  NO. OF THICKENERS
C     40.  SLUDGE HAULAGE                    SLUDGE VOLUME MIG/YR
C     41.  0.0
C     42.  TRICKLING FILTERS                 VOLUME PER UNIT/1000 CUFT
C     43.  NO. OF TRICKLING FILTERS
C     44.  AERATED LAGOONS                   SURFACE AREA PER UNIT/1000 SQFT
C     45.  NO. OF LAGOONS
C     46.  TYPE OF PLANT                     = 1.0 FOR PRIMARY PLANT
C          (FOR UTILITIES COST)              = 2.0 FOR TRICKLING FILTER PLANT
C                                            = 3.0 FOR ACTIVATED SLUDGE PLANT
C     47.  NOT PRESENTLY USED
C     48.  NOT PRESENTLY USED
C     50.  DESIGNED FLOW MIGPD
C     51.  LABOUR COST $/MAN-HOUR
C     52.  ENR INDEX FOR YEAR
C     53.  LABORATORY COSTS  $/YR)
C     54.  STREAM NUMBER OF EFFLUENT (FOR SURCHARGE PURPOSES)
C     55.  ACTUAL PLANT FLOW MIGPD
C
C
      A=1H*
      B=1H-
      ELECT(1)=101000.0
      ELECT(2)=162000.0
      ELECT(3)=378000.0
C
C     ******************************************************************
```

```
C     CAPITAL COST ESTIMATE
C
      WRITE(6,400)
      WRITE(6,401) (A,I=1,22)
      READ (5,200) TITLE
      WRITE(6,550) TITLE
C
C     CALCULATE THE CAPITAL COSTS OF THE VARIOUS UNIT PROCESSES
      Q=EN(50)
      ENRFAC=EN(52)/1120.0
      UPC=0.0
      DO 600 I=1,15
      IF(EN(14+2*I).LE. 0.0) GO TO 600
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15),I
C
1     COST=21800.0*(Q/EN(17))**0.63*ENRFAC*EN(17)
      WRITE(6,451) COST
      GO TO 610
2     COST=(17300.0*EN(18)+6700.0*EN(18)**0.1)*ENRFAC*EN(19)
      WRITE(6,452) COST
      GO TO 610
3     COST=(27000.0*EN(20)+67000.0)*ENRFAC*EN(21)
      WRITE(6,453) COST
      GO TO 610
4     COST=(13600.0+7600.0*EN(22))*ENRFAC*EN(23)
      WRITE(6,454) COST
      GO TO 610
5     COST=(16200.0*EN(24)+6900.0/EN(24)**0.13)*ENRFAC*EN(25)
      WRITE(6,455) COST
      GO TO 610
6     COST=(4700.0+1740.0*Q/EN(27))*ENRFAC*EN(27)
      WRITE(6,456) COST
      GO TO 610
7     COST=(1340.0*EN(28)+13800.0*EN(28)**0.13)*ENRFAC*EN(29)
      WRITE(6,457) COST
      GO TO 610
8     COST=(12600.0*(Q/EN(30))**0.47)*ENRFAC*EN(31)
      WRITE(6,458) COST
      GO TO 610
9     COST=(16500.0+48.0*EN(32))*ENRFAC*EN(33)
      WRITE(6,459) COST
      GO TO 610
10    COST=(7.1*EN(34)/EN(35)+0.3*(EN(34)/EN(35))**1.61)*ENRFAC*EN(35)
      WRITE(6,460) COST
      GO TO 610
11    COST=2.23*EN(36)*EN(37)
      WRITE(6,461) COST
      GO TO 610
12    COST=EN(38)*(24200.0+11700.0/EXP(EN(38)/13.3))*ENRFAC*EN(39)
      WRITE(6,462) COST
      GO TO 610
13    GO TO 600
14    COST=66000.0*EN(42)**0.6*ENRFAC*EN(43)
      WRITE(6,464) COST
      GO TO 610
15    COST=2.5*EN(44)*EN(45)*ENRFAC
      WRITE(6,465) COST
C
610   UPC=UPC+COST
600   CONTINUE
C
      WRITE(6,402) (B,I=1,14)
      WRITE(6,403) UPC
C
C     CALCULATE THE CAPITAL COST OF THE CONTROL HOUSE
      COST=58600.0*Q**0.7*ENRFAC
      WRITE(6,466) COST
      PPC=UPC+COST
C     CALCULATING THE CAPITAL COST OF THE PLANT SITE + IMPROVEMENTS
      COST=4600.0*Q**0.88*ENRFAC
      WRITE(6,467) COST
      PPC=PPC+COST
C
      WRITE(6,402) (B,I=1,14)
```

```
      WRITE(6,404) PPC
C
C     CALCULATE THE ENGINEERING COST FACTOR
      CENG=0.08*(1.0E6/PPC)**0.146
C     CALCULATE THE ENGINEERING COSTS
      COST=CENG*PPC
      WRITE(6,405) COST
      DPC=PPC+COST
C
      WRITE(6,402) (B,I=1,14)
      WRITE(6,406) DPC
C
C     CALCULATING THE CONTRACTOR'S FEE
      COST=DPC*0.1
      WRITE(6,407) COST
      FCI=DPC+COST
C     CALCULATING THE CONTINGENCY COSTS
      COST=DPC*0.15
      WRITE(6,408) COST
      FCI=FCI+COST
C
      WRITE(6,402) (B,I=1,14)
      WRITE(6,409) FCI
      WRITE(6,402) (B,I=1,14)
C
C     ******************************************************************
C     OPERATING AND MAINTENANCE COST ESTIMATE
C
      WRITE(6,410)
      WRITE(6,401) (A,I=1,21)
      READ(5,200) TITLE
      WRITE(6,550) TITLE
      WRITE(6,411)
C
      SUMHRS=0.0
      UPOM=0.0
      Q=EN(55)
C
      DO 620 I=1,15
      IF(EN(14+2*I).LE.0.0) GO TO 620
      GO TO (21,22,23,24,25,26,27,28,29,30,31,32,33,34,35),I
C
21    HOUR=133.0*Q+510.0*Q**0.37
      COST=HOUR*EN(51)
      WRITE(6,501) HOUR,COST
      GO TO 630
22    HOUR=(222.0*EN(18)+555.0*EN(18)**0.5)*EN(19)
      COST=HOUR*EN(51)
      WRITE(6,502) HOUR,COST
      GO TO 630
23    HOUR=(720.0*Q+590.0*Q/EN(20)**0.67)
      COST=HOUR*EN(51)
      WRITE(6,503) HOUR,COST
      GO TO 630
24    GO TO 620
25    GO TO 620
26    GO TO 620
27    HOUR=(13.0*EN(28)+144.0*EN(28)**0.5)
      COST=HOUR*EN(51)
      WRITE(6,507) HOUR,COST
      GO TO 630
28    HOUR=(30.0*Q+170.0*Q**0.37)
