PERFORMANCE IMPROVEMENT OF AN EXTENDED AERATION TREATMENT PLANT

by

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INTRODUCTION

The United States in the years following World War II and to the present has experienced, along with a rapid increase in population, a continual trend of urban development. With the need for new houses to accommodate the increased number of families, man has exhibited a desire to leave city life and move to the country. This desire is often satisfied by mobile home parks where the family can enjoy the small community atmosphere with the breadwinner commuting to employment in the city.

One problem associated with this development is waste treatment facilities. With a growing public concern for the environment, a satisfactory waste treatment facility is necessary. Oftentimes these developments are too remotely located to utilize the nearest municipal system. A method widely used for wastewater treatment in these instances is the extended aeration modification of the activated sludge treatment process.

The number of extended aeration treatment plants has increased along with the increase in development. Three plants were operating in 1950, with many thousands in use today (9). There are several located in the immediate vicinity of Manhattan. These plants have been used to treat wastes from a variety of sources: schools, interstate rest stops, housing developments, overnight camp sites, mobile home parks, hospitals, small industries and small communities. Many extended aeration plants are factory built units, with the only items required for installation being a hookup to the collection system, a stream to receive the effluent and an electrical power connection.

This study is concerned with the operation and performance of an extended aeration treatment plant located at Walnut Grove Mobile Home Park. The plant has operated poorly since its installation. It is a factory built treatment plant, designed and manufactured by the Smith and Loveless Company at Lenexa, Kansas. Background information on the performance of the plant is furnished by Mueldener (10), who studied the effect of a polishing pond receiving the plant effluent. Average effluent BOD_5, COD and SS were 84, 265 and 167 mg/l, respectively, for the year June, 1973, to June, 1974.

Some of the problems associated with the plant were odors, foaming on the aeration basin and failure of sludge to separate from the supernatant in the clarification basin (Figures I and II). The aeration system was evaluated, changed and reevaluated. Plant influent was monitored to characterize both quantity and strength. General observations of plant performance were also made.

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Figure I. Aeration Tank Foam

Figure II. Final Sedimentation Tank

LITERATURE REVIEW

This literature review will briefly cover the areas of problems associated with activated sludge plant operations, sludge bulking, activated sludge settling tanks and the effects of iron addition on activated sludge to improve conditions. The extended aeration activated sludge treatment process was reviewed by Fornelli (7).

One of the most complete articles on sludge bulking was published by Pipes (11). He points out that although treatment plant operators are quick to refer to any loss of sludge in the effluent as bulking, bulking sludge is only one of many different kinds of activated sludges which separate poorly. Pipes categorizes sludges which separate poorly as follows: bulking sludge, rising sludge, septic sludge, overaerated sludge, floating sludge, deflocculated sludge, pinpoint floc and billowing sludge.

A bulking sludge is considered to be one which has a sludge volume index (SVI) greater than 200. Bulking sludge will always separate during a 30 minute settling test, forming a very clear supernatant, and a sharp line between the sludge layer and liquid. Because a bulking sludge will settle, a plant can produce good quality effluent if the settling tank is adequately designed and enough return sludge pumping capacity is provided. If properly controlled, a plant with bulking sludge will produce a higher quality effluent than normal activated sludge.

Bulking sludge can be subdivided into two categories: filamentous bulking and non-filamentous bulking. Microscopic examination will distinguish between the two types. Filamentous sludge, as its name implies, refers to a sludge which has an excessive amount of filamentous growths attached to the floc particles. Non-filamentous bulking is bulking where filamentous growths are not in evidence and is theorized to be caused by an extracellular material with a high degree of hydration which produces excessive amounts of bound water.

A rising sludge settles and compacts well during a 30 minute settling test. However, if the graduated cylinder is allowed to stand undisturbed for a few hours after the test, the sludge will slowly rise enmasse to the top. Rising sludge is caused by nitrification in the aeration tank and denitrification in the settling tank. Nitrogen gas bubbles from the denitrification process become entrapped in the sludge mass and eventually float the mass to the top.

Septic sludge will also rise, although the cause is not nitrification and denitrification. Septic sludge occurs when the final settling tank is designed so poorly that settled sludge can compact in a dead space for a day or longer. The sludge then goes anaerobic and the resulting gases and end products, H_2S, CO_2 and H_2, float the sludge to the top, much as in the case of rising sludge and nitrification-denitrification.

Overaerated sludge is caused by violent agitation of the activated sludge in the aeration tank. The air forms very small bubbles which tend to attach to individual sludge particles. When the sludge enters the settling tank, the particles float to the surface and are lost over the effluent weir.

Floating sludge can be distinguished from rising sludge, septic sludge and overaerated sludge by the characteristic that it will float back to the top of a graduated cylinder if stirred. Rising, septic and overaerated sludge will settle when stirred. Floating sludge floats because it is less dense than water. Nearly all activated sludge plants produce some floating sludge, but it is usually lost to the effluent before noticed.

Deflocculated sludge is distinguished by uniform turbidity in the supernatant above the settled sludge. The portion of the sludge which settles compacts well and is easily separated by sedimentation. The deflocculated supernatant has no tendency to separate. Pipes believes that deflocculation is most often the result of a toxic shock such as an acid discharge or a sudden temperature change. He also considers the possibility that deflocculation is a result of a "complex of different phenomena."

