THE BEHAVIOR OF AN ACTIVATED SLUDGE SYSTEM OPERATED AT HIGH FOOD TO MICRO-ORGANISM LOADING RATIOS

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S_i - Influent soluble substrate concentration

S_e - Effluent soluble substrate concentration

X_a - Average mixed liquor volatile suspended solids concentration

X_e - Effluent volatile suspended solids concentration

U - Specific substrate utilization rate

F:M ratio - Food to micro-organism ratio $\frac{(\text{lbs. BOD})}{(\text{lbs. MLVSS})\text{day}}$

θ_c - Sludge residence time

Y_t - True yield

K_d - Decay coefficient

K_e - Eckenfelder's original model coefficient

K'_e - Eckenfelder's modified model coefficient

CHAPTER I

INTRODUCTION

The first real study of sewage aeration was carried out by Angus Smith in 1882 (1). Initially, activated sludge studies were conducted on a fill and draw basis (2). Since then the activated sludge system has become probably the most widely used for biological treatment of wastewaters. The activated sludge system has been known to even remove priority pollutants and other normally toxic materials from wastewaters.

Treatment plants were at first designed from experience, and ususally on the basis of the flow. Then it progressed through stages to where the design was based upon the BOD loading per unit volume of aeration basin. These "black-box" type designs worked initially since the treatment systems were usually designed for domestic waste alone. But this could not go on for long as more and more industries kept producing wastewaters in large quantities. Studies carried out showed activated sludge to be a promising and more economical treatment alternative to physiochemical treatment processes that were being used by industry at the time. Probably due to this and the stringent control on pollutant of natural resources, the activated sludge system has come a long way. Today, there are a number of kinetic models that can be used as a guide for the design of activated sludge reactors. Most of these models produce relatively reliable results when used to design conventional systems. However, complex treatment needs and the

ever-escalating effluent restrictions have resulted not only in modifications of the conventional activated sludge systems but also in the development of new concepts in wastewater treatment. Moreover, many of the kinetic models have their limitations when one tries to apply them to the operational control of existing treatment systems.

Investigators in the field were in conflict over whether the efficiency of treatment depended on the organic concentration of the waste or the hydraulic flow rate.

Recently, Kincannon and Stover (3,4) have introduced a design concept that is based on the total organic loading approach. This design approach was initially developed for trickling filters (or biological towers).

This experiment was conducted to study the response of an activated sludge system at a high Food:Micro-organism (F:M) ratio.

CHAPTER II

LITERATURE REVIEW

The need for kinetic design models to predict metabolic and biological behavior in the activated sludge process encouraged extensive research in the field. This has resulted in a number of mathematical models which describe relationships governing microbial growth and substrate utilization. Proper use of the models to design full scale treatment plants, involves first obtaining essential biokinetic coefficients from bench and pilot scale studies using the particular wastewater to be treated.

Eckenfelder's (5) original model assumes that the specific substrate utilization rate, U, is a function of the effluent substrate concentration. McKinney's (6) model is identical to Eckenfelder's original model. Lawrence and McCarty's model (7) also assumes that the specific substrate utilization rate is a function of the effluent substrate concentration. Gaudy's model relates substrate removal directly to specific growth rate by use of the Monod relationship. Chapter 7 of the Design Manual (8) published by the Bioenvironmental Engineering Department of Oklahoma State University provides an excellent in-depth comparison of the various kinetic models, and is highly recommended for the interested reader.

It should be noted that when all the actual data obtained from a laboratory scale treatment study is plotted for the models mentioned

above, the variability is very significant. Determination of the bio-kinetic coefficients from the plots for each model becomes a calculated guess. Many engineers in the field tend to plot average values so as to reduce the scatter of data.

The concept of food to micro-organism ratio (F:M ratio) has been used and misused for a number of years. It has been referred to by many different names; for example, the F:M ratio was very often referred to as the "sludge loading factor" (9) or "sludge loadings".

McKinney (11) developed the concept of F:M ratio as a control parameter. Although originally derived from batch type laboratory waste treatment systems, its use has proven very helpful in full scale treatment operation. The F:M ratio may be defined as

$$(F:M) = \frac{FS_i}{XV}$$

where (F:M) is the food:micro-organism ratio, F is the flow rate, S_i is the influent substrate concentration, X is the mixed liquor volatile suspended solids and V is the volume of the aeration chamber.

Unfortunately, confusion has been added to the definition of (F:M). In one widely used reference and textbook (12), the (F:M) was defined as the mass of BOD or COD used per day divided by the mass of solids under aeration. Lawrence and McCarty (7) have demonstrated that this misused definition of (F:M) is actually equal to the specific utilization rate, U, and that the (F:M) can be related to U by the expression

$$U = \frac{(F:M)E}{100} = \left(\frac{FS_i}{XV}\right)\left(\frac{S_i - S_e}{S_i}\right) 100 = \frac{F(S_i - S_e)}{XV}$$

where E is the treatment process efficiency in percentage, and S_e is the effluent substrate concentration. Bliss and Barnes (13), in their

studies with nitrogen control, have also defined a term that they call the "modified F:M ratio." Again their definition is actually the specific utilization rate.

The term BOD or COD sludge age has also been used instead of the F:M (14,15). This term is simply the reciprocal of the F:M ratio or, the mass of micro-organisms present in the aeration chamber divided by the mass of BOD or COD entering the aeration chamber each day.

Although some literature is available for studies conducted using the F:M concept, very little is available for high F:M loading ratios. It was felt that the normal F:M operating range for the activated sludge system was around 0.5, at most. Some researchers have conducted studies on what they called the "high rate activated sludge process" and have operated pilot plants treating sewage at F:M loading ratios above 2.0 (16). They have used both surface aerators and air diffuser systems and have reported BOD removal of only 75 percent and below.

Rennerfelt (17) reports that the BOD removal efficiency dropped from nearly 95 percent at an F:M loading of below 0.25, to 45 percent at an F:M loading of about 1.5 for a pulp mill waste in Sweden. The treatment plant was maintaining a MLSS concentration of 6,000 to 8,000 mg/ℓ. Emde (18) has studied results from four plants running at F:M loading ratios as high as 3.0. The MLSS in two of the plants was maintained at between 5,000 and 6,000 mg/ℓ and around 11,000 mg/ℓ at another plant. He too, reports severe reductions in treatment efficiencies but claims that the high MLSS of 11,000 mg/ℓ does help in the removal efficiency even though the F:M ratios were high. He feels that the biological characteristics are affected by the dissolved oxygen level and the BOD loading on the system. But at high loads,

flagellates replaced ciliates, even at very high dissolved oxygen conditions. He concluded by saying that the efficiency of BOD removal was affected more by the aeration period than by the BOD load.

McKinney (19) has found that well fed, rapidly growing organisms, tended to result in poor flocculation and therefore in dispersed growth. At very high F:M loading ratios, food was surely not the limiting factor. Simpson's (9) studies reinforced McKinney's findings. Simpson found that in "high rate activated sludge systems" the micro-organisms are very active at the end of each contact period, causing poor effluent qualities and the actual sludge age turned out to be between 0.2 and 0.4 days. He has also put out an emperical expression for excess sludge production

$$a = 0.2 + (\text{sludge loading factor})\ 1/2$$

where "a" is the "sludge growth factor" (i.e., kg. sludge formed per kg. of applied BOD). The sludge loading factor (i.e., kg. BOD per kg. sludge day) is basically the F:M ratio. Immediately, one would notice that for F:M ratios greater than 2.0, the sludge growth factor becomes greater than 1.0 and this is questionable.

Cashion et al. (10) has concluded from his studies with activated sludge that meaningful F:M control can only be achieved when provision is made for external storage of biological solids. He concludes that F:M control that can be achieved in an activated sludge system that does not have provision for external storage of biological solids is negligible.

Kincannon et al. (21) assume that the specific substrate utilization rate is a function of the mass loading per mass of

micro-organisms (F:M) rather than the substrate concentration alone. With the other kinetic models, a lot of rationalization is required to determine the respective biokinetic coefficients due to the large scatter of data points when plotted for each model. Kincannon and Stover (21) have recently introduced a kinetic model that eliminates the variability of the biological response to the wastewater being treated which exists with the other models. Moreover, Kincannon et al. (21,22) have also introduced a procedure to account for this variability to a large extent.

CHAPTER III

MATERIALS AND METHODS

To study the effects of the high food to micro-organism loading ratios on the activated sludge system a bench-scale external recycle system was operated. A schematic diagram of the system is shown in Figure 1.

The system consisted of a 2.5 liter capacity, hemispherical bottomed aeration chamber and a 1.0 liter capacity, flat bottomed clarifier. Both units were made of glass. A frame was used to support the two separate units at a difference of elevation of about 14 inches. The clarifier was seated on a magnetic stirrer plate and a 1 inch long teflon coated magnetic stirrer bar was placed in the clarifier to prevent "arching" effects of the settled sludge. Air was supplied to the aeration chamber through a single fine bubble diffuser. The airflow rate was regulated with a Gelman airflow meter to provide an adequate dissolved oxygen level in the aeration chamber. Positive displacement pumps were used to provide a continuous feed flow to the system and also to recycle and waste sludge. Glass tubing was used for both the suction and delivery side of the feed pump and tygon tubing was used in the sludge recycle and wasting system. Flow from the aeration chamber to the clarifier was by gravity. Every time the feed was made up, the feed lines, feed bottle and the effluent bottle were cleaned with chlorox and

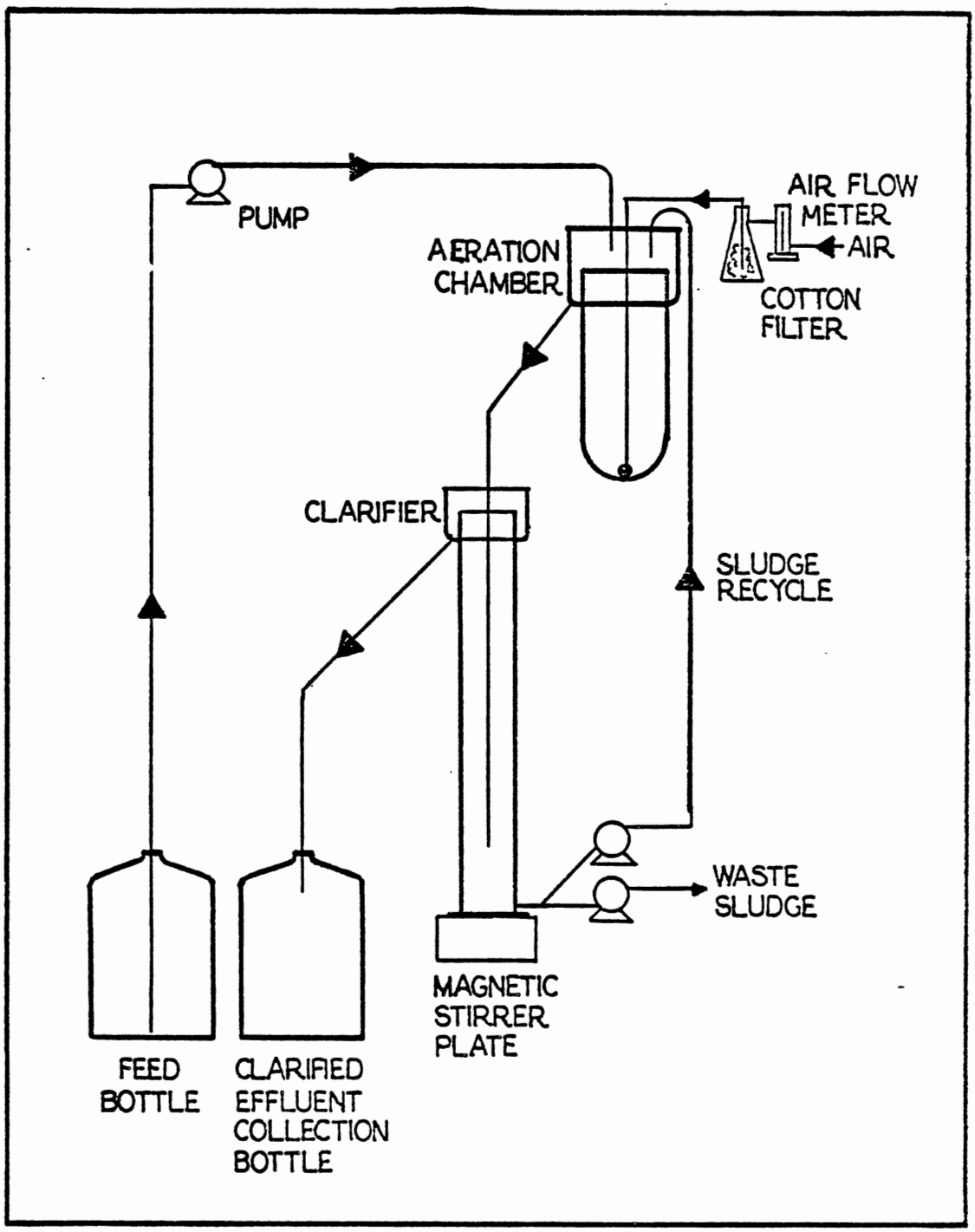

Figure 1. Schematic Diagram of Experimental System

rinsed out several times with tap water to prevent bacterial growth in these parts of the system.