      COST=HOUR*EN(51)
      WRITE(6,508) HOUR,COST
      GO TO 630
29    HOUR=(0.27*Q+154.0*Q**0.37)
      COST=HOUR*EN(51)
      WRITE(6,509) HOUR,COST
      GO TO 630
30    HOUR=(400.0*Q+1600.0*Q**0.37)
      COST=HOUR*EN(51)
      WRITE(6,510) HOUR,COST
      GO TO 630
31    HOUR=(0.014*EN(36)+20.0*EN(36)**0.37)
```

```
      COST=HOUR*EN(51)
      WRITE(6,511) HOUR,COST
      GO TO 630
32    GO TO 620
33    GO TO 620
34    HOUR=(10.0*EN(42)+120.0*EN(42)**0.5)
      COST=HOUR*EN(51)
      WRITE(6,514) HOUR,COST
      GO TO 630
35    HOUR=(50.0*EN(44)+100.0*EN(44)**0.5)
      COST=HOUR*EN(51)
      WRITE(6,515) HOUR,COST
C
630   CONTINUE
      SUMHRS=SUMHRS+HOUR
      UPOM=UPOM+COST
620   CONTINUE
C
      WRITE(6,415) (B,I=1,28)
      WRITE(6,413) SUMHRS,UPOM
C
C     CALCULATE THE SUPERVISION COST
      COST=0.1*UPOM
      WRITE(6,414) COST
      DOM=UPOM+COST
C     CALCULATE THE UTILITIES COST
      KI=EN(46)+0.01
      COST=ELECT(KI)*Q**0.65*EN(47)
      WRITE(6,416) COST
      DOM=DOM+COST
C     CALCULATE SLUDGE HAULAGE COSTS
      COST=8000.0*EN(40)**0.5
      WRITE(6,513) COST
      DOM=DOM+COST
C     CALCULATE THE CHEMICALS COST
      COST=0.06*UPOM
      WRITE(6,417) COST
      DOM=DOM+COST
C     CALCULATE PLANT SUPPLIES
      COST=0.05*UPOM
      WRITE(6,418) COST
      DOM=DOM+COST
      WRITE(6,419) (B,I=1,14)
      WRITE(6,420) DOM

C     CALCULATING LABORATORY COSTS
      COST=EN(53)
      WRITE(6,421) COST
      OMNET=DOM+COST
C     CALCULATING SURCHARGE ON EFFLUENT (IF EFFLUENT QUALITY IS POOR)
      IF(EN(54).LE. 0.0) GO TO 50
      S= EN(54)
      CALL STREAM(S)
      LBS=SN(IS,3)*3.0E-4
      IF(SN(IS,10).LT.LBS) GO TO 51
      SURBOD=(SN(IS,10)-LBS)*0.05
      GO TO 52
51    SURBOD=0.0
52    IF(SN(IS,11).LT.LBS) GO TO 53
      SURSS=(SN(IS,11)-LBS)*0.05
      GO TO 54
53    SURSS=0.0
54    TOTSUR=SURBOD+SURSS
      WRITE(6,422) TOTSUR
      OMNET=OMNET+TOTSUR
50    CONTINUE
C
      WRITE(6,419) (B,I=1,14)
      WRITE(6,423) OMNET
C
C     CALCULATING THE COST OF THE FIXED CAPITAL INVESTMENT.
C     BASED ON AN INTEREST RATE OF 8.0 PERCENT AND A PLANT LIFE OF 25
C     YEARS.  NOTE THAT THE ANNUITY PAYMENTS REPRESENT DEBT RETIREMENT
C     AND INTEREST CHARGED IN THE CASE OF BORROWED CAPITAL OR
```

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C     DEPRECIATION AND OPPORTUNITY COST IN THE CASE OF OWNED CAPITAL.
C     CAPITAL RECOVERY FACTOR = S*(1+S)**N/((1+S)**N-1)
C     WHERE S IS THE INTEREST RATE AND N THE LIFE OF THE PLANT
      CF=(1.0+0.08)**25.0
      COST=FCI*0.08*CF/(CF-1.0)
      WRITE(6,424) COST
C
      WRITE(6,419) (B,I=1,14)
      TAC=OMNET+COST
      WRITE(6,428) TAC
      WRITE(6,419) (B,I=1,14)
      WRITE(6,430)
C
C
200   FORMAT(10A8)
400   FORMAT(1H1,30X,22HFIXED CAPITAL ESTIMATE )
401   FORMAT(1H0,30X,22A1)
402   FORMAT(1H0,50X,14A1)
403   FORMAT(1H0,10X,40HTOTAL UNIT PROCESSES (INSTALLED)        $ ,F14.2)
404   FORMAT(1H0,10X,40HPHYSICAL PLANT COST                     $ ,F14.2)
405   FORMAT(1H0,10X,40HENGINEERING                               ,F14.2)
406   FORMAT(1H0,10X,40HDIRECT PLANT COST                       $ ,F14.2)
407   FORMAT(1H0,10X,40HCONTRACTOR'S FEE (0.1 DPC)                ,F14.2)
408   FORMAT(1H0,10X,40HCONTINGENCY (0.15 DPC)                    ,F14.2)
409   FORMAT(1H0,10X,40HFIXED CAPITAL COST                      $ ,F14.2)
410   FORMAT(1H1,30X,22HANNUAL OPERATING COST  )
411   FORMAT(1H0,15X,15HUNIT PROCESSES ,15X,9HMAN-HOURS,10X,9HCOST $/YR)
413   FORMAT(1H0,10X,30HTOTAL UNIT PROCESSES O AND M    ,F14.2,4X,1H$,
     1 F14.2)
414   FORMAT(1H0,10X,30HSUPERVISION (0.1 L)             ,19X,F14.2)
415   FORMAT(1H0,40X,14A1,5X,14A1)
416   FORMAT(1H0,10X,30HUTILITIES                       ,19X,F14.2)
417   FORMAT(1H0,10X,30HCHEMICALS  (0.06 L)             ,19X,F14.2)
418   FORMAT(1H0,10X,30HPLANT SUPPLIES (0.05 L)         ,19X,F14.2)
419   FORMAT(1H0, 59X,14A1)
420   FORMAT(1H0,10X30HDIRECT O AND M COST              ,18X,1H$,F14.2)
421   FORMAT(1H0,10X,30HLABORATORY                      ,19X,F14.2)
422   FORMAT(1H0,10X,30HSURCHARGE ON EFFLUENT           ,19X,F14.2)
423   FORMAT(1H0,10X,30HNET O AND M COST                ,18X,1H$,F14.2)
424   FORMAT(1H0,10X,30HANNUITY PAYMENTS                ,19X,F14.2)
428   FORMAT(1H0,10X,30HTOTAL ANNUAL COST               ,18X,1H$,F14.2)
430   FORMAT(1H1)
451   FORMAT(1H0,10X,40HPRETREATMENT                            $ ,F14.2)
452   FORMAT(1H0,10X,40HPRIMARY SETTLING TANKS                    ,F14.2)
453   FORMAT(1H0,10X,40HACTIVATED SLUDGE TANKS                    ,F14.2)