Pinpoint floc are small particles, visible to the eye, which remain suspended in the supernatant after the sludge has settled. There appears to be two types of pinpoint floc. The first type appears microscopically as normal activated sludge particles of small size. These particles exert a high effluent BOD. The other type, white amorphous masses, does not exert an oxygen demand.

Billowing sludge is not actually a type of sludge, but a condition caused by any disturbance to settling sludge, such as hydraulic surges, density currents or stirring by the sludge scrapers. Billowing sludge appears as clouds of sludge rising in mushroom form from the bottom. Any type of sludge will billow if stirred gently.

In a later article (12), Pipes discusses the problem of controlling bulking sludge. He mentions that on occasion a normally well operating treatment plant will experience periods when the sludge bulks. In these cases where sludge bulking is evident but the cause is unknown, it is easier to use some form of chemical control than to locate and correct the cause of bulking. A flow chart is offered to help an operator solve his bulking problem (Appendix). Basically, the procedure is to determine if bulking is the actual problem, in contrast to possibilities of rising sludge, floating sludge or overaerated sludge. If bulking sludge is indicated, it is necessary to determine if it is filamentous or non-filamentous. If filamentous bulking is discovered, further examination is needed to determine if the cause is fungus organisms or bacterial organisms. A trial and error approach is then recommended as the philosophy of problem solution.

Pipes (11) also mentioned the fact that any activated sludge can be lost to the effluent if the final settling tank is poorly designed. Almost any disturbance in the activated sludge process shows up as a solids loss in the effluent. Further support for this idea is given by Eye, et al. (6). In a study of extended aeration activated sludge plants, treatment performance based on effluent quality depended mainly on the ability of the system to retain suspended solids. It was also noted that the frequent discharge of suspended solids was generally caused by hydraulic overloading of the final clarifier. Seymour (14) indicated that clarifier or settling tank design criteria in the areas of surface overflow rates, surface loading, baffling and solids recycling should be reexamined by regulatory agencies, manufacturers and consultants. Dick (5) maintains that traditionally, final settling tanks are designed only on the basis of clarification. Since sedimentation tanks have two functions, clarification and thickening, or compaction of the sludge, more attention and care should be given to the thickening function in design. Improper consideration of thickening can lead to loss of suspended solids just as poor clarification can. Improper thickening can also deteriorate the biological phase of treatment. If suspended solids in the raw waste flow and synthesis of solids in the aeration tank are ignored, performing a mass balance on the system will show that the mixed liquor suspended solids (MLSS) is directly proportional to the solids concentration in the return sludge. If the return sludge concentration drops off, the MLSS decreases and the net result is an increase in organic loading intensity. This may lead to further problems in solids separation, and what appears to be a problem related to biological aspects of treatment is actually caused by poor design of the clarifier.

It is well known that inorganic nutrients are required by bacteria for cell growth, oxidation and enzyme activity (8). If a trace inorganic nutrient is missing, then a species of bacteria will grow which does not need that particular element. Thus, having the "right kind" of bacteria present, or having desirable bacteria in biological waste treatment systems, depends on having an environment which encourages their growth. Carter and McKinney (3) showed that for a glucose activated sludge system, when adequate iron concentrations were present, well settling sludges would predominate. Although not mentioned by Carter and McKinney, it is possible that iron improves the settleability of a sludge due to a weighting and flocculating mechanism in addition to providing an essential nutrient.

DESCRIPTION OF FACILITIES

Walnut Grove Mobile Home Park is located in Pottawatomie County 1/8 mile north of U.S. 24 and six miles east of Manhattan. The park is being developed in two phases. The first phase is completed and has a capacity of around 100 mobile homes. Utility hookups and landscaping have been completed for the second phase and lots are slowly being occupied. The first and second phases are connected to separate sanitary sewage treatment facilities. This study is concerned only with the treatment facilities for the first phase.

Sewage is conducted by gravity to the treatment plant site. No lift stations are used. Polyvinylchloride (PVC) pipe is used exclusively for the collection system. There is evidence of either leaky joint connections or poor lateral connections for, with every rainfall, considerable amounts of sand are washed into the plant. On one occasion, infiltration was so high that the aeration tank flooded over the top. There are no manholes in the entire collection system.

The wastewater treatment plant is an extended aeration unit manufactured by the Smith and Loveless Company of Lenexa, Kansas. The plant is below grade. Sewage enters the plant with no pretreatment other than a large wire mesh basket which is meant to screen out diapers, handi-wipes, etc. The plant consists of two basins: a 22,500 gallon aeration tank and a sedimentation basin. The tank was installed in a very fine soil, and the south side has settled so that the effluent weir at the north end of the tank is 0.3 inch higher than the south end. Problems were experienced with foaming on the aeration tank and a garden hose with attached copper tube was used to keep foam from washing into the clarification basin. Effluent goes to a concrete walled polishing pond.

The polishing pond is 50 feet by 25 feet and has a capacity of 94,250 gallons. This basin is intended to capture any effluent solids from the treatment plant. Unchlorinated effluent is discharged to a small unnamed stream 50 yards south of the basin.

An airlift pump was installed in the polishing pond with discharge to the front end of the aeration tank. The air for this pump was supplied by the aeration tank blowers. This pump was provided to return digested stable solids that floated to the surface to the aeration tank. The solids were meant to provide a good heavy nucleus to improve the settling of the sludge. The pump was not operated during this study.