Table I shows the composition of the synthetic wastewater used in this study. Glucose was used as the carbon source. Stock solutions were made for each of the chemicals in Table I, and depending on the required concentration of the feed to provide specific loadings on the system, equal measured volumes of each stock solution were mixed in a 25 liter capacity bottle and the mixture diluted to 20 liters with tap water. Tap water was used to provide the trace elements required for microbial growth. The pH of the fresh feed was checked and adjusted if required. At F:M loadings of 0.5 and 1.0, the feed was prepared once every two days, but as the concentration of the feed increased for the higher loadings, the feed was prepared daily. A Cole-Palmer 7013 variable speed flex pump was used to deliver the synthetic feed from the feed bottle into the aeration chamber. The pump was regulated to deliver a flow of 10 liters per day at a continuous rate of seven milliliters per minute. The flow was measured regularly to ensure a constant flow rate. By so doing, the hydraulic detention time in the aeration chamber was maintained at six hours throughout the study.

A Cole-Palmer 7015 variable speed flex pump was used to recycle settled sludge from the bottom of the clarifier back to the aeration chamber. The recycle sludge flow rate was fixed at 3/10 of the incoming feed rate. This recycle rate was chosen as it was found by trial and error that at that recycle ratio, the sludge blanket depth remained relatively stable in the clarifier.

At an F:M loading of 1.0 and below, a third pump had been connected to the recycle flow line to enable continuous wasting from the clarifier

underflow. This pump was later removed when sludge wasting was done directly from the aeration chamber. The sludge recycle pump, the sludge wasting pump and the magnetic stirrer plate were connected to the power supply through timers. The timers were set so as to operate the sludge recycle pump for a duration of seven seconds out of every five minutes, the sludge wasting pump for a duration of three seconds out of every five minutes and the magnetic stirrer plate for a duration of thirty seconds out of every five minutes throughout the day. Moreover, the magnetic stirrer would be switched on by the timer about ten seconds before the recycle and waste pumps were operated.

TABLE I

COMPOSITION OF SYNTHETIC WASTEWATER

Constituents	Concentrations (mg/ℓ) used for F:M ratios of 0.5	1.0	2.0	3.0
Glucose	400	800	1600	2400
Glycerol	25	50	100	150
Glutamic acid	25	50	100	150
Yeast extract	25	50	100	150
Ammonium Chloride	50	100	200	300
Potassium Phosphate	10	20	--	--
Manganese Sulphate	10	20	20	20
1M Phosphate buffer (ml/ℓ of feed)	--	--	10	30

The ammonium chloride and potassium phosphate concentrations are in terms of nitrogen and phosphorous concentrations respectively.

The original seed of micro-organisms was taken from the clarifier underflow of a domestic wastewater treatment plant. The mixed liquor volatile suspended solids (MLVSS) of the seed sludge was determined and a volume of the seed sludge was placed into the aeration chamber and feed was added. The resulting initial MLVSS concentration in the aeration chamber was 2000 mg/ℓ. The feed concentration was made up to provide an F:M loading of 0.5. The system was allowed to acclimate for four weeks before data collection was started. During this time, the MLVSS in the system was monitored and maintained at a level to provide an F:M loading of 0.5.

At the first loading, that is, at an F:M loading of 0.5, samples were taken from the mixed liquor, effluent, recycle line and waste line on a daily basis and the suspended solids and volatile suspended solids determination was carried out according to procedures set out in "Standard Methods" (26). On alternative days when fresh feed was made-up a soluble BOD analysis was conducted on the feed and the filtered effluent. The pH of the feed, the mixed liquor and the effluent were checked throughout each day, using a pH probe. Microscopic observations were made periodically.

Data was collected at the F:M ratio of 0.5 for about five weeks and then the flow rate was doubled, keeping the feed concentration constant and maintaining the same MLVSS concentrations in the aeration chamber to maintain an F:M ratio of 1.0. The system was run in this way for four weeks, but continuous monitoring of the system from the second week onwards warned of impending problems with the sludge settling characteristics. Therefore, at this point, the first change was made in the method of operation.

The flow rate was returned to the 10.0 liters per day rate, but the concentration of the feed was increased. Again, the system was allowed to go through an acclimatization period of three weeks before any data was collected. The samples were collected as for the previous loading. A second change made in the operation of the system was in the method of sludge wasting. The sludge wasting pump was removed and sludge wasting was made once a day directly from the aeration chamber. This was done to directly control the MLVSS in the aeration chamber. At about the same time every day, the MLVSS was measured just before and immediately after wasting. A filtered volume of the effluent was used to replace the sludge volume wasted from the aeration chamber. By doing so, the level of mixed liquor in the aeration chamber was maintained. The daily sludge wastage was calculated using

$$Fw = \frac{2.5\ (X_{24} - X_0)}{X_{24}}$$

where Fw is the volume in liters to be wasted, 2.5 is the volume of the aeration chamber in liters, X_{24} is the measured MLVSS before wasting and X_0 is the target MLVSS required after wasting and refilling the aeration chamber with an equal quantity of filtered effluent. The target X_0 was calculated using the expression

$$X_0 = 2\ X_a - X_{24}$$

where X_a is the average MLVSS that is required in the aeration chamber to maintain the required F:M ratio.

After five weeks of data collection at an F:M loading of 1.0 the concentration of the feed was further doubled, but both the feed flow

rate and the MLVSS concentration were kept the same. This provided an F:M loading of 2.0 on the system. The system was allowed to acclimatize for four weeks. During these four weeks, further changes were made to facilitate proper operation of the system. The potassium phosphate was removed from the stock solution and instead, a 1.0 M phosphate buffer was made using monobasic and dibasic phosphate. Ten mls. of the buffer was added to each liter of the feed after the feed pH was adjusted with sodium hydroxide. Moreover, the feed was made up daily. The data was collected as before.

After about four weeks of data collection at an F:M loading of 2.0, the feed concentration was increased to three times the concentration used at an F:M loading of 1.0. This brought the F:M loading to 3.0. The system was run for four weeks before the data collection was started. Data was collected for three weeks and the unit was shut down.

During all the loadings, at times the MLVSS in the reactor dropped below the target values. When this happended, sludge wasting was stopped and the solids were allowed to build up to the required level again.

The Kincannon and Stover model was used to analyze the data collected. This model was chosen over all the other models because of the high F:M loadings used. The Kincannon and Stover model reduced scatter of data (when plotted) to a minimal compared to the "shotgun-blast" type of data (when plotted) when other models were tried.

The Kincannon and Stover model is based upon the following relationship for specific substrate utilization rate.

$$\left(\frac{ds}{dt}\right)_g = \frac{U_{max} \cdot X \cdot \frac{FS_i}{XV}}{K_B + \frac{FS_i}{XV}}$$

where $\left(\frac{ds}{dt}\right)_g$ = Mass rate of change in substrate due to growth

U_{max} = Maximum substrate utilization rate

K_B = Substrate loading at which the rate of substrate utilization is one half the maximum rate

F = Flow rate of substrate into reactor

S_i = Initial substrate concentration

X = MLVSS in the reactor

V = Volume of reactor

This relationship assumes that substrate utilization is a function of the mass loading per mass of micro-organisms rather than the substrate concentration alone. The term $\frac{FS_i}{XV}$ is the F:M ratio.

The biokinetic coefficient K_B and U_{max} were obtained by linearizing the above equation

$$\frac{1}{1/X\left(\frac{ds}{dt}\right)} = \frac{K_B}{U_{max}} \frac{1}{\frac{FS_i}{XV}} + \frac{1}{U_{max}}$$

and plotting $1/(1/X)(ds/dt)$ vs. $1/FS_i/XV$. The Y-axis intercept is equal to the $1/U_{max}$ value and the slope of the line is equal to K_B/U_{max}. Linear regression was used to determine the slope and intercept of the line.

The reciprocal of the sludge retention time was plotted against the substrate utilization rate for each loading rate and an attempt was made to determine the true yields (Y_t) and the decay coefficients from the slope of the curve and the intercept on the Y-axis respectively.

CHAPTER IV

RESULTS AND DISCUSSIONS

The synthetic feed was relatively simple to make-up for the lower F:M loading, but increased in difficulty as the concentration of the feed was increased. At the F:M loading of 0.5, no pH adjustment was required after the feed was made up, but at F:M loadings of 1.0 and above, pH adjustments were necessary.

Operational Aspects

At an F:M loading of 0.5, the system was quite stable and produced treatment efficiencies consistently above 99.5 percent. The system required only minimal daily care when compared to the higher loadings. The sludge flocculated quite well and settling in the clarifier was very good, thereby producing a very clear effluent. The golden-brown colored sludge also compacted well in the clarifier and enabled a good recycle sludge concentration. The pH throughout the system--usually about 7.4--remained relatively stable at this loading.

When the feed flow rate was increased slowly to attain an F:M ratio of 1.0, the first change that was noticed in the system, was a tremendous increase in the mixed liquor solids. The system seemed to be trying to prevent a higher loading than it was used to. Following this, the pH in the mixed liquor dropped, just as fast as the solids increased, to around 6.0. The very fast growth caused dispersed solids

which did not flocculate well and therefore did not settle well in the clarifier. The result was an increase in the suspended solids in the effluent. The increased solids in the reactor caused the F:M loading to remain at 0.5. The recycle ratio was reduced from 0.3 to 0.1 and after a lag time of about one day, the mixed liquor suspended solids seemed to reduce to the required 1800 mg/ℓ (to maintain an F:M of 1.0). The sludge wasting from the clarifier had to be increased to prevent solids build-up in the clarifier. The effuent suspended solids concentration increased to a level four times higher than the effluent solids at a loading of 0.5, and the underflow suspended solids concentration reduced to where it was close to the mixed liquor suspended solids concentration. This in turn caused a reduction in the mixed liquor suspended solids and nothing much could be done to correct it due to the amount of solids wash-out from the system. About one week after the flow rate was increased, the pH in the reactor dropped to about 5.85 for no apparent reason. A predominance change seemed to have occurred in the aeration chamber during the night when the unit was not monitored. The mixed liquor had changed in color to a lighter brown than the original darker color. The sludge, although not slimy to the feel, had formed a film on the inside of the aeration chamber and along all the tubing. When scraped off with a spatula, it came off in sheets. Even the clarifier had a thin film attached to the sides. The clarifier could not handle the dispersed and non-flocculating solids and the effluent suspended solids increased. When a sample of mixed liquor was taken and filtered through a glass fiber filter, the filtrate was clear but had a straw colored tint to it. This color change in the filtrate was also noticed on the day before the visual predominance change. Moreover, the sample

took a considerably longer time to filter, probably due to dispersed solids. The coloring in the filtrate was probably due to some metabolic byproducts excreted by the micro-organisms.