454   FORMAT(1H0,10X,40HAIR BLOWERS                               ,F14.2)
455   FORMAT(1H0,10X,40HSECONDARY SETTLING TANKS                  ,F14.2)
456   FORMAT(1H0,10X,40HSLUDGE RETURN PUMPS                       ,F14.2)
457   FORMAT(1H0,10X,40HANAEROBIC DIGESTERS                       ,F14.2)
458   FORMAT(1H0,10X,40HCHLORINATOR                               ,F14.2)
459   FORMAT(1H0,10X,40HVACUUM FILTERS                            ,F14.2)
460   FORMAT(1H0,10X,40HSLUDGE INCINERATORS                       ,F14.2)
461   FORMAT(1H0,10X,40HSLUDGE DRYING BEDS                        ,F14.2)
462   FORMAT(1H0,10X,40HSLUDGE THICKENERS                         ,F14.2)
463   FORMAT(1H0,10X,40H                                          ,F14.2)
464   FORMAT(1H0,10X,40HTRICKLING FILTERS                         ,F14.2)
465   FORMAT(1H0,10X,40HAERATED LAGOONS                           ,F14.2)
466   FORMAT(1H0,10X,40HCONTROL HOUSE                             ,F14.2)
467   FORMAT(1H0,10X,40HPLANT SITE                                ,F14.2)
501   FORMAT(1H0,10X,30HPRETREATMENT                    ,F14.2,5X,F14.2)
502   FORMAT(1H0,10X,30HPRIMARY SEDIMENTATION           ,F14.2,5X,F14.2)
503   FORMAT(1H0,10X,30HACTIVATED SLUDGE                ,F14.2,5X,F14.2)
507   FORMAT(1H0,10X,30HANAEROBIC DIGESTION             ,F14.2,5X,F14.2)
508   FORMAT(1H0,10X,30HCHLORINATION                    ,F14.2,5X,F14.2)
509   FORMAT(1H0,10X,30HVACUUM FILTRATION               ,F14.2,5X,F14.2)
510   FORMAT(1H0,10X,30HSLUDGE INCINERATION             ,F14.2,5X,F14.2)
511   FORMAT(1H0,10X,30HSLUDGE DRYING BEDS              ,F14.2,5X,F14.2)
513   FORMAT(1H0,10X,30HSLUDGE HAULING                  ,19X,F14.2)
514   FORMAT(1H0,10X,30HTRICKLING FILTERS               ,F14.2,5X,F14.2)
515   FORMAT(1H0,10X,30HAERATED LAGOONS                 ,F14.2,5X,F14.2)
550   FORMAT(1H0,5X,10A8,///)
C
      RETURN
      END
```

```
      PROGRAM WWTP(INPUT,OUTPUT,WWRUN,TAPE2=INPUT,TAPE6=OUTPUT,
     1TAPE5=WWRUN)
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
      DIMENSION TITLE(10)
      DIMENSION NAME(20)
C
C     GEMCS/INTERCOM
C
C     ***** PRINTING CONTROL CHARACTERS *****
C
C     KPRNT(1)=1  CAUSES PRINTING OF LLST,NS
C     KPRNT(1)=0  SUPPRESSES ABOVE PRINTING
C     KPRNT(2)=1  CAUSES PRINTING OF INITIAL STREAMS
C     KPRNT(2)=0  SUPPRESSES ABOVE PRINTING
C     KPRNT(3)=1  CAUSES PRINTING OF MODULES SETS
C     KPRNT(3)=0  SUPPRESSES ABOVE PRINTING
C     KPRNT(4)=1  CAUSES PRINTING OF NPOINT
C     KPRNT(4)=0  SUPPRESSES ABOVE PRINTING
C     KPRNT(5)=1  CAUSES PRINTING OF SN TABLE ON ENTERING LOOP
C     KPRNT(5)=0  SUPPRESSES ABOVE PRINTING
C     KPRNT(6)=1  CAUSES PRINTING OF FINAL OUTPUT STREAMS
C                 PRINTING OF FINAL OUTPUT STREAMS OF UNIMPORTANT
C                 MODULES MAY BE SUPPRESSED BY PUTTING A NEGATIVE
C                 SIGN ON THE MODULE TYPE FOR THE EQUIPMENT.
C     KPRNT(6)=0  SUPPRESSES ABOVE PRINTING
C     KPRNT(7)=1  PRINTS THE FRACTIONAL CHANGES IN STREAMS TESTED-CONTL1
C     KPRNT(7)=0  SUPPRESSES ABOVE PRINTING
C     KPRNT(8)=1  PRINTS **CONVERGED** OR **NOT CONVERGED** -CONTL1
C     KPRNT(8)=0  SUPPRESSES ABOVE PRINTING
C     ALL PRINTING OF INPUT AND OUTPUT STREAMS LEAVING A MODULE
C     ARE SUPPRESSED BY SETTING ISP=0 .
C
      REWIND5
C
      NAME(1)=8H MIXER1
      NAME(2)=8H CONTL1
      NAME(3)=8H SETST1
      NAME(4)=8H SETSP1
      NAME(5)=8H SEPA01
      NAME(6)=8H PRISET1
      NAME(7)=8H ACTSL1
      NAME(8)=8H DPTR1
      NAME(9)=8H SECLAR1
      NAME(10)=8H TRICK1
      NAME(11)=8H GRIT1
      NAME(12)=8H ANDIG1
      NAME(13)=8H CHLOR1
      NAME(14)=8H COST1
      NAME(15)=8H SCREEN1
      NAME(16)=8H REPT01
      NAME(17)=8H CONT02
      NAME(18)=8H CONV01
      NAME(19)=8H CASET
      NAME(20)=8H THICK1
C
      WRITE(6,234)
234   FORMAT(1H0,50HTO ANSWER QUESTIONS BELOW TYPE 1.0/YES OR 0.0/NO    )
C
      III=25
      CALL DLOAD1
C
C
C     IK IS AN INDICATOR AS TO WHETHER A STRAIGHT THROUGH CALCULATION
C     IS USED (IK=1) OR WHETHER A RECYCLE IS PRESENT (IK=0)
      IK=0
      IF(LOOP.EQ.999) IK=1
C
```

```
      WRITE(6,240)
240   FORMAT(1H0,30HWANT TO SET UP A NEW PLANT -      )
      READ(2,221) FLAG
      IF(FLAG.LE.0.0) GO TO 92
90    CONTINUE
      CALL FLWCHT
92    CONTINUE
C
96    CONTINUE
      WRITE(6,238)
238   FORMAT(1X,45HWANT TO SET A RANDOM FLOW AND CASE STUDY -      )
      READ(2,221) FLAG
      IF(FLAG.LE.0.0) GO TO 93
C
236   CONTINUE
C     SETS A CASE RUN AROUND INPUT FEED
C     CASET MUST HAVE EQUIPMENT NUMBER 25 AND SHOULD NOT BE INCLUDED
C     IN THE CALCULATION ORDER.