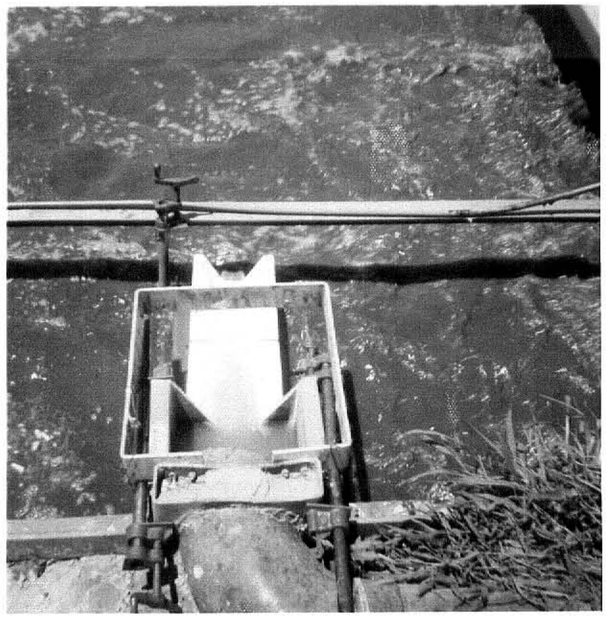
PROCEDURES

Flow Measurement

Treatment plant influent was measured with a fiber glass venturi flume. A wooden, combination stilling box and support for the flume was constructed out of 2 inch by 12 inch lumber. An opening was cut in the stilling box to match the opening of the flume, and the flume was then screwed to the box. The joints of the box were sealed with Dow silicone rubber bathtub caulking. The stilling box-flume assembly was attached to the aeration tank with two furniture clamps. See Figure III. A strip of foam rubber was nailed to the end of the stilling box to provide a seal.

The flume was calibrated in the Hydraulics Laboratory, Department of Civil Engineering, Kansas State University, with a hose, stop watch and 2.48 gallon bucket. Water was supplied through the flume at a constant head and the corresponding flow rate was measured. Flow rates for different heads were measured and a calibration chart was prepared on log paper.

The flume was attached to a stilling well with a 3/8 inch plastic hose. The stilling well was a short piece of 4 inch PVC with a rubber plug in the bottom. Head was recorded by a Stevens Leupold stage recorder. One chart recorded 24 hours of flow record. Problems were experienced at the start of the study with sand clogging the hose connecting the flume to the stilling well. From 4 to 12 hours of good flow record could be obtained before sand would accumulate in the lowest part of the tube, blocking any transmission of head. The problem was solved



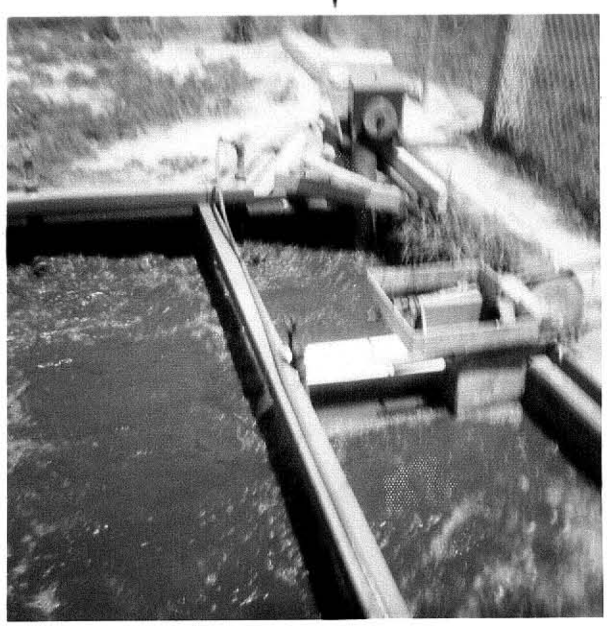


Figure III. Flow Measurement

by inserting a plastic "tee" in the hose and attaching a one liter jar to the leg of the tee. The bottle provided sufficient capacity to hold any sand entering the flume during a 24 hour period. When the chart was changed, the bottle would be removed, emptied and filled with fresh water.

Influent Sampling

Influent samples were obtained with a Servco automatic sampler. The sampler manifold had 24 openings, each connected by rubber hose to a 500 ml numbered bottle. A vacuum was applied to the manifold in the field, removing the air from each bottle. The bottles were then sealed by pinching off the hose in front of each bottle. A spring-wound clock released the vacuum at one hour intervals. The sampler manifold was placed into the stilling box. Although there was approximately one inch of sand in the box at all times, the samples obtained were sand free. Samples were transported to the Sanitary Engineering Laboratory and stored in a refrigerator until tests could be run.

Biochemical Oxygen Demand

Five day biochemical oxygen demand tests (BOD_5) were run on each sample, using the procedures suggested in Standard Methods (1). All samples were aerated by vigorous hand shaking for a period of 3-4 minutes before sample addition to the BOD bottles. Only carbonaceous BOD_5 values were desired, so it was necessary to eliminate BOD due to nitrogenous demands. This was accomplished by addition of the Hach Chemical Company's nitrification inhibitor. This compound is 2-chloro-6-(trichloromethyl) pyridine (TCMP). Dilution water was prepared according to Standard Methods and saturated with oxygen by aerating for several hours with laboratory compressed air and porous diffuser stones. The dissolved oxygen (DO) value of the blank at the end of the five day incubation period was assumed to be the initial DO of the sample plus dilution water. Seeding material was mixed liquor obtained from the aeration tank at Walnut Grove. For each set of BOD_5 tests, three blanks containing dilution water only were used.