By the next day, the mixed liquor became a much darker color than the original golden brown color that existed throughout the F:M loading of 0.5. The settling characteristics improved tremendously and the effluent suspended solids concentration reduced, but the filtered sample of the clarified effluent was nearly black in color. The dissolved oxygen and the pH were immediately checked throughout the system and found to be above 3.2 mg/ℓ and around 7.3 respectively. This ruled out the first impression of possible anaerobic activity in the effluent bottle causing the color.

Soon after the predominance change occurred, the mixed liquor suspended solids concentration began to fluctuate. Microscopic analysis of a sample of sludge showed a total absence of higher forms of life (protozoa etc.). Moreover, there also seemed to be a total absence of any filamentous type organisms. Tiny but very active micro-organisms were the only life-forms noticed. Since the recycle alone could not cope with the fluctuations in the mixed liquor suspended solids, it was decided to control the mixed liquor suspended solids concentration by wasting directly from the aeration chamber, and immediately replacing the volume of mixed liquor wasted, with filtered effluent. This allowed a much better control of the mixed liquor suspended solids concentration.

Since by this time, the system was totally upset, fresh sludge was used from a municipal treatment plant to re-seed the system. The system was now run at an F:M loading of 1.0 by increasing the feed

concentration and maintaining the same feed flow rate of 10ℓ/day that was used at an F:M loading of 0.5. But now, the higher concentration of glutamic acid in the feed make-up probably exceeded the buffering capacity of the tap water and caused a drop in the pH. The pH was adjusted to 7.0 with sodium hydroxide solution after the feed was made-up. This adjustment of the pH did help a little although very often, the pH in the mixed liquor did drop below 7.0 after about 18 hours. When the feed pH was adjusted to 7.5, the mixed liquor pH tended to remain around 7.0.

At the F:M loading of 1.0, the sludge looked very filamentous and a microscopic examination of the sludge confirmed this. The dissolved oxygen level in the aeration chamber was maintained around 4.5 mg/ℓ but the filaments still prevailed. Apart from the reduction in the settling efficiency, the filamentous sludge in the mixed liquor tended to collect on the lip of the overflow from the aeration chamber. During the day, this was prevented to a certain extent by regularly scraping the solids off and washing them down into the clarifier. But during the night, the solids collected on the lip and did not pass into the clarifier. Therefore, although the recycle rate was maintained during the night, the concentration of recycle solids reduced tremendously. There were times when the recycle solids concentration was very close to the mixed liquor suspended solids concentration. This caused a problem in trying to set the recycle ratio by calculation. From trial and error, it was found that a recycle ratio of 0.3 maintained a reasonable sludge blanket level in the clarifier. From this observation, it was decided to maintain the recycle ratio at 0.3 of the flow throughout the experiment. The average removal efficiency at an F:M loading of 1.0 was 96.9 percent.

The F:M loading was then increased to 2.0. The flow rate was kept constant, thereby maintaining the same hydraulic detention time, but the feed concentration was increased. The pH of the feed had to be adjusted with even larger volumes of sodium hydroxide solution. Again, the pH of the feed and the mixed liquor were monitored and it was noticed that the pH in both the feed and the mixed liquor had dropped drastically. The pH in the feed bottle dropped from the adjusted level of 7.5 to around 6.5 while the pH of the mixed liquor dropped to levels below 6.0. Therefore, the pH of the feed was adjusted to 8.0 but this did not seem to be able to cope as the pH in the mixed liquor did not improve. Moreover, adjustment of the pH to levels of 8.0 and above, caused some precipitation of the salts in the feed and also released the ammonium salt as free ammonia gas into the atmosphere. It was then decided to add a buffer to the feed to control the pH. In spite of the addition of 20 mls. of phosphate buffer to each liter of feed made up, the pH in the mixed liquor had a tendency to drop to levels between 6.5 and 7.0.

At the F:M loading of 2.0, the mixed liquor slowly changed color to become a greenish-yellow color. A filtered sample showed the same coloring in the filtrate whereas the residue on the filter paper was beige in color. This coloring of the sludge remained throughout the run at the F:M loading of 2.0. It was also noticed that this coloring in the mixed liquor was pH sensitive. If the pH of a filtered sample was slowly reduced with acid, the greenish-yellow color would clear up and only a clear, colorless liquid remained at pH levels below 6.5. On the other hand, if the pH of the filtrate was increased with sodium hydroxide, the greenish-yellow color returned at a pH of about 7.5 and

continued to become darker and more greenish in color with any further increase in the pH.

When the feed was made-up, it was always cloudy in contrast to the clear feed make-up at the lower concentrations. It was noticed that the feed was clear if the pH was left at 4.5 after make-up. When the sodium hydroxide was added to adjust the pH to 7.0 before adding the buffer, the feed became cloudy. The salts were being pushed out of the solution. Also, due to the higher concentration, ionic exchange was probably taking place in the solution and when insoluble compounds form, they immediately precipitate. This problem became more severe at an F:M loading of 3.0.

At an F:M loading of 3.0, the major problem encountered was with the pH control. The pH of the feed would reduce to around 5.2 in the feed bottle and in the aeration chamber over a period of 24 hours in spite of the phosphate buffer addition (30 mls per liter of feed). No more buffer could be added due to fear of toxicity resulting from the high potassium concentration in the buffer. This type of pH drawdown has been noticed in fixed bed reactors too. Deen (20) reported that in the fixed bed reactor, pH drawdown was practically all in the first foot of reactor depth and that thereafter, the pH tended to rise towards its original nozzle value. He also found that the pH recovery is greater for lower organic laodings and therefore, as the organic loadings became heavier, the tendency for the pH to recover becomes less and less, until theoretically, at some total organic loading, the pH in each foot of the fixed bed reactor is the same, Apparently, this applies to the activated sludge also but at much lower F:M loading rates than that noticed by Deen in the fixed bed reactors. The lack of pH recovery at higher

loadings in the A.S. system could be due to the fact that the F:M loading does not reduce with time whereas in the tower, the organic load reduces with increase in depth.

Foaming in the aeration chamber became a problem. At times, the white foam would prevent the mixed liquor suspended solids from leaving the aeration chamber, thereby causing a build-up of suspended solids in the aeration chamber, and a detrimental effect on the solids concentration in the clarifier. Foam would also build-up and flow over the lip of the aeration chamber and into the clarifier. When this happended, it would cause rising of the solids in the clarifier due to the fine bubbles of foam.

At the F:M loading of 0.5, settling characteristics of the sludge was very good, but as the loading was increased, the effluent solids increased and due to the dispersed growth, even a filtered sample was very cloudy. Cashion, et al. (10) has found that suspended solids that pass over the weirs of secondary clarifiers vary in direct proportion to the organic loading to the aeration basin. Although in this study too, an increase in loading had generally produced an increased effluent suspended solids concentration, no definite relationship was found.

The mixed liquor suspended solids did not fluctuate very much at the lower loadings but fluctuation amplitude increased with increase in the total organic loading. The increase in mixed liquor suspended solids concentration over a 24-hour period was very unpredictable at the higher F:M loadings. Some days, the solids concentration would double over a 24-hour period and on other days, the increase was not half as much. When the mixed liquor solids concentration increased a lot, large volumes of the reactor were wasted but when the following 24 hours

produced very little increase in the mixed liquor suspended solids, nothing was wasted. This caused fluctuations in the average mixed liquor suspended solids concentration especially at the higher loadings. Sludge draping over the lip of the reactor also contributed to these large fluctuations. When the sludge was scraped off the lip of the aeration chamber, it came off in chunks. This settled very well in the clarifier and was immediately recycled. Therefore, the solids in the reactor would increase.

Performance of Reactor

The plots of θ_c against time (Figures 2 through 5) generally show very low sludge retention times with sudden increases and decreases over very short time intervals, in spite of the relatively stable F:M ratios. This was very surprising as it was assumed that low F:M loadings would produce high sludge retention times and vice-versa, but no definite relationship could be found between the sludge retention time and the F:M ratio. Throughout the study, the θ_c tended to stay around one day. This low θ_c was probably the only way that the system could produce a sufficiently high yield to cope with the high F:M ratio imposed on it.

Figures 2 through 5 show the main parameters monitored over the duration of each loading rate studied. At an F:M loading of 0.5 the parameter that was directly controlled was the influent BOD concentration (S_i). At the other loading rates, both the influent BOD concentration and the mixed liquor suspended solids were directly controlled. At the loading rate of 0.5, the mixed liquor suspended solids concentration was controlled by the recycle rate. As mentioned before,