      CALL DISKIO(1,25)
      CALL CASET
      GO TO 1000
C
93    CONTINUE
      CALL STREAM(1.0)
      IN=IS
      CALL STREAM(2.0)
      IF(IS.LE.III) GO TO 94
      CALL STREAM(0.0)
      SN(IS,1)=2.0
94    CONTINUE
      DO 600 J=2,JJ
600   SN(IS,J)=SN(IN,J)
C
1000  CONTINUE
      LOOPC=1
      WRITE (6,196) LOOPC
C
100   CONTINUE
C
C     CALCULATING EQUIPMENT IN CALCULATION ORDER LIST
      NC=1
      MODE=0
      KTEST=0
      LOOP=1
      IF(IK.EQ.0) GO TO 98
      MODE=1
      KTEST=1
      LOOP=999
98    CONTINUE
C
C     READ EN VECTOR
C
102   IF (KPRNT(5)) 108,108,104
104   CONTINUE
      WRITE (6,182) LOOP
      DO 106 IKE=1,III
      IF (SN(IKE,1).LE.0.0) GO TO 106
      WRITE (6,194) (SN(IKE,J),J=1,JJ)
106   CONTINUE
C
108   NE=LLST(NC)
      MM=NE
      CALL DISKIO (1,MM)
      NN=EN(3)+.001
      NIN=EN(6)+.001
      NOUT=EN(11)+.001
      NTYPE=ABS(EN(2))+.001
      KSW=0
      IF (EN(2).LE.0.) KSW=1
C     ISP=0 SUPPRESSES ALL PRINTING OF INPUT AND OUTPUT STREAMS
      ISP=0
C
C     FINDING INPUT STREAMS
C
```

```
      IF(NIN.EQ.0) GO TO 128
      DO 122 I=1,NIN
      S=EN(I+6)
      CALL STREAM (S)
      IF (IS-III) 114,114,110
110   CONTINUE
      SI(I,1)=S
      DO 112 J=2,JJ
      SI(I,J)=0.
112   CONTINUE
      GO TO 122
114   DO 116 J=1,JJ
      SI(I,J)=SN(IS,J)
116   CONTINUE
      IF (INT(S+.001)) 122,122,118
118   CONTINUE
      M=S+.001
      IF (NS(M)-6) 122,120,120
120   CONTINUE
      SN(IS,1)=0.
122   CONTINUE
      IF (ISP) 128,128,124
124   WRITE (6,184) NE ,NAME(NTYPE)
      DO 126 IKE=1,NIN
      WRITE(6,194)
      WRITE (6,194) (SI(IKE,J),J=1,JJ)
126   CONTINUE
C
128   CONTINUE
C
C
      CALL MODULE (NTYPE)
C
C
C     STORING OUTPUT STREAMS AND PRINTING
C
      IF(NOUT) 166,166,136
136   CONTINUE
      DO 150 I=1,NOUT
      IF(SO(I,3).LE.0.0) GO TO 150
      S=EN(I+11)
      SO(I,1)=S
      M=S+.001
      IF(NS(M)-6) 140,150,140
140   CALL STREAM(S)
      IF (IS-III) 146,146,142
142   CALL STREAM (0.)
      IF (IS-III) 146,146,144
144   WRITE (6,190)
      GO TO 150
146   DO 148 J=1,JJ
      SN(IS,J)=SO(I,J)
148   CONTINUE
150   CONTINUE
C
      IF (ISP) 158,158,154
154   WRITE (6,186) NE , NAME(NTYPE)
      DO 156 IKE=1,NOUT
      WRITE(6,194)
      WRITE (6,194) (SO(IKE,J),J=1,JJ)
156   CONTINUE
C
158   IF (LOOP-999) 166,160,160
160   IF (KSW.NE.0) GO TO 166
      IF(KPRNT(6).LT.1) GO TO 166
      WRITE(6,188) NE, NAME(NTYPE)
      DO 164 IKE=1,NOUT
      WRITE(6,194)
      WRITE(6,195) (SO(IKE,J),J=1,JJ)
195   FORMAT(1X,5F12.3)
164   CONTINUE
C
166   NC=NC+1
      IF (NC-NCALC) 102,102,168
```

```
C
168    CONTINUE
       IF (LOOP-999) 170,172,172
170    CONTINUE
       NC=0
       GO TO 166
172    IF (KTEST) 174,174,176
174    NC=0
       KTEST=1
       MODE=1
       GO TO 166
176    CONTINUE
       CALL ICLOAD
       WRITE(6,220)
220    FORMAT(1X,35HWANT TO MAKE ANY PLANT CHANGES -        )
       READ(2,221) FLAG
       IF(FLAG.LE.0.0) GO TO 230
       CALL ENSET
       LOOPC=LOOPC+1
       WRITE(6,196) LOOPC
       GO TO 100
230    CONTINUE
       WRITE(6,238)
232    FORMAT(1X,45HWANT TO GENERATE A NEW RANDOM CASE STUDY -         )
       READ(2,221) FLAG
       IF(FLAG.LE.0.0) GO TO 95
       GO TO 236
95     CONTINUE
       WRITE(6,240)
       READ(2,221) FLAG
       IF(FLAG.GE.1.0) GO TO 90
       STOP
C
182    FORMAT (1H0,32H$$$$$  SN TABLE ON ENTERING LOOP  ,I5,7H  $$$$$ )
184    FORMAT (1H0,31H$$$$$  INPUT STREAMS FOR MODULE ,I5,4H  - ,
      1A8,7H  $$$$$ )
186    FORMAT (1H0,32H$$$$$  OUTPUT STREAMS FOR MODULE ,I5,4H  - ,A8,
      2 7H  $$$$$ )
188    FORMAT (1H0,38H$$$$$  FINAL OUTPUT STREAMS FOR MODULE ,I5,4H  - ,
      3 A8,7H  $$$$$ )
190    FORMAT (1H0,25H*****  ERROR IN SN  *****  )
192    FORMAT (1H0,38H**********  END OF EXECUTION  **********  )
194    FORMAT (1H ,10F12.3)
196    FORMAT(1H0,20H******************** ,10H       RUN,I4,26H      ****
      1**************** ,//)
198    FORMAT(10A8)
200    FORMAT(1H0,10A8)
221    FORMAT(F12.3)
C
       END
```

```
      SUBROUTINE FLWCHT
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     SETS THE CALCULATION ORDER OF A GIVEN PLANT AND
C     SETS THE VARIOUS EQUIPMENT PARAMETERS
C
C
      LP1=0
      LP2=0
      LLST(1)=2
      LLST(2)=3
      LLST(3)=4
      NCALC=3
C
      WRITE(6,400)
400   FORMAT(1H0,22HANY PRIMARY TANKS -            )
      READ(2,200) F
200   FORMAT(F12.3)
C
C     SETTING SPLITTER BEFORE PRIMARY SETTLER
      MQ=NPOINT(4,1)
      EEN(MQ+16)=F
      EEN(MQ+17)=1.0-F
      EEN(MQ+18)=0.0
C
      IF(F.LT.1.0) GO TO 10
C
C     ASKING FOR DETAILS ON PRIMARY SETTLER
      NCALC=NCALC+1
      LLST(NCALC)=5
      MQ=NPOINT(5,1)
      WRITE(6,500)
500   FORMAT(1X,20HPRIMARY CLARIFIER          )
      WRITE(6,510)
510   FORMAT(5X,30HNUMBER OF TANKS IN PARALLEL =        )
      READ(2,200) F
      EEN(MQ+4)=F
      WRITE(6,520)
520   FORMAT(5X,26HLENGTH OF TANK (IN FT) =        )
      READ(2,200) F
      EEN(MQ+16)=F
      WRITE(6,530)
530   FORMAT(5X,25HWIDTH OF TANK (IN FT) =        )
      READ(2,200) F
      EEN(MQ+17)=F
      WRITE(6,540)
540   FORMAT(5X,25HDEPTH OF TANK (IN FT) =        )
      READ(2,200) F
      EEN(MQ+18)=F