The DO values were obtained with a Yellow Springs Instrument Model 51A Oxygen Meter with a 5420A remote stirring probe. An occasional sample was selected for DO determination by the azide modification of the Winkler Method as outlined in Standard Methods. The incubator was a Precision Scientific Model 805. The following formula was used for calculating BOD_5:

$$BOD_5 \text{ (mg/l)} = (DO_b - DO_i) \text{ 300 ml/ml of sample}$$

DO_b is the average 5-day DO value of the blanks, DO_i is the 5-day DO value of the diluted sample, and 300 ml is the volume of the BOD bottle.

Chemical Oxygen Demand

Chemical Oxygen Demand (COD) determinations were run on each sample according to Standard Methods (1). Samples of 10 ml were used, with 0.25 N potassium dichromate as the oxidizing agent, and 0.05 N ferrous ammonium sulfate as the titrating agent. The equipment was either 200 or 250 ml Erlenmeyer flasks with 24/40 ground glass necks, 300 ml pyrex condensers with 24/40 ground joints, and either a Lindberg Hevi-Duty type H-5 or LabConCo heater. COD values are given by the following formula:

$$COD \text{ (mg/l)} = (a - b)(1{,}000/c)\, DF$$

a = ml titrant for blank

b = ml titrant for sample

c = ml titrant for standard

DF = dilution factor = 1 for a 10 ml sample

Total Suspended Solids

The Millipore vacuum filter technique was used for total suspended solids (SS) determinations. Gelman fiber glass filters, Type A, 47 mm, were placed in aluminum dishes and dried overnight at 103° C in a Thelco model 17 drying oven. The dishes were cooled to room temperature in a dessicator, and weighed on a Mettler Type H6 analytical balance. The filter paper was then placed on a ground glass filter holder with funnel. The sample was pipetted in, vacuum applied, the filter was placed in its dish and returned to the oven to dry at least one hour. The cooling and weighing procedure was repeated to obtain the suspended solids concentration.

Mixed Liquor Suspended Solids

Mixed liquor suspended solids (MLSS) were determined with the Millipore vacuum filter technique described for the total suspended solids determination.

Mixed Liquor Volatile Suspended Solids

Mixed liquor volatile suspended solids (MLVSS) tests were run independently of the MLSS determinations. Gooch crucibles were brought to a constant weight in Thermolyne muffle furnace at 600° C, cooled in a dessicator, and weighed on the Mettler balance. Twenty-five ml of mixed liquor was pipetted into the crucible and the samples were placed in the muffle furnace at 600° C for 15 minutes. The crucibles were removed, cooled and weighed to determine the fixed material. The MLVSS concentration was obtained by subtracting the fixed matter from the MLSS value.

Effluent Suspended Solids

Plant effluent solids were obtained with the Millipore vacuum filter technique described previously.

Sludge Volume Index

The sludge volume index was obtained by following the guidelines in Standard Methods (1). A one liter sample of mixed liquor was allowed to settle for 30 minutes in a 1,000 ml graduated cylinder. The volume of settled sludge in ml at the end of 30 minutes was read.

$$\text{SVI (ml/gm)} = \frac{\text{(30 min. settled volume) 1,000}}{\text{MLSS}}$$

Hydrogen Ion Concentration (pH)

The hydrogen ion concentration (pH) was measured with a Fisher Accumet model 320 pH meter.

Dissolved Oxygen

Initially, attempts were made to connect a potentiometer to the Yellow Springs Instrument Oxygen Meter. The potentiometer recorded the voltage signal sent from the probe to the meter. This worked fine in the lab, but at the plant site there was electrical interference and the potentiometer could not be made to correspond to DO readings.

Next an attempt was made to use a Delta Scientific Model 3310-PB recording DO meter. The unit developed circuitry problems and was abandoned. All DO values used were spot readings taken with Yellow Springs Instrument Model 51A DO meter. Readings were taken at about a four foot depth.

Power Readings

Power readings were taken directly from the kilowatt-hour recorder supplied by the utility company. Readings were taken both before and after the aeration system was changed.

Oxygen Uptake Rate

Several on-site measurements of dissolved oxygen uptake rates (r) were obtained (2,13). A sample of mixed liquor was aerated to a DO level of 5 - 6 mg/l by hand shaking in an Erlenmeyer flask. The sample was placed in a 300 ml BOD bottle and DO values were obtained with the Yellow Springs Meter and remote stirring probe. Dissolved oxygen values were recorded at 30 second intervals until a depletion of 3 or 4 mg/l was obtained, usually in 4 - 8 minutes. Values of DO were plotted against time and the slope of the line gave r in mg/l/hour. At this time a saturation DO value was measured also. Supernatant from the clarification basin was saturated by vigorous shaking in an Erlenmeyer flask for 5 - 8 minutes and by pouring back and forth from one beaker to another.