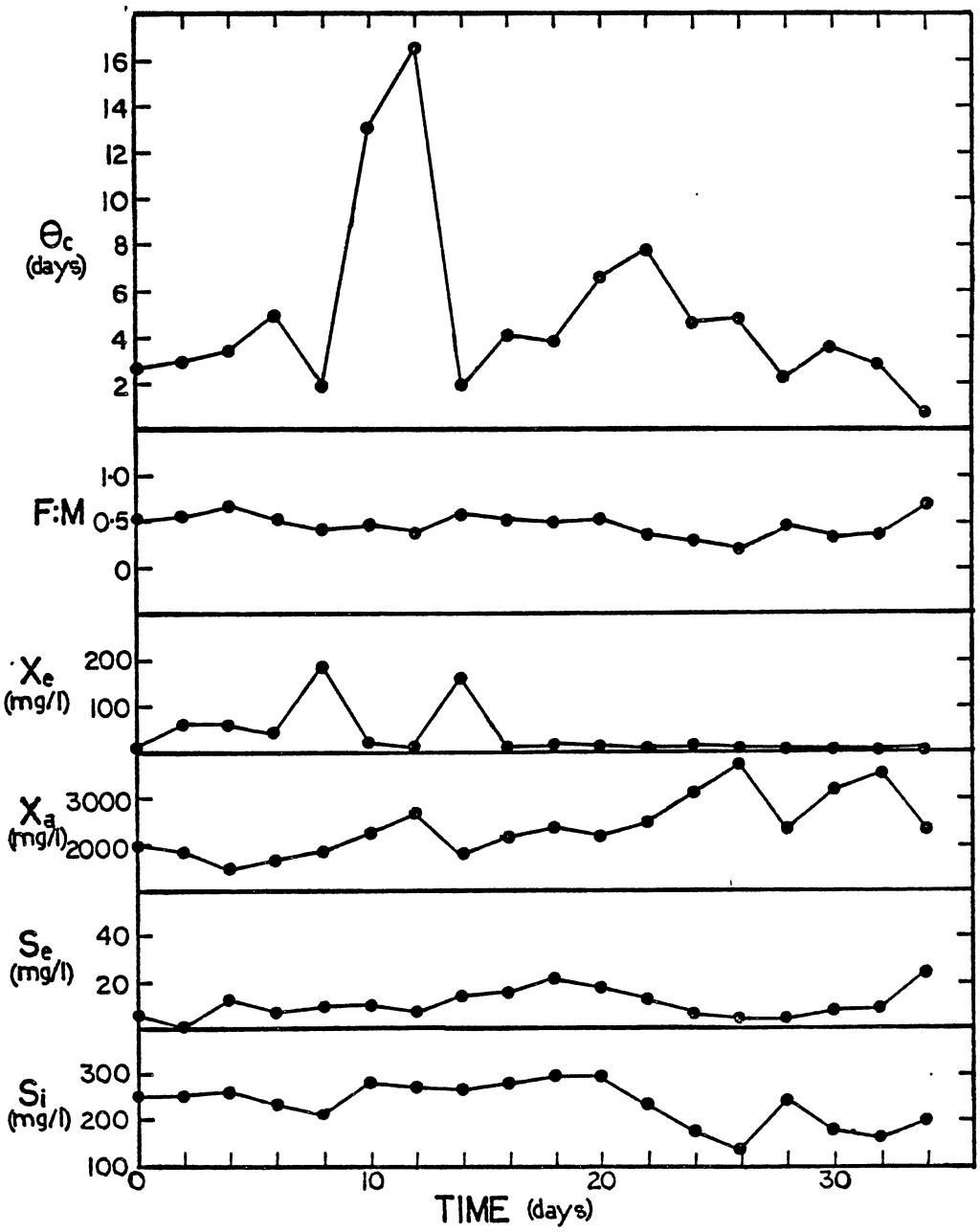

Figure 2. Some Parameters Monitored with Time at F:M Loading Ratio of 0.5

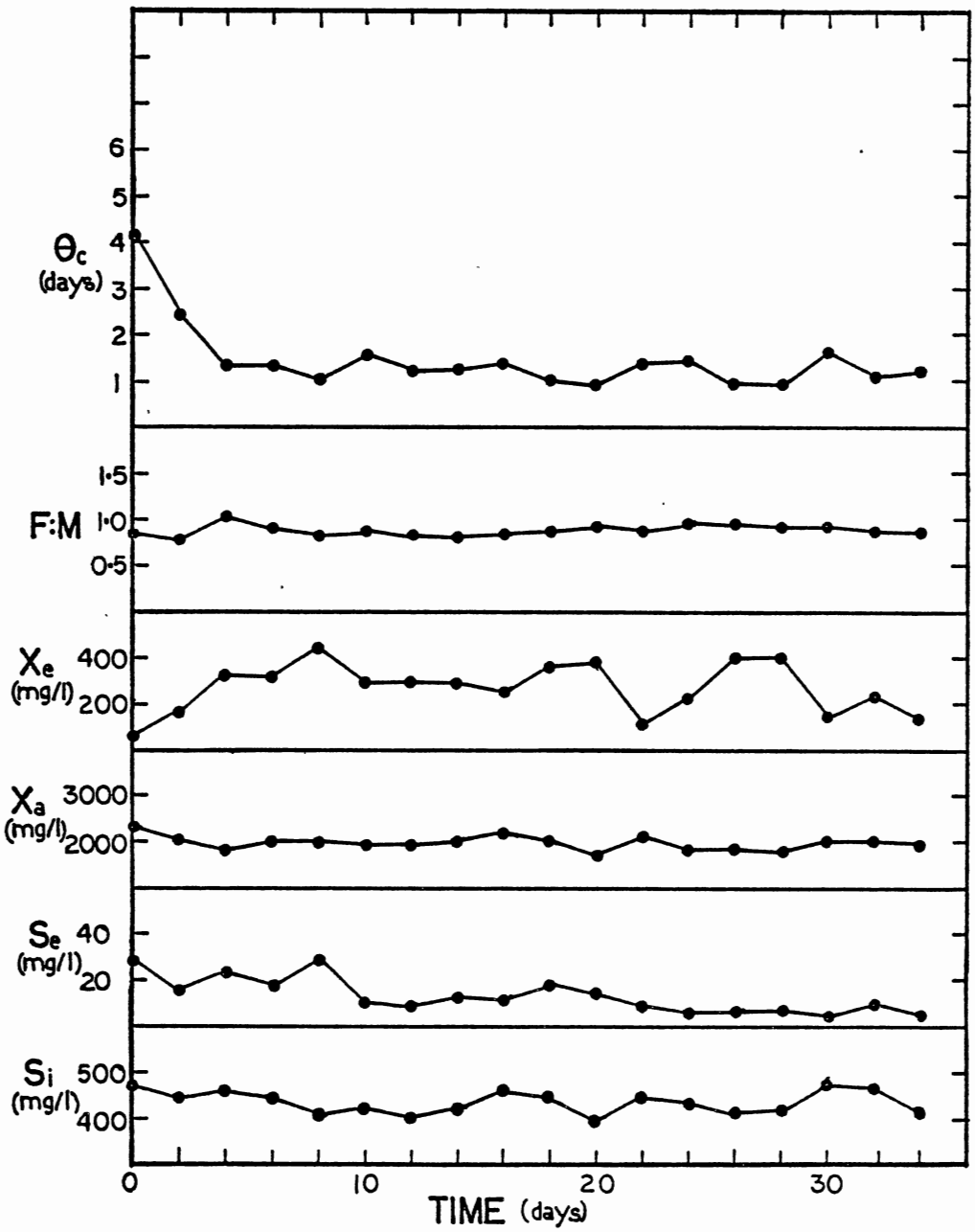

Figure 3. Some Parameters Monitored with Time at F:M Loading Ratio of 1.0

this could not be done for the higher loadings so a more direct method was employed.

In Figure 2, in spite of the slight variation in the influent soluble BOD concentrations, the effluent soluble BOD concentration was consistently below 20 mg/ℓ with a major part of the run producing effluent soluble BODs of 15 mg/ℓ or less. For the first 20 days of the run, the mixed liquor volatile suspended solids (MLVSS) was maintained relatively stable. From the 22nd day to the 26th day, the MLVSS kept increasing. This increase followed after the settling characteristics in the clarifier improved tremendously as can be seen from the low effluent volatile suspended solids concentration levels. At this point, further reduction of the recycle flow rate did not help to reduce the MLVSS concentration since the sludge compaction in the clarifier increased with reduction in the recycle flow rate. From the 26th day onward, the MLVSS was not as stable as the initial part of the run. From Table II, it can be seen that the fluctuations seemed to occur immediately after the flow rate was increased to compensate the reduction in the BOD concentration of the influent. This increase in the flow rate also contributed indirectly to the increase in the MLVSS as the recycle rate was a fraction (α) of the flow rate. Since this fraction (α) was not reduced much, the actual recycle flow increased. Despite these fluctuations, the main parameter, the F:M ratio, did not vary much. Throughout the run, the F:M ratio was maintained stable.

At an F:M loading of 1.0 (Figure 3) more control was exerted on the MLVSS concentration. Figure 3 shows a far more stable MLVSS. The influent substrate concentration was also maintained relatively stable and so was the flow (Table III). This in turn produced much smaller

fluctuations in the F:M loading rate in the aeration chamber. At this loading rate, the effluent soluble BOD and the effluent volatile suspended solids varied considerably, although during the final week of the run at this loading rate, the effluent soluble BODs were consistently below 10 mg/ℓ.

Figures 4 and 5 relate to the performance of the system at F:M loading ratios of 2.0 and 3.0 respectively. In Figure 4, even though the MLVSS and the F:M ratio was maintained relatively stable, the variatons in the performance of the system was considerable. The effluent soluble BODs seldom went below 100 mg/ℓ and the effluent volatile suspended solids concentrations were consistently above 100 mg/ℓ with maximum values above 450 mg/ℓ. The first 10 days produced high effluent solids concentrations and lower effluent BODs. Similarly, the higher effluent BODs correspond to lower effluent suspended solids during the final week of the run. This observation, when related to dissolved oxygen levels above 2.0 mg/ℓ in the effluent, might lead to hasty deductions of biodegradation occurring in the clarified effluent collection bottle. This could be a possibility, but by no means do the results obtained from this study affirm or contradict this possibility.

In Figure 5, the variations in the parameters plotted against time is substantial. The variations in the raw wastewater BODs were either due to variations in the volume of stock solutions added to the feed make-up or due to growth in the feed sample. Due to the very high concentration of the stock solution, even a minute error in measurement either in making up the feed or in the running of the BOD test could result in large fluctuations in the results. Secondly, even though the sample of feed was stored in the refrigerator for no more than 24 hours