      WRITE(6,550)
550   FORMAT(5X,26HNUMBER OF SLUDGE PUMPS =        )
      READ(2,200) F
      EEN(MQ+23)=F
      WRITE(6,560)
560   FORMAT(5X,35HCAPACITY OF SLUDGE PUMPS (IGPH) =        )
      READ(2,200) F
      EEN(MQ+24)=F
      WRITE(6,570)
570   FORMAT(5X,40HFRACTION OF CAPACITY PUMPS ARE USED =        )
      READ(2,200) F
      EEN(MQ+25)=F
C
10    NCALC=NCALC+1
      LLST(NCALC)=6
C
      WRITE(6,410)
410   FORMAT(1H0,30HANY ACTIVATED SLUDGE TANKS -        )
      READ(2,200) F
C
C     SETTING THE SPLITTER BEFORE THE ACTIVATED SLUDGE TANKS
      MQ=NPOINT(6,1)
```

```
      EEN(MQ+16)=F
      EEN(MQ+17)=1.0-F
      IF(F.LT.1.0) GO TO 40
C
C     ASKING FOR DETAILS ON THE ACTIVATED SLUDGE TANKS
      LP1=1
      NCALC=NCALC+1
      LLST(NCALC)=7
      MQ=NPOINT(7,1)
      WRITE(6,580)
580   FORMAT(1X,25HACTIVATED SLUDGE TANKS         )
      WRITE(6,510)
      READ(2,200) F
      EEN(MQ+4)=F
      WRITE(6,520)
      READ(2,200) F
      EEN(MQ+16)=F
      WRITE(6,530)
      READ(2,200) F
      EEN(MQ+17)=F
      WRITE(6,540)
      READ(2,200) F
      EEN(MQ+18)=F
      WRITE(6,545)
545   FORMAT(5X,37HNUMBER OF STIRRED TANKS IN SERIES =         )
      READ(2,200) F
      EEN(MQ+34)=F
      WRITE(6,555)
555   FORMAT(5X,30HARE YOU USING STEP AERATION      )
      READ(2,200) F
      EEN(MQ+19)=1.0
      IF(F.LE.0.0) EEN(MQ+19)=EEN(MQ+34)
      IF(F.LE.0.0) GO TO 35
      SUM=0.0
      DO 600 KM=1,10
      WRITE(6,565) KM
565   FORMAT(1X,25HFRACTION OF FEED TO TANK   ,I3,4H  =  )
      READ(2,200) F
      EEN(MQ+34+KM)=F
      SUM=SUM+F
      IF(SUM.GE.1.0) GO TO 35
600   CONTINUE
35    WRITE(6,575)
575   FORMAT(5X,25HNUMBER OF AIR BLOWERS =    )
      READ(2,200) F
      EEN(MQ+45)=F
      WRITE(6,585)
585   FORMAT(5X,32HCAPACITY OF BLOWERS (SCF/HR) =        )
      READ(2,200) F
      EEN(MQ+46)=F
C
      NCALC=NCALC+1
      LLST(NCALC)=8
C
C     ASKING FOR DETAILS OF THE SECONDARY CLARIFIERS
      MQ=NPOINT(8,1)
      WRITE(6,590)
590   FORMAT(1H0,20HSECONDARY CLARIFIER        )
      WRITE(6,510)
      READ(2,200) F
      EEN(MQ+4)=F
      WRITE(6,505)
505   FORMAT(5X,25HSURFACE AREA (SQ FT) =        )
      READ(2,200) F
      EEN(MQ+18)=F
      WRITE(6,550)
      READ(2,200) F
      EEN(MQ+20)=F
      WRITE(6,560)
      READ(2,200) F
      EEN(MQ+21)=F
      WRITE(6,570)
      READ(2,200) F
      EEN(MQ+22)=F
```

```
C
      NCALC=NCALC+1
      LLST(NCALC)=9
      NCALC=NCALC+1
      LLST(NCALC)=10
C
C     ASKING FOR DETAILS OF THE WASTE SLUDGE POLICY
      MQ=NPOINT(10,1)
      WRITE(6,535)
535   FORMAT(1X,30HFRACTION OF SLUDGE WASTED =      )
      READ(2,200) F
      EEN(MQ+17)=F
      EEN(MQ+16)=1.0-F
      NCALC=NCALC+1
      LLST(NCALC)=11
C
      WRITE(6,420)
420   FORMAT(1X,20HIF WASTE ACT SL TO    ,/,5X,20HPRI CLAR -TYPE 1.0
     1,/,5X,31HDIRECTLY TO DIGESTER -TYPE 2.0  ,/,5X,21HTHICKENER -TYPE
     23.0     ,/)
      READ(2,200) F
      JF=F+0.01
      MQ=NPOINT(11,1)
      EEN(MQ+16)=0.0
      EEN(MQ+17)=0.0
      EEN(MQ+18)=0.0
      EEN(MQ+15+JF)=1.0
      IF(F.LT.3.0) GO TO 40
      NCALC=NCALC+1
      LLST(NCALC)=12
      NCALC=NCALC+1
      LLST(NCALC)=19
      WRITE(6,430)
430   FORMAT(1X,40HIS THICKENED SLUDGE SENT TO DIGESTER -       )
      READ(2,200) F
      MQ=NPOINT(19,1)
      EEN(MQ+17)=F
      EEN(MQ+16)=1.0-F
C
40    NCALC=NCALC+1
      LLST(NCALC)=20
C
      WRITE(6,440)
440   FORMAT(1H0,18HANY DIGESTERS -        )
      READ(2,200) F
      IF(F.LT.1.0) GO TO 50
      LP2=1
      NCALC=NCALC+1
      LLST(NCALC)=13
C
C     ASKING FOR DETAILS OF THE DIGESTERS
      WRITE(6,450)
450   FORMAT(1X,30HONE OR TWO STAGE DIGESTION -        )
      READ(2,200) F
      MQ=NPOINT(13,1)
      EEN(MQ+16)=F-1.0
      EEN(MQ+17)=1.0-EEN(MQ+16)
      IF(F.LT.2.0) GO TO 60
      NCALC=NCALC+1
      LLST(NCALC)=14
      MQ=NPOINT(14,1)
      WRITE(6,460)
460   FORMAT(1X,22HFIRST STAGE DIGESTER        )
      WRITE(6,510)
      READ(2,200) F
      EEN(MQ+4)=F
      WRITE(6,515)
515   FORMAT(5X,30HDIAMETER OF TANK (IN FT) =       )
      READ(2,200) F
      EEN(MQ+16)=F
      WRITE(6,540)
      READ(2,200) F
      EEN(MQ+17)=F
      WRITE(6,525)
```

```
525     FORMAT(5X,35HTEMPERATURE OF DIGESTION DEG C =          )
        READ(2,200) F
        EEN(MQ+19)=F
C
        NCALC=NCALC+1
        LLST(NCALC)=15
        WRITE(6,470)
470     FORMAT(1X,23HSECOND STAGE DIGESTER       )
        GO TO 65
C
60      NCALC=NCALC+1
        LLST(NCALC)=15
        WRITE(6,480)
480     FORMAT(1X,20HANAEROBIC DIGESTER      )
65      CONTINUE
        MQ=NPOINT(15,1)
        WRITE(6,510)
        READ(2,200) F
        EEN(MQ+4)=F
        WRITE(6,515)
        READ(2,200) F
        EEN(MQ+16)=F
        WRITE(6,540)
        READ(2,200) F
        EEN(MQ+17)=F
        WRITE(6,525)
        READ(2,200) F
        EEN(MQ+19)=F
        NCALC=NCALC+1
        LLST(NCALC)=16
C
50      IF(LP1.NE.1) GO TO 70
        NCALC=NCALC+1
        LLST(NCALC)=22
        MQ=NPOINT(22,1)
        EEN(MQ+4)=(FLOAT(LP1+LP2-1))*100.0 +1.0
        EEN(MQ+20)=1.0
        EEN(MQ+21)=1.0
        EEN(MQ+17)=10.0
        IF(LP2.NE.1) EEN(MQ+17)=20.0
70      IF(LP2.NE.1) GO TO 80