Microscopic Observations

Each mixed liquor sample was examined with a Bausch and Lomb Dynazoom Laboratory Research Microscope. A note of the general condition of the sludge was made, both as to the extent of filamentous growth, and the relative numbers of free swimming protozoa, stalked ciliates and rotifers. Photomicrographs were taken at the beginning of the study showing the general filamentous condition of the floc.

RESULTS AND DISCUSSION

Plant Influent Characteristics - Quantity

Figures IV through X show the typical flow quantity to the plant for each day of the week. Total flow in gallons ranged from a low of 13,600 on Tuesday, to a high of 24,300 on Saturday, with an average of 18,800. With 100 mobile homes and assuming three people per home, these values give 81, 46 and 63 gallons per capita per day for the high, low and average days, respectively. These values are reasonable when compared to typical design values (4). There was no rainfall immediately preceding the recording of the flow charts, so infiltration was considered to be minimal.

Trouble was experienced with the flow recorder ink pen mechanism. The pen would jam on its slide bar and remain stuck for the remainder of the 24 hour period, ruining the whole day's data. At other times, something would plug the opening in the flume where the stilling well connection was made. This would cause the recorder to record a constant head at whatever level the flow was at when the opening plugged, leaving substantial gaps in the record. However, several charts were obtained with crisp, clear lines, indicating good float response to changes in head.

Plant Influent Characteristics - Strength

Influent samples were taken on five different occasions, November 15, November 25, December 3, December 14, and January 23. Some sample bottles failed to fill on each of these dates, but each sampling gave a good