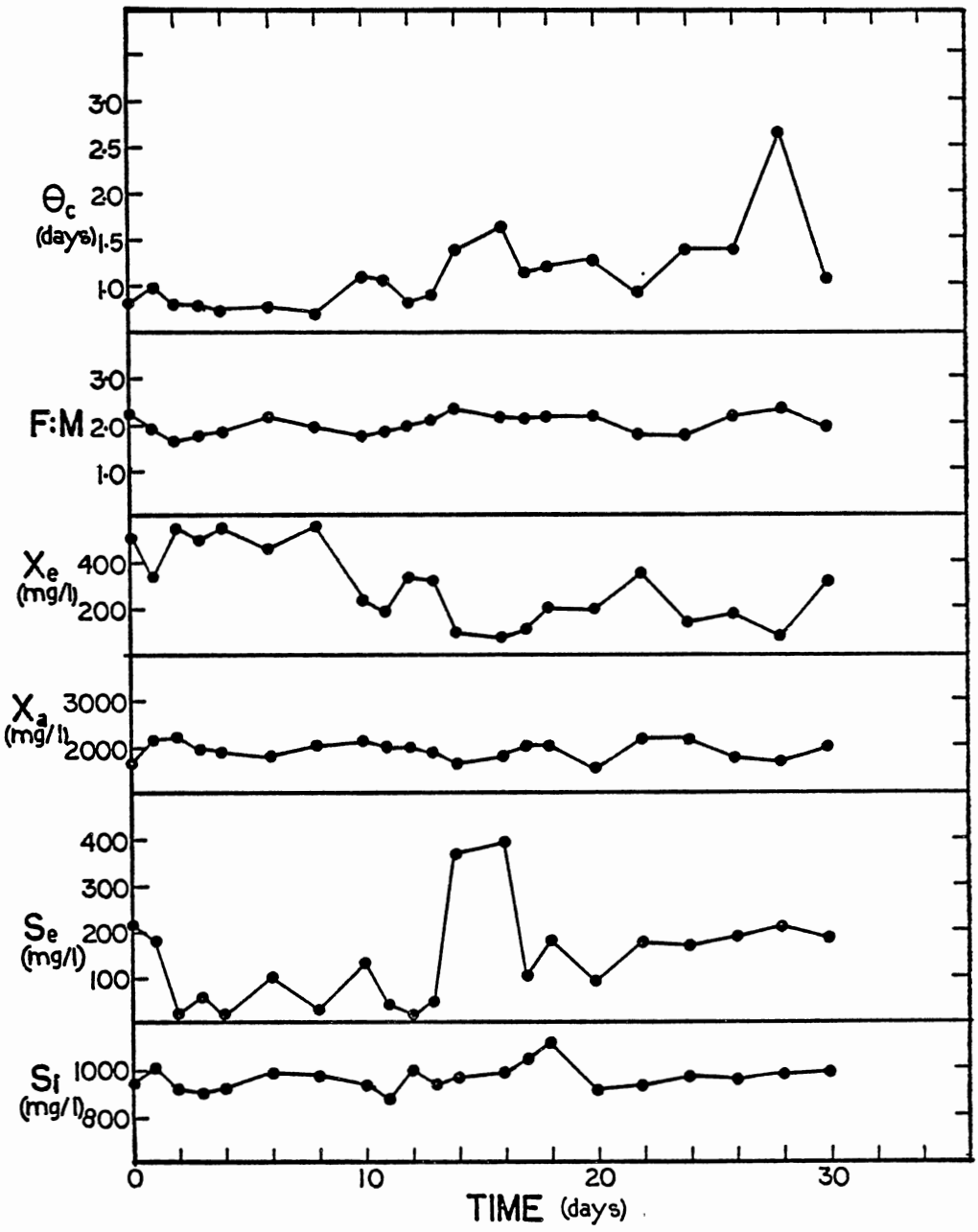

Figure 4. Some Parameters Monitored with Time at F:M Loading Ratio of 2.0

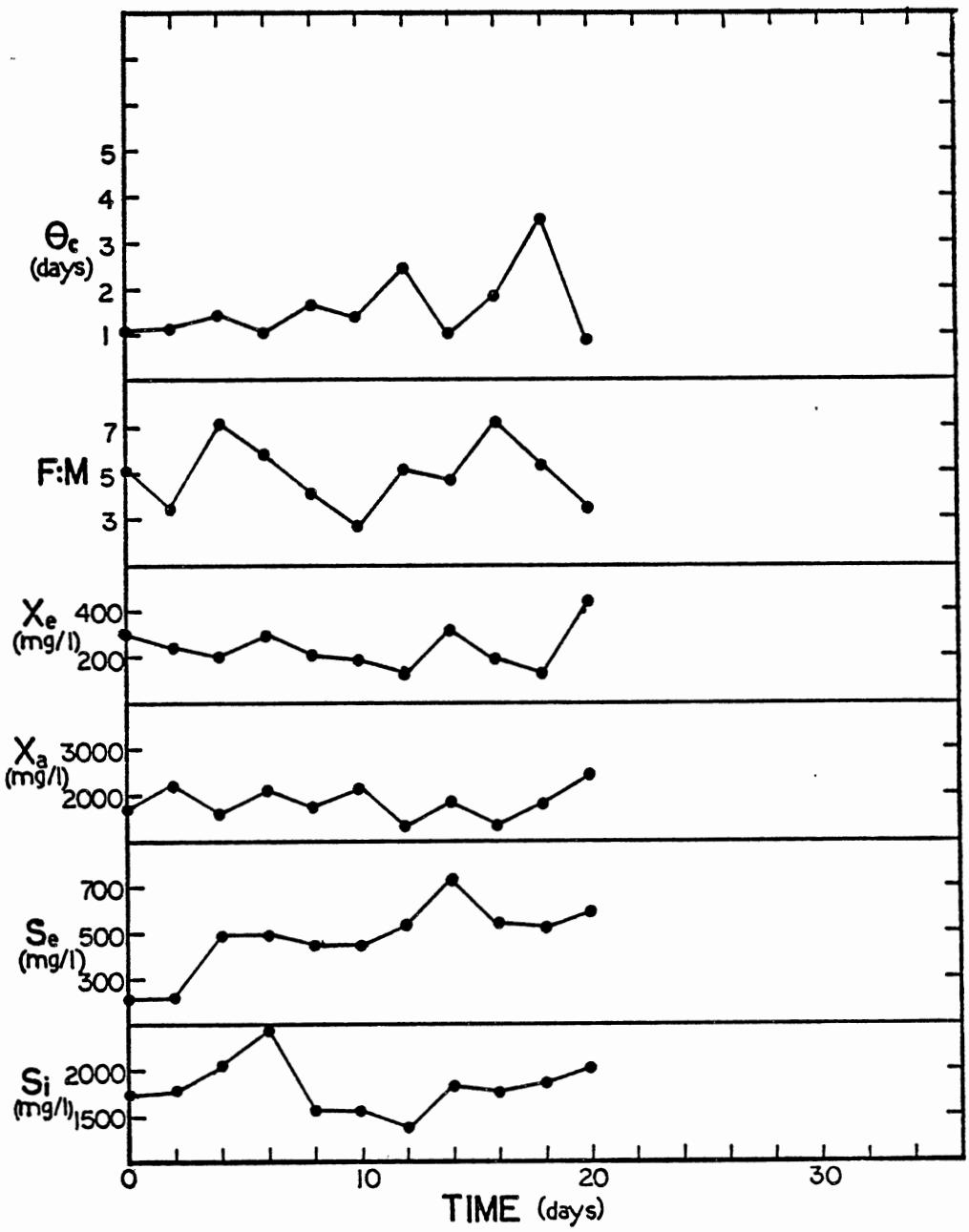

Figure 5. Some Parameters Monitored with Time at F:M Loading Ratio of 3.0

prior to the BOD test being done, errors could result. The effluent BODs seemed to be on a generally increasing trend until the system was shut down. The MLVSS zig-zagged through the run. This was probably due to the irregular growth and acummulation of solids in the reactor as mentioned earlier on in this chapter. The effluent volatile suspended solids also varied between 150 mg/ℓ and 300 mg/ℓ most of the time. Due to the combination of the influent BOD and the MLVSS fluctuations, the F:M ratio was not maintained very stable. This probably contributed to the generally increasing trend in the effluent BODs.

Evaluation of Kinetic Models

During the analysis of the data to determine the biokinetic coefficients, it was noticed that most of the existing kinetic models returned the "shotgun-blast" type of plots with very low correlation coefficients. The only model that did handle the data relatively well was the Kincannon and Stover model. A plot of U, the specific substrate utilization rate against S_e, the effluent substrate concentration to determine the Eckenfelder's "K_e" is shown in Figure 6. From this plot, Eckenfelder's "K_e" could not be accurately determined. This had to happen since the specific substrate utilization rate for a particular substrate cannot increase indefinitely. It has to bend over and tend to level off at some point. Figure 7 shows the plot of the product of the influent BOD and the specific substrate utilization rate against the effluent BOD. The scatter of the points is even more obvious here for the higher loading rates. From this plot, the Eckenfelder's modified kinetic coefficients could not be determined either. Figure 8 shows the reciprocal of the specific substrate utilization rate plotted against

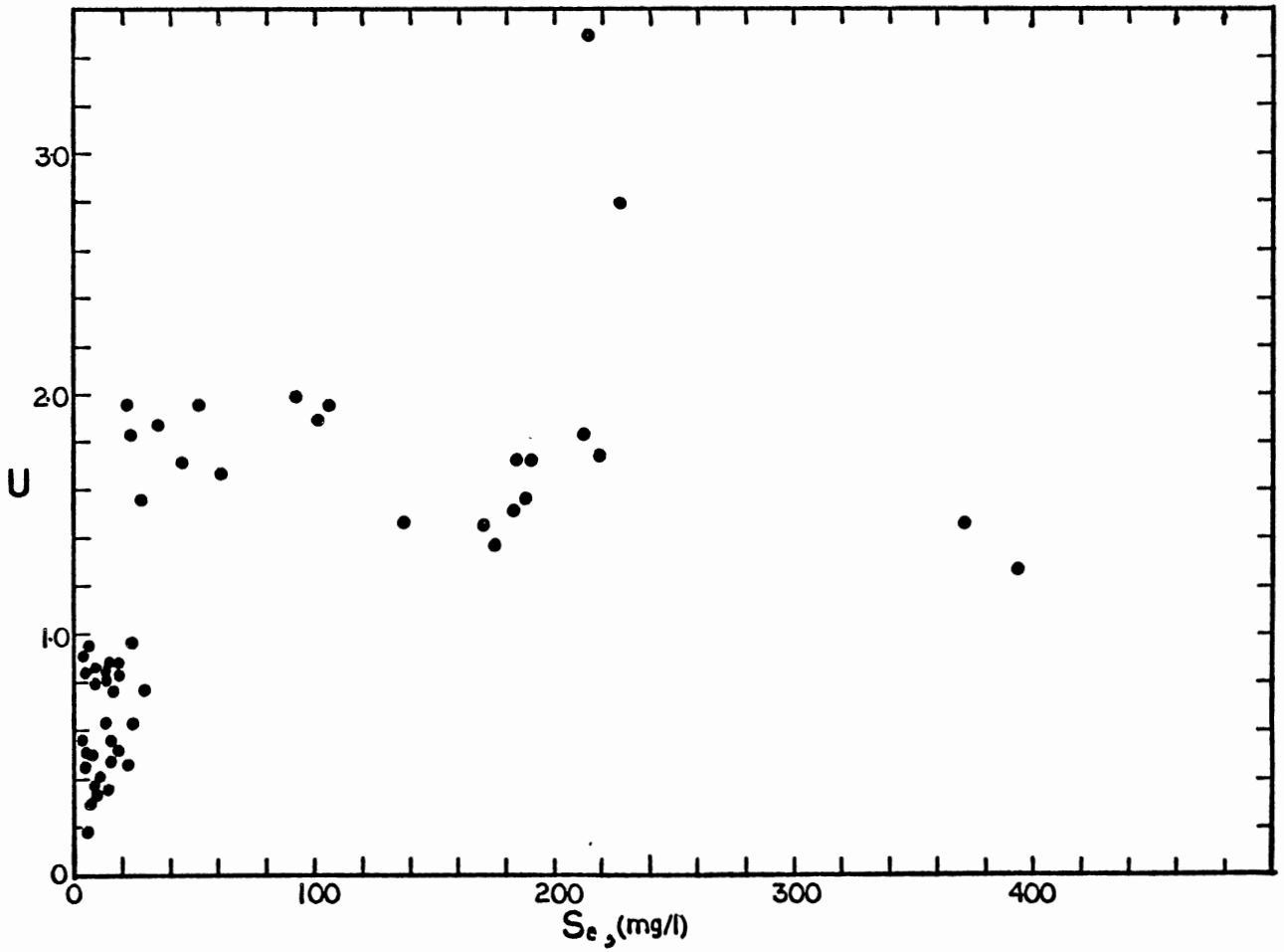

Figure 6. Specific Substrate Utilization Rate vs. Effluent Substrate Concentration