        NCALC=NCALC+1
        LLST(NCALC)=23
        MQ=NPOINT(23,1)
        EEN(MQ+4)=(FLOAT(LP1+LP2-1))*100.0 +1.0
        EEN(MQ+20)=EEN(MQ+4)
        EEN(MQ+21)=EEN(MQ+4)
        EEN(MQ+17)=5.0
        IF(LP1.NE.1) EEN(MQ+17)=20.0
C
80      CONTINUE
        NCALC=NCALC+1
        LLST(NCALC)=17
        NCALC=NCALC+1
        LLST(NCALC)=18
C
C
C       ASKING FOR AVERAGE FEED CONDITIONS
        WRITE(6,750)
750     FORMAT(1H0,30HWANT TO SET UP FEED STREAM        )
        READ(2,200) F
        IF(F.LE.0.0) RETURN

        CALL STREAM(1.0)
        WRITE(6,700)
700     FORMAT(1H0,40HAVERAGE FLOW TO YOUR PLANT (MIGD) =      )
        READ(2,200) F
        FLOW=F*1.0E6/24.0
        FRAC=FLOW/SN(IS,3)
        DO 610 J=6,JJ
610     SN(IS,J)=SN(IS,J)*FRAC
        SN(IS,3)=FLOW
        WRITE(6,760)
760     FORMAT(1X,50HNOTE THAT BOD APPROX GREATER THAN TWICE DOC      )
```

```
      WRITE(6,710)
710   FORMAT(1X,31HAVERAGE BOD5 TO YOUR PLANT =      )
      READ(2,200) F
      SN(IS,10)=FLOW*10.0*F*1.0E-6
      WRITE(6,720)
720   FORMAT(1X,43HAVERAGE SUSPENDED SOLIDS TO YOUR PLANT =      )
      READ(2,200) F
      SN(IS,11)=FLOW*10.0*F*1.0E-6
      WRITE(6,730)
730   FORMAT(1X,36HAVERAGE DISSOLVED ORGANIC CARBON =      )
      READ(2,200) F
      SN(IS,9)=FLOW*10.0*F*1.0E-6
      SN(IS,22)=0.0
      SN(IS,20)=0.2*SN(IS,9)
      SN(IS,21)=SN(IS,9)-SN(IS,20)-SN(IS,22)
      BODSOL=1.9*(SN(IS,20)+SN(IS,21))
      BODP=SN(IS,10)-BODSOL
      VSS=BODP/1.2
      SN(IS,15)=FLOW*10.0*5.0E-6
      SN(IS,16)=0.5*VSS
      SN(IS,17)=0.0
      SN(IS,18)=0.2*VSS
      SN(IS,19)=0.3*VSS
      SN(IS,12)=2.1*(VSS+SN(IS,15))
      SN(IS,13)=0.6*(SN(IS,11)-SN(IS,12))
      SN(IS,14)=0.4*(SN(IS,11)-SN(IS,12))
      SN(IS,8)=SN(IS,9)+VSS+SN(IS,15)
      IV=IS

      CALL STREAM(2.0)
      DO 620 J=2,JJ
620   SN(IS,I)=SN(IV,I)
C
      CALL STREAM(16.0)
      DO 640 J=6,JJ
      SN(IS,J)=SN(IS,J)*FRAC
640   CONTINUE
      SN(IS,3)=SN(IS,3)*FRAC

C     PURGE SN FILE
      DO 630 I=1,III
      IS=SN(I,1)+0.01
      IF((IS.EQ.1).OR.(IS.EQ.16).OR.(IS.EQ.2)) GO TO 630
      SN(I,1)=0.0
630   CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE CASET
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
      COMMON /C/ IND
C
C     GENERATES A CASE STUDY AROUND THE AVERAGE RAW FLOW
C
C     EN VECTOR
C     *********
C     1.-15. STANDARD FORMAT
C     6.     = 1.0
C     7.     STREAM NUMBER OF USUAL RAW WASTE FLOW (=1.0)
C     11.    = 1.0
C     12.    STREAM NUMBER OF GENERATED INPUT STREAM (=2.0)
C     16.    EQUIPMENT NUMBER OF PRIMARY SETTLER  (=5.0)
C     17.    EQUIPMENT NUMBER OF THE ACTIVATED SLUDGE TANKS  (=7.0)
C     18.    EQUIPMENT NUMBER OF THE SECONDARY CLARIFIERS  (=8.0)
C     19.    EQUIPMENT NUMBER OF THE DIGESTERS  (=15.0)
C     20.    ANY NUMBER BETWEEN 1.0E6 TO 1.0E8 - USED AS THE STARTER
C            IN THE RANDOM NUMBER GENERATOR
C
      IF(EN(20).GE.1.0E6) GO TO 9
      WRITE(6,470)
470   FORMAT(1X,50HTYPE ANY NUMBER BETWEEN 1 MILLION TO 100 MILLION    )
      READ(2,200) F
200   FORMAT(F12.3)
      MQ=NPOINT(25,1)
      EEN(MQ+20)=F
      EN(20)=F
      IND=EN(20)
      IND=IND*2+1
9     CONTINUE
C
      WRITE(6,500)
500   FORMAT(1X,20HREADY TO PLAY GAMES    ,/,20H.....CLUES.....          )
C
      S=EN(7)
      CALL STREAM(S)
      IIN=IS
      S=EN(12)
      CALL STREAM(S)
      IF(IS.LE.III) GO TO 22
      CALL STREAM(0.0)
22    CONTINUE
      IO=IS
      SN(IO,1)=EN(12)
C
C     GENERATING A RAW WASTE FLOW
C     SET WATER FLOW
10    CONTINUE
      CALL RANDOM(Z)
      IF(Z.LT.0.25) GO TO 10
      SN(IO,6)=SN(IIN,6)*Z*2.0
C
C     SET COMPONENT FLOWS
      DO 600 J=13,JJ
20    CONTINUE
      CALL RANDOM(Z)
      IF(Z.LT.0.25) GO TO 20
      SN(IO,J)=SN(IIN,J)*Z*2.0
600   CONTINUE
C
C     SET TOXIC COMPONENT FLOW
      CALL RANDOM(Z)
      SN(IO,30)=Z
      SN(IO,2)=SN(IIN,2)
      SN(IO,4)=SN(IIN,4)
      SN(IO,5)=SN(IIN,5)
      SN(IO,7)=SN(IIN,7)
C
      CALL BALNCE(1,IO)
C
```

```
C
C     GENERATING EQUIPMENT FAILURES
24    CONTINUE
      CALL RANDOM(Z)
      KO=Z*11.0+1.0
      GO TO (1,1,2,2,3,3,4,4,4,4,5,5),KO
1     MM=EN(16)+0.01
      DO 610 I=1,NCALC
610   IF(LLST(I).EQ.MM) GO TO 620
      GO TO 24
620   CONTINUE
      MQ=NPOINT(MM,1)
      IF(KO.EQ.2) GO TO 11
      EEN(MQ+4)=EEN(MQ+4)-1.0
      WRITE(6,400)
400   FORMAT(1X,25HONE PRIMARY TANK IS DOWN        )
      GO TO 5
11    EEN(MQ+23)=EEN(MQ+23)-1.0
      WRITE(6,410)
410   FORMAT(1X,50HONE OF THE PRIMARY SLUDGE PUMPS IS NOT WORKING       )
      GO TO 5
C
2     MM=EN(17)+0.01
      DO 630 I=1,NCALC
630   IF(LLST(I).EQ.MM) GO TO 640
      GO TO 24
640   CONTINUE
      MQ=NPOINT(MM,1)
      IF(KO.EQ.4) GO TO 12
      EEN(MQ+4)=EEN(MQ+4)-1.0
      WRITE(6,420)
420   FORMAT(1X,35HONE ACTIVATED SLUDGE TANK IS DOWN       )
      GO TO 5
12    EEN(MQ+45)=EEN(MQ+45)-1.0
      WRITE(6,430)
430   FORMAT(1X,40HONE OF THE AIR BLOWERS IS DOWN            )
      GO TO 5
C
3     MM=EN(18)+0.01
      DO 650 I=1,NCALC
650   IF(LLST(I).EQ.MM) GO TO 660
      GO TO 24
660   CONTINUE
      MQ=NPOINT(MM,1)
      IF(KO.EQ.6) GO TO 13
      EEN(MQ+4)=EEN(MQ+4)-1.0
      WRITE(6,440)
440   FORMAT(1X,35HONE OF THE SECONDARY CLARIFIERS IS DOWN      )