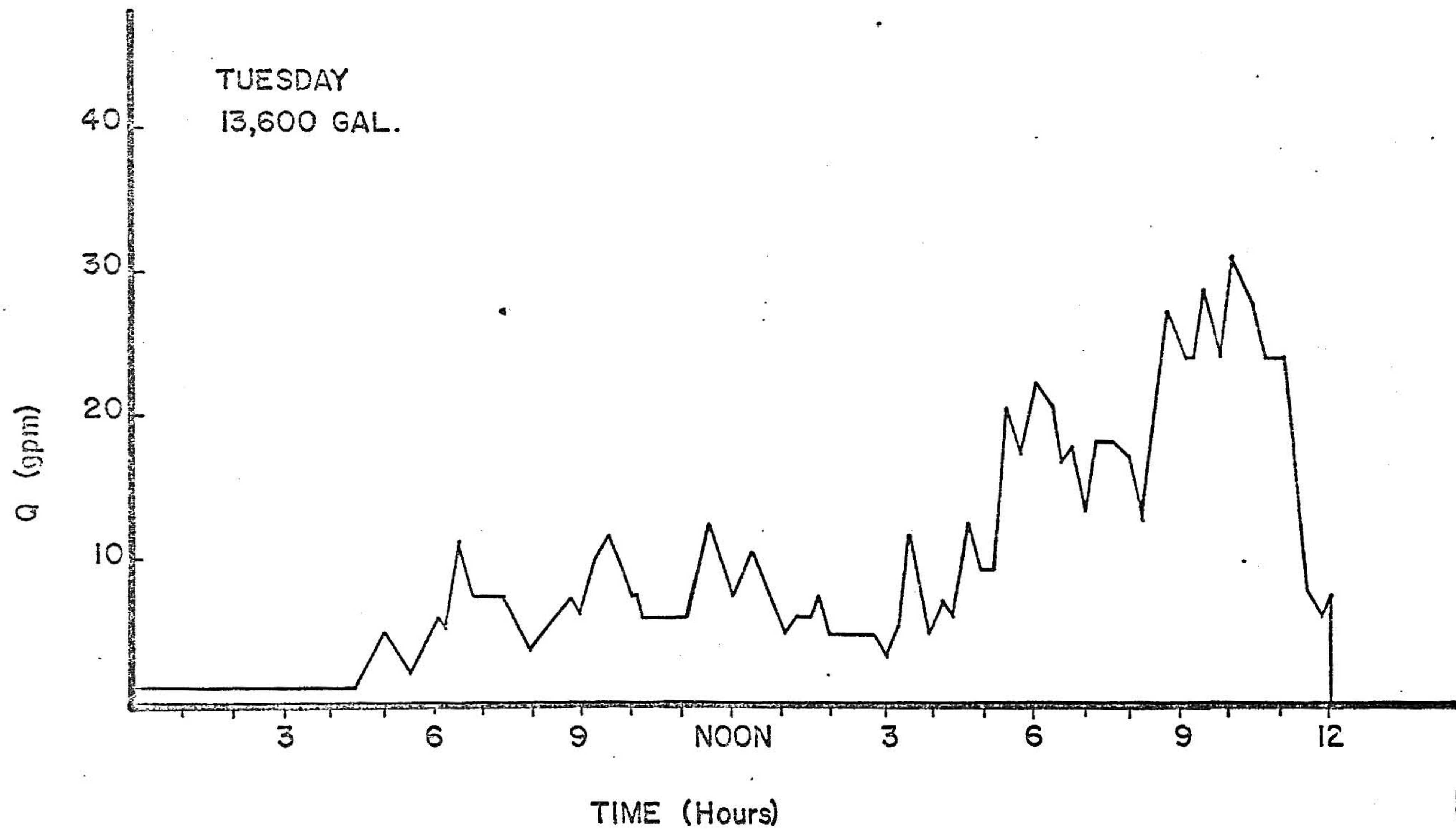


FIGURE IV. PLANT INFLOW

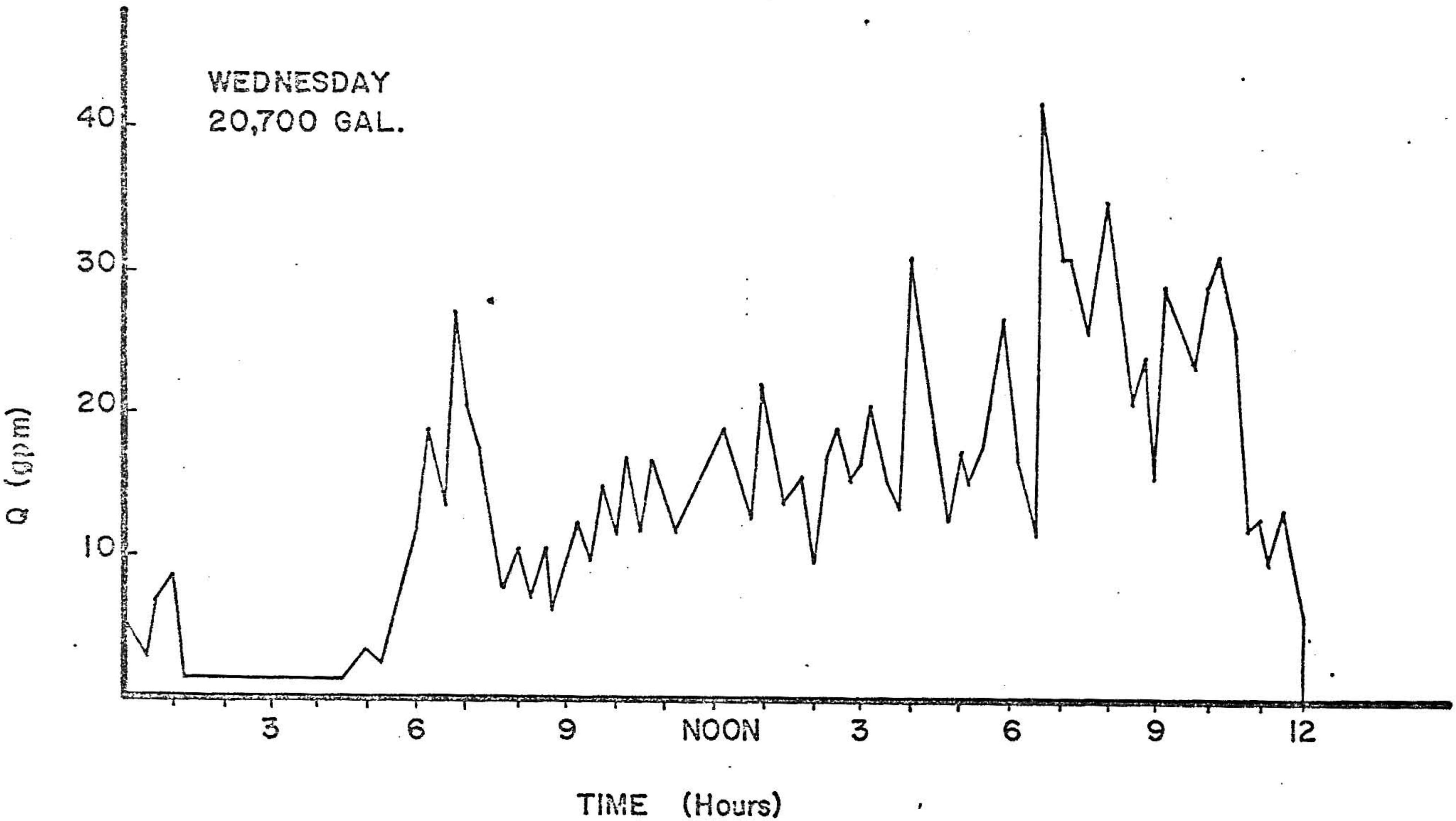