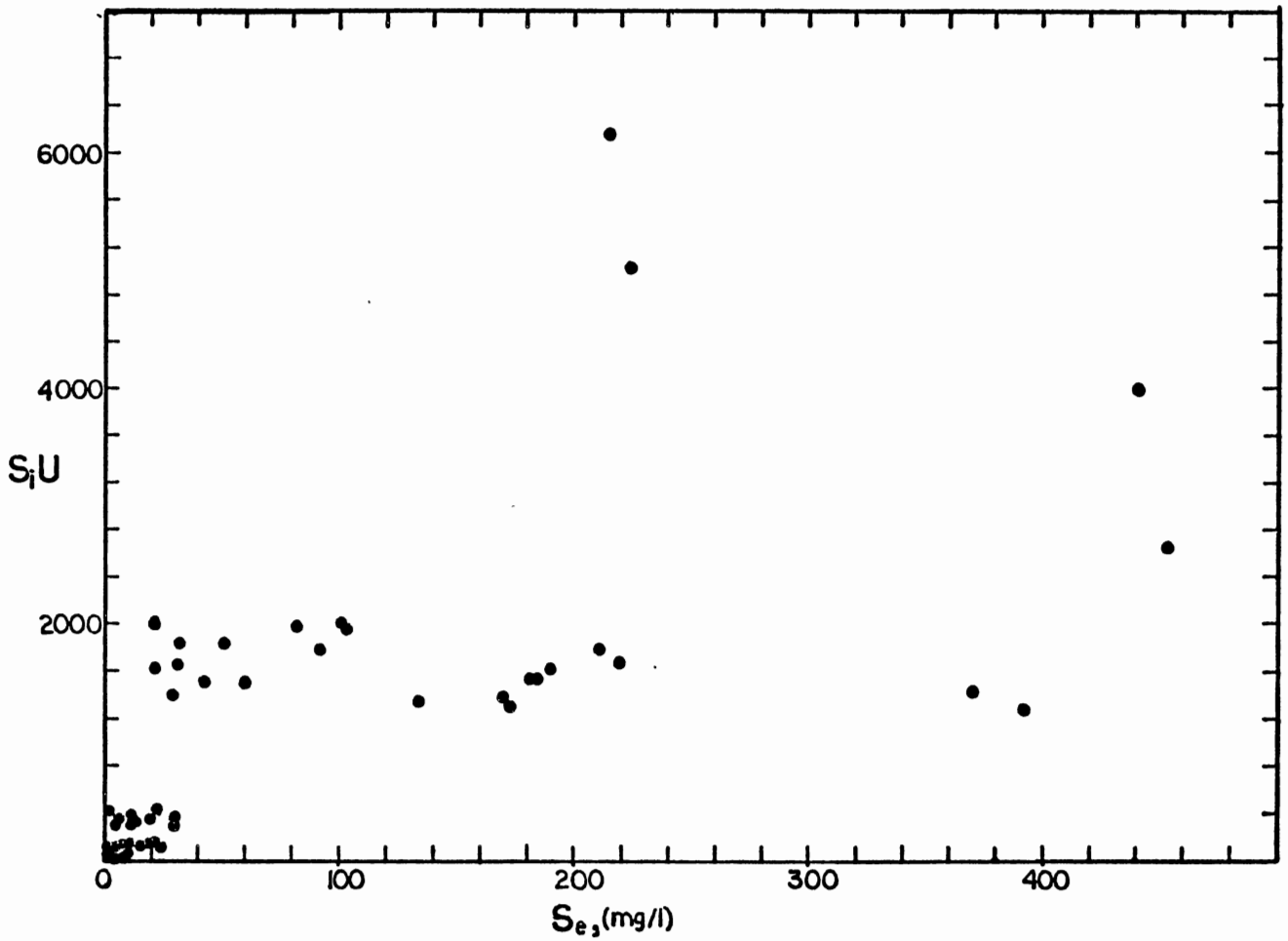

Figure 7. Product of Influent Substrate and Specific Utilization Rate vs. Effluent Substrate Concentration

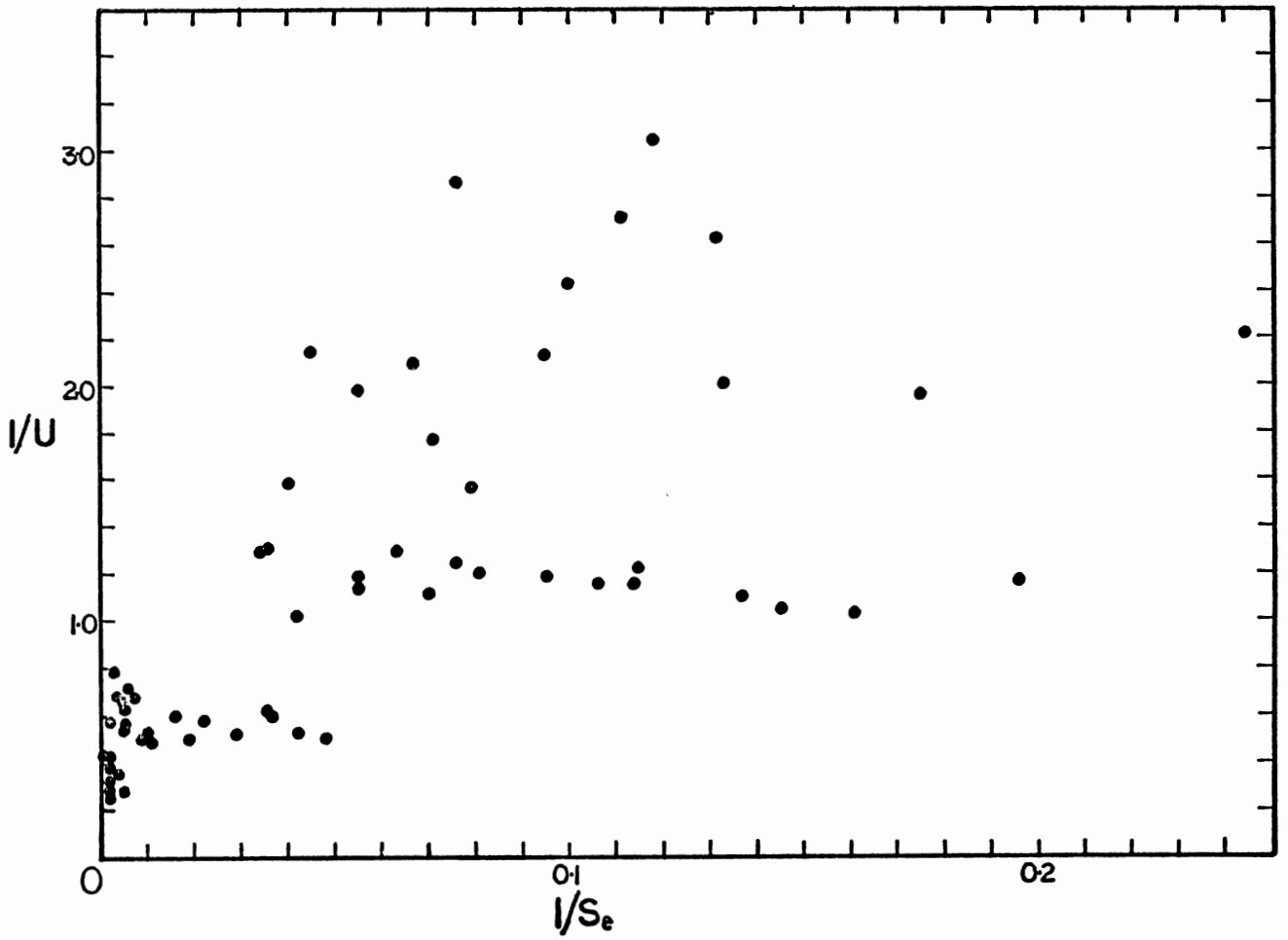

Figure 8. Reciprocal Specific Substrate Utilization Rate vs. Reciprocal Effluent Substrate Concentration

the reciprocal of the effluent BOD. This plot is normally used to determine the kinetic coefficients for the Lawrence and McCarty's model. However, here again the specific substrate utilization is related to the effluent substrate and therefore poses the same problem in the accurate determination of the kinetic coefficients as was found with the Eckenfelder's models.

In contrast to this, Kincannon and Stover relate the specific substrate utilization rate to the F:M ratio and get far less scatter of data. Figure 9 shows the relationship of the specific substrate utilization to the F:M ratio for the particular feed used for this study. As the F:M ratio was increased, the substrate utilization increased following a monomolecular type relation at first and then started to bend over. The substrate used in this study was easily metabolized and therefore the bending over was not as much as might be obtained for some other wastewater that contained very complex organic compounds. If a particular wastewater contained matter that was toxic to micro-organisms, the graph would have probably leveled off and then begun to drop, showing that any further increase in the F:M ratio would cause a reduction in the substrate utilization. The bending over of the graph could also be due to oxygen transfer limitations. Even though the dissolved oxygen in the mixed liquor is sufficiently high, the transfer of oxygen into the mass of micro-organisms may be inefficient due to clumping of the solids at higher F:M ratios. Ganezarzyk (23) and Washington et al. (24) concluded that the bending over of the graph is due to inhibiting effects of inert and slowly degradable materials including the metabolic byproducts accumulating in the mixed liquor. Dohanyos et al. (25) found that the initial substrate removal in an

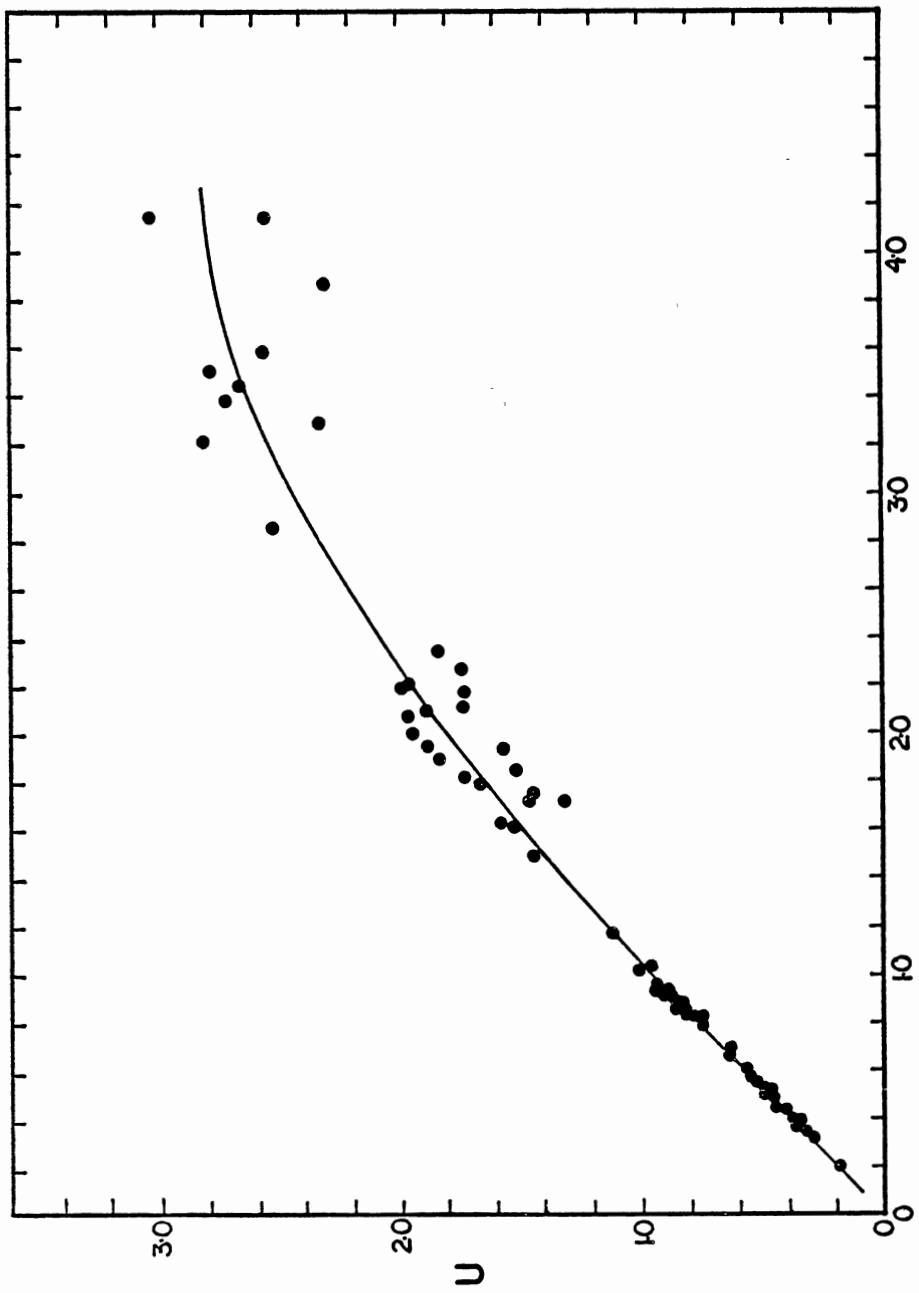

Figure 9. Specific Substrate Utilization Rate vs. F:M Loading Ratio

activated sludge system depended not on the storage capacity of the cells but rather, on what they term as the "accumulation capacity" of the cell. They used glucose as the substrate, balanced with nutrients required by the cells, and controlled the sludge age at 10 days. The F:M loading turned out to be 2.9. Although the storage capacity of the cells in their study did not reach a maximum, the glucose removal rate reduced. They imply that the drop in removal rate is due to saturation of the "accumulation capacity" of the cells. This, if true, could also have contributed to the bending over of the graph in Figure 6.