      GO TO 5
13    EEN(MQ+20)=EEN(MQ+20)-1.0
      WRITE(6,450)
450   FORMAT(1X,45HONE OF THE SECONDARY SLUDGE PUMPS IS DOWN      )
      GO TO 5
C
4     MM=EN(19)+0.01
      DO 670 I=1,NCALC
670   IF(LLST(I).EQ.MM) GO TO 680
      GO TO 24
680   CONTINUE
      MQ=NPOINT(MM,1)
      KO=KO-6
      GO TO (14,15,16,17),KO
14    IF(EEN(MQ+4).LT.2.0) GO TO 24
      EEN(MQ+4)=EEN(MQ+4)-1.0
      WRITE(6,460)
460   FORMAT(1X,25HONE DIGESTER IS DOWN       )
      GO TO 5
15    CONTINUE
      GO TO 5
16    CALL RANDOM(Z)
      EEN(MQ+24)=Z
      GO TO 5
17    EEN(MQ+19)=25.0
5     CONTINUE
```

```
C
C
      RETURN
      END


      SUBROUTINE RANDOM(Z)
C
C     GENERATES RANDOM NUMBERS HAVING A UNIFORM DISTRIBUTION BETWEEN 0-1
C     USES THE MIXED MULTIPLICATIVE CONGRUENTIAL METHOD
C
      COMMON /C/ IND
      DATA IL/1/
C
      IF(IL.EQ.0) GO TO 1
      IL=0
      M=2**30
      FM=M
      N=2**15+3
      IX=IND
C
1     CONTINUE
      IX=MOD(N*IX,M)
      FX=IX
      Z=FX/FM
C
      RETURN
```

```
      SUBROUTINE ICLOAD
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
      DIMENSION COST(15)
C
      COST(1)=0.0
      COST(2)=8.0
      COST(3)=20.0
      COST(4)=2.0
      COST(5)=0.0
      COST(6)=20.0
      COST(7)=8.0
      COST(9)=8.0
      COST(10)=10.0
      COST(8)=8.0
      COST(11)=8.0
      COST(12)=15.0
      COST(13)=20.0
      COST(14)=20.0
      COST(15)=20.0
      TCOST=0.0
C
C     ALLOWS PLAYER TO MAKE DECISIONS AS TO PLANT OPERATIONS AND
C     TO MAKE ANALYSES OF ANY STREAM COMPONENT
C     COSTS ARE CALCULATED FOR ANY ANALYSIS AND A SURCHARGE IS APPLIED
C     TO ANY PLANT DISCHARGING AN UNSATISFACTOY EFFLUENT
C     THE FINAL EFFLUENT MUST BE STREAM 35.0
C
      CALL STREAM(35.0)
      FLOW=SN(IS,3)*24.0*1.0E-6
      WRITE(6,400) FLOW
400   FORMAT(1X,15HEFFLUENT FLOW =  ,F12.6,6H  MIGD )
      BOD=SN(IS,10)*1.0E5/SN(IS,3)
      WRITE(6,410) BOD
410   FORMAT(1X,15HEFFLUENT BOD =     ,F8.1)
      TCOST=TCOST+COST(10)
      SS=SN(IS,11)*1.0E5/SN(IS,3)
      WRITE(6,420) SS
420   FORMAT(1X,15HEFFLUENT SS =      ,F8.1)
      TCOST=TCOST+COST(11)
C
C     APPLY SURCHARGE ON EFFLUENT
      BODCH=SN(IS,10)-30.0*SN(IS,3)*1.0E-5
      IF(BODCH.LE.0.0) BODCH=0.0
      SSCH=SN(IS,11)-30.0*SN(IS,3)*1.0E-5
      IF(SSCH.LE.0.0) SSCH=0.0
      SURCH=1.2*(BODCH+SSCH)
      WRITE(6,480) SURCH
480   FORMAT(1H0,35H........SURCHARGE ON EFFLUENT = $    ,F8.2,6H  /DAY )
C
C     ASKING FOR ANALYSES
      WRITE(6,430)
430   FORMAT(1H0,25HWANT ANY ANALYSES DONE -      )
      READ(2,200) AN
      IF(AN.LE.0.0) GO TO 100
110   CONTINUE
      WRITE(6,440)
440   FORMAT(1X,20HTYPE STREAM NUMBER     )
      READ(2,200)  S
200.  FORMAT(F12.3)
210   FORMAT(2F12.4)
      IF(S.LE.0.0) GO TO 100
      CALL STREAM(S)
      CALL CONVERT(1,1,IS,3,1)
120   CONTINUE
      WRITE(6,450)
450   FORMAT(1X,20HTYPE ELEMENT NUMBER          )
      READ(2,200) SJ
      IF(SJ.LE.0.0) GO TO 110
      IJ=SJ+0.01
      WRITE(6,460) SI(1,IJ)
460   FORMAT(1X,20H.....ANALYSIS GIVES    ,F12.1)
      IF(IJ.EQ.30) IJ=15
```

```
      TCOST=TCOST+COST(IJ)
      GO TO 120
C
100   CONTINUE
      WRITE(6,470) TCOST
470   FORMAT(1H0,30H.....TOTAL ANALYTICAL COST = $    ,F8.2)
C
      WRITE(6,520)
520   FORMAT(1H0,45HWANT TO SEE THE SUMMARY REPORT ON STREAMS -    )
      READ(2,200) AN
      IF(AN.LT.1.0) GO TO 190
      CALL DISKIO(1,24)
      CALL REPT01
190   CONTINUE
C
      RETURN
      END



      SUBROUTINE ENSET
C
C
      COMMON LLST(50),NS(100),EN(100),SI(4,30),SO(4,30),KPRNT(10)
      COMMON IS,NE,JJ,LOOP,NIN,NOUT,MSN,ISP,NC,III,NCALC,NOCOMP,NSR
      COMMON MODE,NPLNT,LOOPC
      COMMON SN(25,30),EEN(600),NPOINT(25,2)
C
C     ALLOWS PLAYER TO MAKE PLANT ADJUSTMENTS
C
140   CONTINUE
      WRITE(6,500)
500   FORMAT(1X,22HTYPE EQUIPMENT NUMBER     )
      READ(2,200) S
200   FORMAT(F12.3)
      IF(S.LE.0.0) GO TO 130
      MM=S+0.01
      MQ=NPOINT(MM,1)
150   CONTINUE
      WRITE(6,510)
510   FORMAT(1X,40HTYPE ELEM. NUMBER AND VALUE CHANGED TO       )
      READ(2,210) SJ,EL
210   FORMAT(2F12.3)
      IF(SJ.LE.0.0) GO TO 140
      IJ=SJ+0.01
      EEN(MQ+IJ)=EL
      GO TO 150
C
130   CONTINUE
C
      RETURN
      END
```

Data set for the interactive version

```
MCMASTER WASTEWATER TREATMENT PLANT SIMULATION - INTERACTIVE VERSION
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
19.0        25.0        10.0
2.0         3.0         4.0         5.0         6.0
7.0         8.0         9.0         10.0        11.0
20.0        13.0        14.0        15.0        16.0
22.0        23.0        17.0        18.0
-35.0
1.0         1.0         7.0         1.0         1.0
7.0         1.0         1.0         1.0         1.0
7.0         1.0         1.0         7.0         1.0
1.0         1.0         7.0         7.0         7.0
1.0         7.0         7.0         6.0         7.0
1.0         7.0         1.0         7.0         1.0
7.0         7.0         7.0         7.0         1.0
2.0
1.0         7.0         66000.0     25.0        0.0
660000.0    4.0         0.0         0.0         0.0
0.0         0.0         78.0        30.0        5.0
37.0        10.0        5.0         30.0        10.0