FIGURE V. PLANT INFLOW

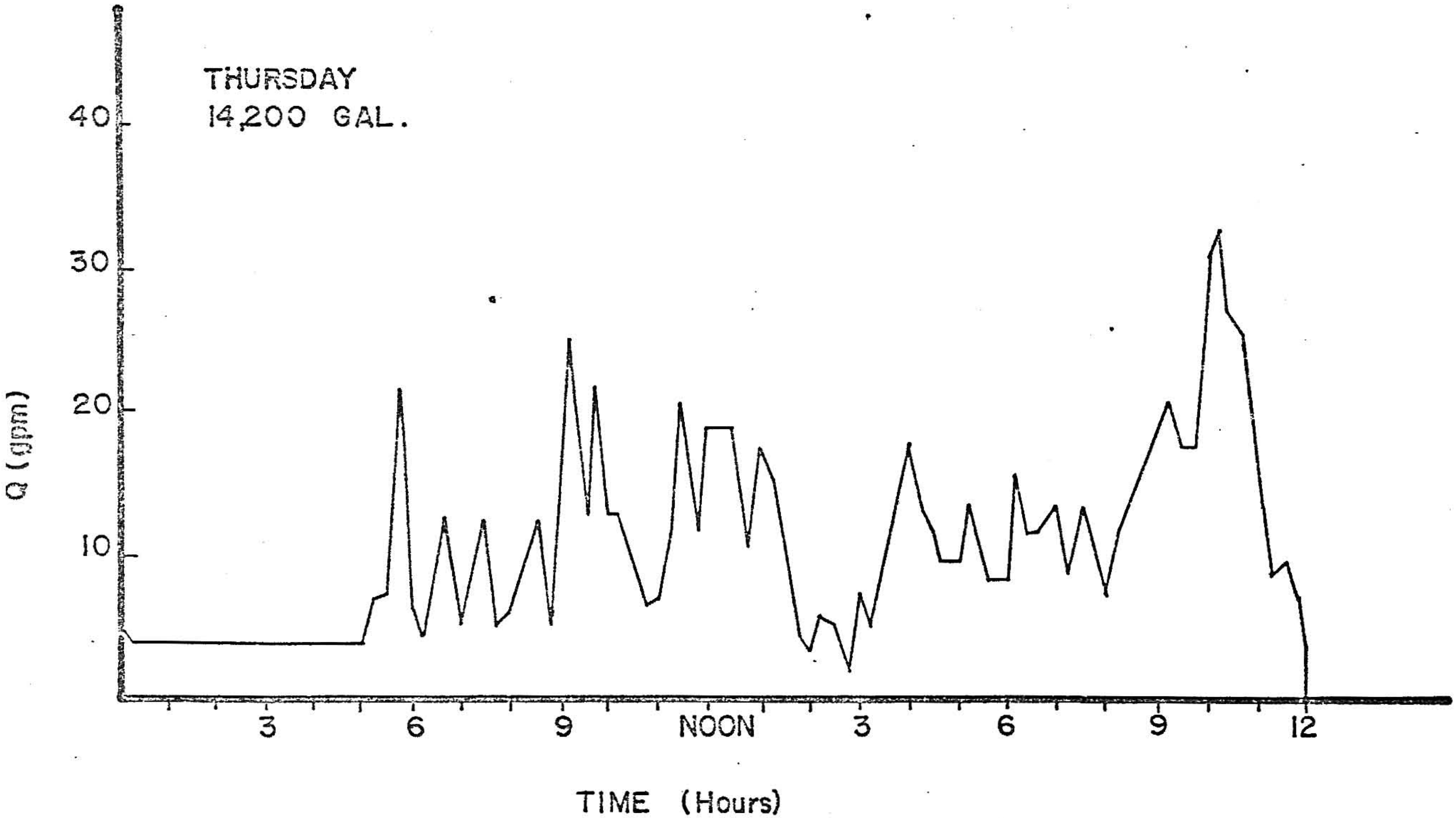


FIGURE VI. PLANT INFLOW

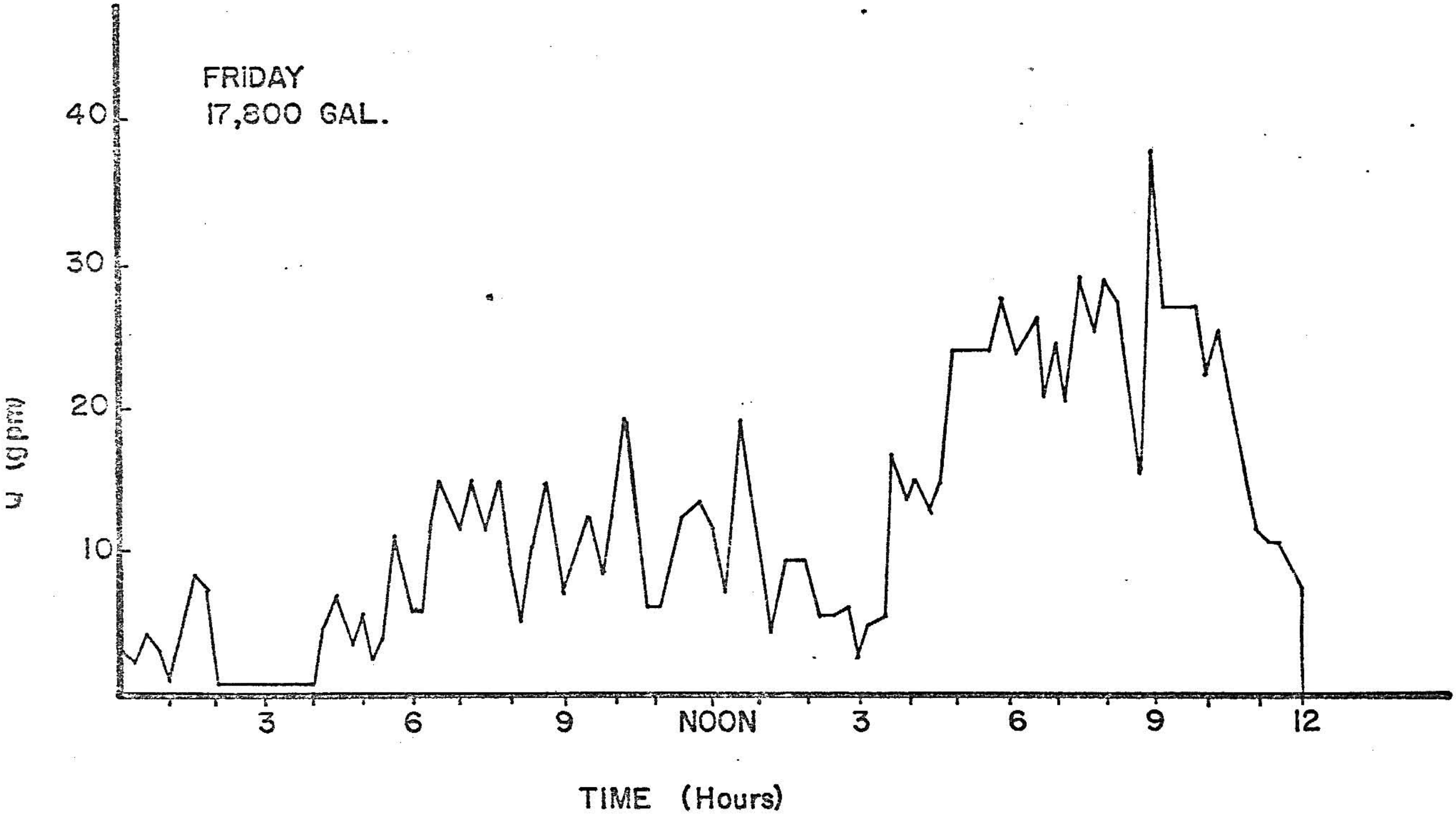