Using the Kincannon and Stover model, the data could be analyzed with very good correlation. Figure 10 shows the Kincannon and Stover plot of the reciprocal of the substrate utilization rate against the reciprocal of the F:M ratio. The correlation coefficient was found to be 0.998, which was far better than the correlation coefficient obtained from any of the other kinetic models. The Kincannon and Stover design model is the only model that expresses substrate utilization as a function of mass loading; all the other design models express substrate utilization as a function of substrate concentration in the reactor. Using the Kincannon and Stover model, the biokinetic coefficients, U_{max} and K_B can be determined. U_{max} is defined as the maximum specific utilization rate and K_B is the substrate loading at which the rate of substrate utilization is half the maximum rate. The Y-axis intercept in Figure 10 is the reciprocal of U_{max} and the slope of the line is equal to K_B/U_{max}. In this study, U_{max} and K_B were found to be 17.3 and 17.5 respectively with a correlation coefficient of 0.998. Studies done with alcohol production wastewater by Stover and Gomathinayagam (27) have

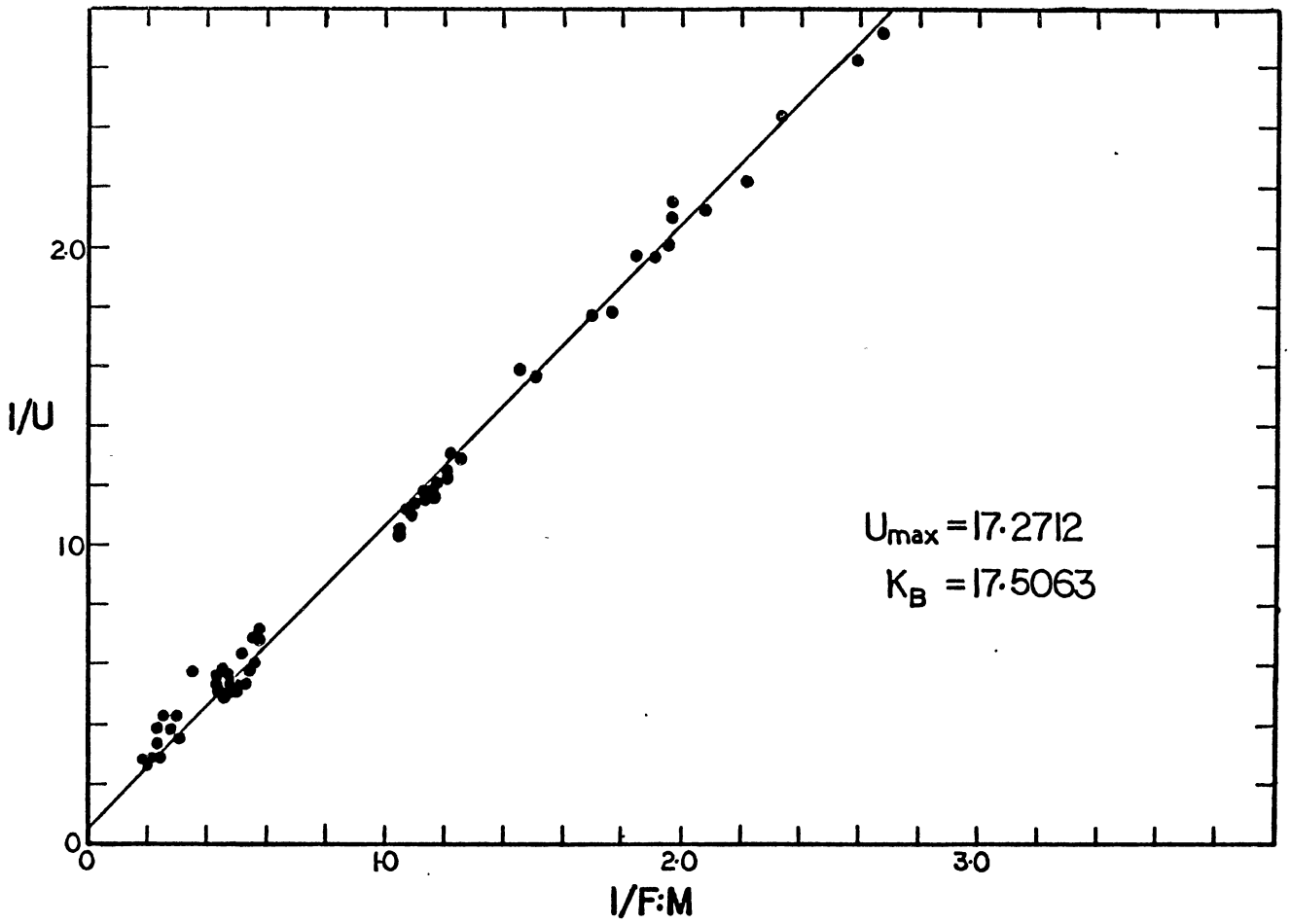

Figure 10. Reciprocal Specific Substrate Utilization Rate vs. Reciprocal F:M Loading Ratio

produced U_{max} and K_B values of 16.7 and 16.7 respectively. These, and other studies at the Bioenvironmental Laboratories, Oklahoma State University, seem to encourage the belief that easily biodegradable, non-inhibitory wastewaters have K_B and U_{max} values in the ranges mentioned above. The presence of heavy metals or other toxic substances in a wastewater being treated tend to induce much lower K_B and U_{max} values.

The common procedure to determine the true yield (Y_t) and the decay coefficient (K_d) is to plot the reciprocal of the sludge retention time against the specific substrate utilization rate (U). The slope of the straight line obtained is the yield while the intercept on the Y-axis is the decay coefficient. Kincannon et al. (23,24) have shown that variability occurs in the biological response to the wastewater being treated. They have found that when the sludge retention time was kept constant, the specific substrate utilization rate (U) varied considerably. In this study, the F:M ratio was held quite constant and the sludge retention time was found to vary. Figure 11 shows a plot of the data obtained from this study. It can be seen from the plot that the true yield and the decay coefficient cannot be satisfactorily determined. If results obtained by Dohanyos et al. (25) are any indication of what happens in a heavily loaded activated sludge system, then, it is a possibility that this phenomenon (Figure 11) occurred due to a lack of growth during the "accumulation" period followed by very high growth rates. This would be consistent with the resulting fluctuations in the sludge retention time at each loading rate (Figures 2 through 5). However, when the true yield and the decay coefficient were determined from the plot in Figure 11 using the data obtained at the lower F:M loading ratios of 0.5 and 1.0, the true yield and the decay coefficient were

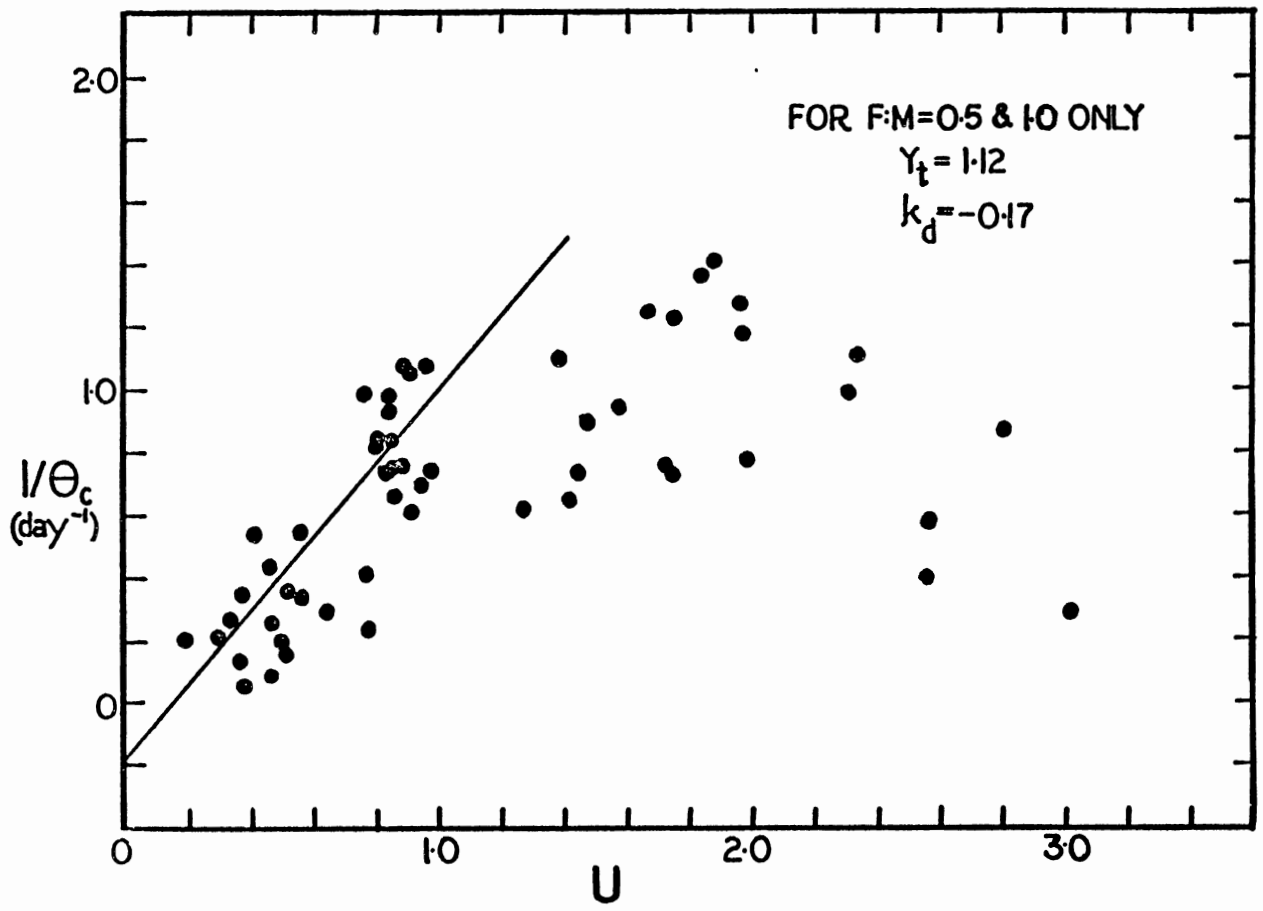

Figure 11. Reciprocal Sludge Retention Time (θ_c) vs. Specific Substrate Utilization Rate

found to be 1.12 and 0.17 respectively, with a correlation coefficient of 0.74. Although a lot of problems were encountered as the F:M ratio was increased to 3.0, it can be seen from the Kincannon and Stover plot in Figure 10 that the kinetics at the lower and higher loadings are about the same. These observations coupled with the whitish color of the mixed liquor suspended solids at the higher loadings could mean that at these high loadings, the sytem was encouraging the growth of micro-aerophilic organisms like the Beggiatoa. A whitish growth is very common on heavily loaded fixed bed reactors like the rotating biological contractor and has been suspected to be Beggiatoa. This organism seems to become visually apparent as a whitish growth on the discs of the rotating biological contractor when oxygen limiting conditions were suspected on the growth media in spite of satisfactory dissolved oxygen levels in the liquid portion. Therefore in this study, the possibility of Beggiatoa in the system, contributing to the difficulty in determining the true yield and decay coefficient for loadings above F:M ratios of 1.0, cannot be completely ruled out.