50.0        5.0         100.0       0.0         0.0
0.0         23.0        0.5         6.0         0.0
16.0        7.0         16000.0     25.0        0.0
160000.0    0.0         0.0         0.0         0.0
0.0         0.0         2000.0      1500.0      1000.0
1000.0      40.0        0.0         1000.0      4.0
6.0         10.0        90.0        0.0         0.0
0.0         10.0        5.0         4.0         0.0
23.0
2.0         15.0        16.0        1.0         0.0
1.0         2.0         0.0         0.0         0.0
1.0         3.0         0.0         0.0         0.0
1.0
3.0         11.0        15.0        0.7         0.0
1.0         3.0         0.0         0.0         0.0
1.0         4.0         0.0         0.0         0.0
4.0         1.0         18.0        0.0         0.0
3.0         4.0         22.0        30.0        0.0
3.0         5.0         6.0         7.0         0.0
1.0         0.0         0.0
5.0         6.0         25.0        2.0         0.0
2.0         5.0         18.0        0.0         0.0
3.0         8.0         9.0         31.0        0.0
50.0        18.0        12.25       60000.0     80000.0
0.85        0.1         2.0         800.0       0.25
6.0         1.0         17.0        0.0         0.0
2.0         8.0         6.0         0.0         0.0
2.0         10.0        11.0        0.0         0.0
1.0         0.0
7.0         7.0         46.0        2.0         0.0
2.0         16.0        10.0        0.0         0.0
1.0         12.0        0.0         0.0         0.0
315.0       18.0        10.7        3.0         0.0015
0.0027      0.000002    2.2         0.54        0.42
0.07        90000.0     0.0012      0.01        0.15
0.09        0.0         0.0         3.0         1.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         3.0
60000.0
8.0         9.0         22.0        2.0         0.0
1.0         12.0        0.0         0.0         0.0
3.0         13.0        14.0        32.0        0.0
1.0         0.2         982.0       80000.0     2.0
25000.0     0.3
9.0         4.0         15.0        0.0         0.0
1.0         14.0        0.0         0.0         0.0
1.0         15.0        0.0         0.0         0.0
10.0        1.0         17.0        0.0         0.0
1.0         15.0        0.0         0.0         0.0
2.0         16.0        17.0        0.0         0.0
0.9         0.1
11.0        1.0         18.0        0.0         0.0
1.0         17.0        0.0         0.0         0.0
3.0         18.0        19.0        20.0        0.0
1.0         0.0         0.0
```

```
12.0        5.0         15.0        0.7         0.1
1.0         20.0        0.0         0.0         0.0
2.0         22.0        21.0        0.0         0.0
13.0        1.0         17.0        0.0         0.0
4.0         9.0         25.0        31.0        32.0
2.0         26.0        27.0        0.0         0.0
1.0         0.0
14.0        12.0        24.0        2.0         0.0
1.0         26.0        0.0         0.0         0.0
1.0         27.0        0.0         0.0         0.0
40.0        20.0        2.0         40.0        1.0
1.0         1.0         0.0         1.0
15.0        12.0        24.0        1.0         0.0
1.0         27.0        0.0         0.0         0.0
2.0         29.0        28.0        0.0         0.0
40.0        18.0        1.0         40.0        0.5
0.16        0.08        0.0         1.0
16.0        4.0         15.0        0.0         0.0
1.0         29.0        0.0         0.0         0.0
1.0         30.0        0.0         0.0         0.0
17.0        1.0         16.0        0.0         0.0
3.0         13.0        11.0        7.0         0.0
1.0         33.0        0.0         0.0         0.0
1.0
18.0        13.0        15.0        5.0         0.0
1.0         33.0        0.0         0.0         0.0
1.0         35.0        0.0         0.0         0.0
19.0        1.0         17.0        0.0         0.0
1.0         21.0        0.0         0.0         0.0
2.0         24.0        23.0        0.0         0.0
1.0         0.0
20.0        1.0         16.0        0.0         0.0
2.0         19.0        23.0        0.0         0.0
1.0         25.0        0.0         0.0         0.0
1.0
22.0        2.0         50.0        101.0       5.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
3.0         10.0        12.0        0.01        1.0
1.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
23.0        2.0         50.0        101.0       5.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
3.0         5.0         30.0        0.01        101.0
101.0       0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
24.0        16.0        35.0        0.0         0.0
0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0
2.0         5.0         8.0         9.0         0.0
12.0        0.0         13.0        15.0        16.0
17.0        26.0        30.0        28.0        20.0
21.0        0.0         0.0         7.0         0.0
25.0        19.0        20.0        0.0         0.0
1.0         1.0         0.0         0.0         0.0
1.0         2.0         0.0         0.0         0.0
5.0         7.0         8.0         15.0        0.0
```