Since the Gaudy's model relates the mass rate of substrate utilization to the growth of the biomass and the biomass characteristic constants, this model could not be used to determine the kinetic coefficients.

CHAPTER V

CONCLUSIONS

From the experimental data and observations obtained through this study, the following conclusions may be drawn.

1. High F:M loading ratios on an activated sludge system tends to produce poorly settling sludge and low treatment efficiencies (measured as soluble BOD).

2. The true yield (Y_t) and the decay coefficient (K_d) could not be accurately determined by plotting the reciprocal of the sludge retention time against the specific substrate utilization rate.

3. The Kincannon and Stover model returned a very high correlation coefficient when the reciprocal of the specific substrate utilization rate was plotted against the reciprocal of the F:M ratio.

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APPENDIX

RAW DATA FOR EACH OF FOUR F:M LOADING RATIOS

TABLE II

RAW DATA FOR F:M LOADING RATIO OF 0.5 $\frac{(\text{lbs. BOD})}{(\text{lbs. MLVSS})\text{day}}$

S_i	S_e	X_A	X_e	X_R	F_w	F	t_d	U	F:M	1/U	1/F:M	θ_c	$1/\theta_c$	S_iU	$1/S_e$ $X10^{-2}$
258	5.7	1990	17	--	0.54	10.0	0.25	0.51	0.52	1.97	1.91	2.69	0.37	132	17.5
256	0.3	1830	61	--	0.30	10.0	0.25	0.56	0.57	1.79	1.77	2.92	0.34	143	333
263	12.6	1460	60	3690	0.20	9.22	0.27	0.64	0.66	1.57	1.51	3.41	0.29	168	7.9
233	7.5	1680	39	4030	0.17	9.22	0.27	0.50	0.51	2.01	1.96	4.91	0.20	117	13.3
216	10.0	1860	181	3330	0.29	9.22	0.27	0.41	0.43	2.44	2.34	1.89	0.53	89	10.0
285	10.5	2250	21	2930	0.19	9.50	0.26	0.47	0.48	2.13	2.08	13.15	0.08	134	9.5
270	7.6	2660	11	2970	0.22	9.50	0.26	0.38	0.39	2.63	2.59	16.48	0.06	103	13.2
267	14.1	1800	164	3090	0.36	9.94	0.25	0.56	0.59	1.78	1.70	1.83	0.55	150	7.1
277	15.0	2200	10	4170	0.45	10.0	0.25	0.48	0.51	2.10	1.97	4.24	0.24	133	6.7
298	22.1	2370	16	4000	0.41	10.0	0.25	0.47	0.51	2.15	1.97	3.97	0.25	140	4.5
297	18.1	2210	10	4260	0.32	10.0	0.25	0.51	0.54	1.98	1.85	6.58	0.15	151	5.5
238	13.2	2490	5	2610	0.20	10.0	0.25	0.36	0.39	2.77	2.59	7.89	0.13	86	7.6
173	6.8	3120	13	3330	0.56	14.11	0.18	0.30	0.31	3.38	3.20	4.73	0.21	52	14.7
135	4.8	3790	2	3030	0.67	14.11	0.18	0.19	0.20	5.24	4.97	4.89	0.20	26	20.8
243	4.1	2310	7	2410	1.55	10.70	0.23	0.45	0.45	2.22	2.22	2.33	0.43	109	24.4
176	8.5	3190	2	3510	1.23	15.26	0.16	0.33	0.34	3.05	2.97	3.66	0.27	58	11.8
166	9.0	3560	5	2880	1.50	20.02	0.12	0.37	0.37	2.72	2.68	2.89	0.35	61	11.1
199	24.7	2310	5	4070	3.60	20.02	0.12	0.63	0.69	1.59	1.45	0.75	1.33	125	4.0

TABLE III

RAW DATA FOR F:M LOADING RATIO OF 1.0 $\frac{(\text{lbs. BOD})}{(\text{lbs. MLVSS})\text{day}}$

S_i	S_e	X_A	X_e	X_R	F_w	F	t_d	U	F:M	1/U	1/F:M	θ_c	$1/\theta_c$	S_iU	$1/S_e$ $X10^{-2}$
475	29.7	2320	70	2770	0.31	10.0	0.25	0.77	0.82	1.30	1.22	4.15	0.24	366	3.4
445	16.0	2070	162	2180	0.32	9.20	0.27	0.77	0.79	1.30	1.26	2.47	0.41	343	6.3
465	24.0	1810	324	1660	0.05	10.0	0.25	0.97	1.03	1.03	0.79	1.36	0.74	451	4.2
443	18.1	2020	316	2200	0.31	10.37	0.24	0.88	0.91	1.14	1.10	1.33	0.75	390	5.5
410	28.6	2000	440	2080	0.31	10.0	0.25	0.76	0.82	1.31	1.22	1.02	0.98	312	3.5
420	9.4	1910	308	2050	0.0	10.0	0.25	0.86	0.88	1.16	1.14	1.55	0.65	361	10.6
404	8.7	1950	298	1970	0.63	10.0	0.25	0.81	0.83	1.23	1.21	1.21	0.83	327	11.5
420	13.2	2035	296	1560	0.65	10.0	0.25	0.80	0.83	1.25	1.21	1.24	0.81	336	7.6
460	12.3	2170	256	2170	0.70	10.0	0.25	0.83	0.85	1.21	1.18	1.39	0.72	382	8.1
441	18.2	2010	360	1340	0.80	10.0	0.25	0.84	0.88	1.19	1.14	1.02	0.98	370	5.5
397	14.3	1715	384	1920	0.59	10.0	0.25	0.89	0.93	1.12	1.08	0.93	1.08	353	7.0
449	8.8	2135	118	1890	1.37	10.23	0.24	0.86	0.86	1.16	1.16	1.34	0.75	386	11.4
433	6.2	1812	226	1730	0.59	10.0	0.25	0.94	0.96	1.04	1.05	1.42	0.70	407	16.1
413	6.9	1855	402	1940	0.50	10.65	0.23	0.95	0.95	1.05	1.05	0.93	1.08	392	14.5
419	7.3	1820	406	2470	0.55	10.0	0.25	0.90	0.92	1.11	1.09	0.94	1.06	377	13.7
475	3.8	2070	154	1730	0.80	10.0	0.25	0.91	0.92	1.10	1.09	1.68	0.60	432	26.3
464	10.4	2070	237	1400	1.35	9.79	0.26	0.84	0.88	1.19	1.14	1.08	0.93	390	9.6
413	5.1	1920	140	2500	1.45	10.0	0.25	0.85	0.86	1.18	1.16	1.21	0.83	351	19.6

TABLE IV

RAW DATA FOR F:M LOADING RATIO OF 2.0 $\frac{(\text{lbs. BOD})}{(\text{lbs. MLVSS})\text{day}}$

S_i	S_e	X_A	X_e	X_R	F_w	F	t_d	U	F:M	1/U	1/F:M	θ_c	$1/\theta_c$	S_iU	$1/S_e$ $X10^{-2}$
950	219	1675	520	2960	0.0	10.0	0.25	1.75	2.27	0.57	0.44	0.81	1.23	1663	0.5
1016	183	2195	350	1960	1.15	10.0	0.25	1.52	1.85	0.66	0.54	0.98	1.02	1544	0.5
921	28	2255	556	1990	0.8	10.0	0.25	1.58	1.63	0.63	0.61	0.81	1.24	1455	3.6
902	61	2020	506	1580	0.81	10.0	0.25	1.67	1.79	0.60	0.56	0.80	1.25	1506	1.6
923	24	1955	558	1390	0.81	10.0	0.25	1.84	1.89	0.54	0.53	0.73	1.37	1698	4.2
992	106	1805	472	1450	0.80	10.0	0.25	1.96	2.20	0.51	0.45	0.78	1.28	1944	0.9
986	34	2025	578	1930	0.90	10.0	0.25	1.88	1.95	0.53	0.51	0.71	1.41	1854	2.9
936	137	2180	236	2410	1.31	10.0	0.25	1.47	1.72	0.68	0.58	1.11	0.90	1376	0.7
872	46	1990	196	1570	1.50	10.37	0.24	1.73	1.82	0.58	0.55	1.05	0.95	1509	2.2
1023	21	2050	344	2640	1.63	10.0	0.25	1.96	2.0	0.51	0.50	0.82	1.22	2005	4.8
940	52	1880	322	1420	1.40	10.37	0.24	1.97	2.07	0.51	0.48	0.85	1.18	1852	1.9
973	371	1650	146	2040	1.00	10.0	0.25	1.46	2.36	0.69	0.42	1.39	0.72	1421	0.3
993	394	1815	72	930	1.20	9.79	0.26	1.27	2.19	0.79	0.46	1.62	0.62	1261	0.3
1062	102	2025	256	1790	1.05	10.0	0.25	1.90	2.10	0.53	0.48	1.15	0.87	2018	1.0
1123	184	2070	210	4270	1.33	9.79	0.26	1.74	2.12	0.57	0.47	1.14	0.88	1954	0.5
902	93	1565	202	2070	0.83	9.50	0.26	1.99	2.19	0.50	0.46	1.28	0.78	1795	1.1
937	175	2185	352	1340	1.34	10.0	0.25	1.39	1.72	0.72	0.58	0.91	1.10	1302	0.6
965	170	2195	140	1910	1.21	10.0	0.25	1.45	1.76	0.69	0.57	1.38	0.72	1399	0.6
943	190	1745	176	3730	0.96	10.0	0.25	1.73	2.16	0.58	0.46	1.34	0.75	1631	0.5
978	212	1665	76	2480	0.51	10.0	0.25	1.84	2.35	0.54	0.43	2.65	0.38	1800	0.5
987	187	2034	306	3340	1.0	10.0	0.25	1.57	1.94	0.64	0.52	1.06	0.94	1550	0.5

TABLE V

RAW DATA FOR F:M LOADING RATIO OF 3.0 $\frac{(\text{lbs. BOD})}{(\text{lbs. MLVSS})\text{day}}$

S_i	S_e	X_A	X_e	X_R	F_w	F	t_d	U	F:M	1/U	1/F:M	θ_c	$1/\theta_c$	S_iU	$1/S_e$ $X10^{-2}$
1760	215	1700	306	2160	0.6	9.79	0.26	3.50	4.14	0.29	0.24	1.11	0.90	6160	0.5
1796	228	2235	252	1810	1.17	10.0	0.25	2.81	3.21	0.36	0.31	1.15	0.87	5047	0.4
2051	497	1605	200	2780	0.59	9.79	0.26	3.72	5.11	0.27	0.20	1.44	0.69	7630	0.2
2486	490	2230	300	2200	1.16	9.79	0.26	3.44	4.46	0.29	0.22	1.08	0.93	8552	0.2
1560	441	1740	212	1520	0.3	10.0	0.25	2.57	3.59	0.39	0.28	1.69	0.59	4009	0.2
1545	456	2170	182	2110	1.21	8.64	0.29	1.73	2.85	0.58	0.35	1.36	0.74	2673	0.2
1416	541	1365	138	3810	0.0	10.0	0.25	2.56	4.15	0.39	0.24	2.47	0.40	3625	0.2
1830	739	1890	322	1050	0.93	10.0	0.25	2.31	3.87	0.43	0.26	1.01	0.99	4227	0.1
1760	537	1380	190	740	0.0	10.0	0.25	3.54	5.10	0.28	0.20	1.82	0.55	6230	0.2
1890	518	1820	130	3220	0.0	10.0	0.25	3.02	4.15	0.33	0.24	3.50	0.29	5708	0.2
2030	593	2470	454	2600	1.15	10.0	0.25	2.33	3.29	0.43	0.30	0.90	1.11	4730	0.2

VITA

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