FIGURE VII. PLANT INFLOW

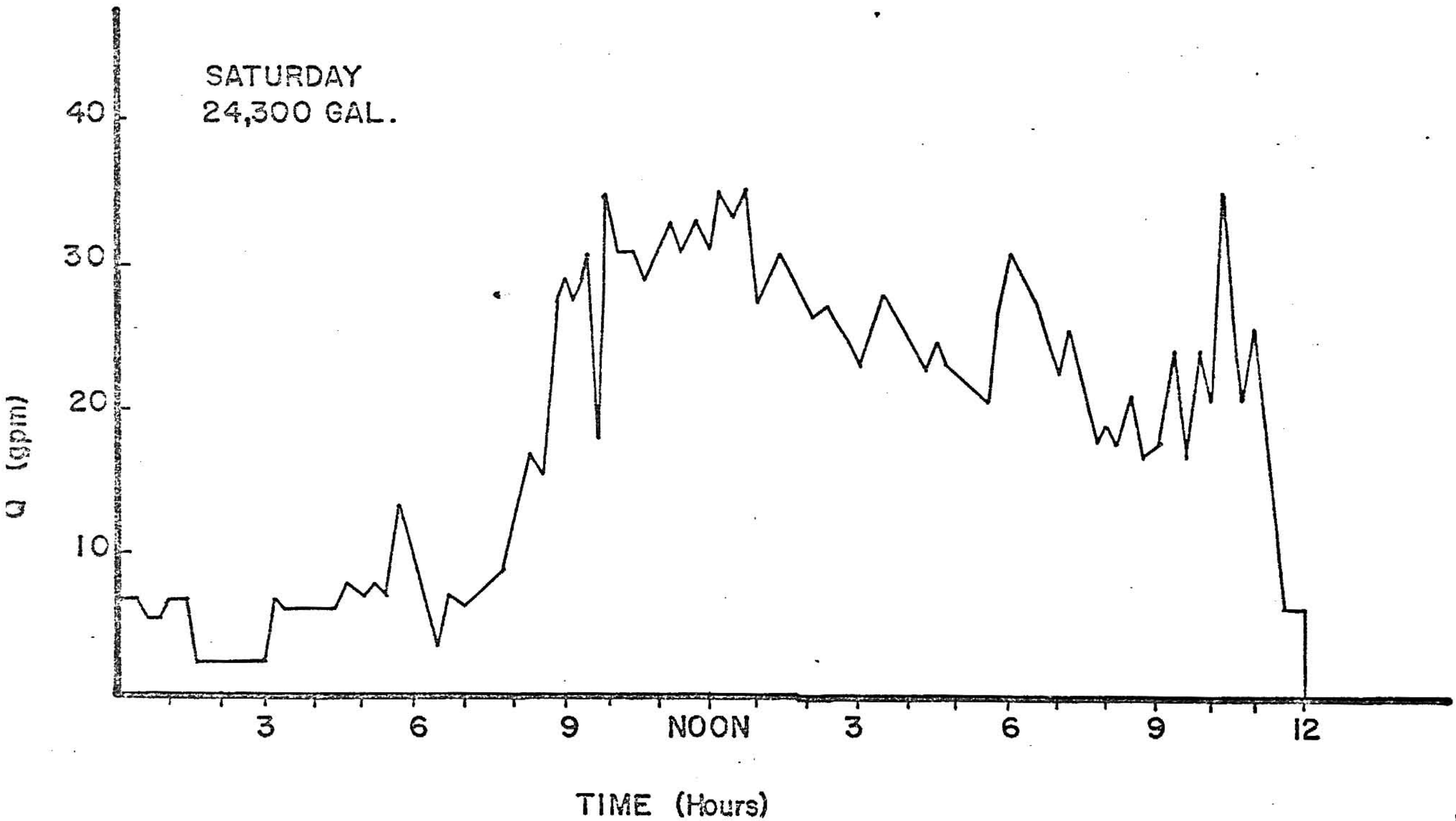


FIGURE VIII. PLANT INFLOW

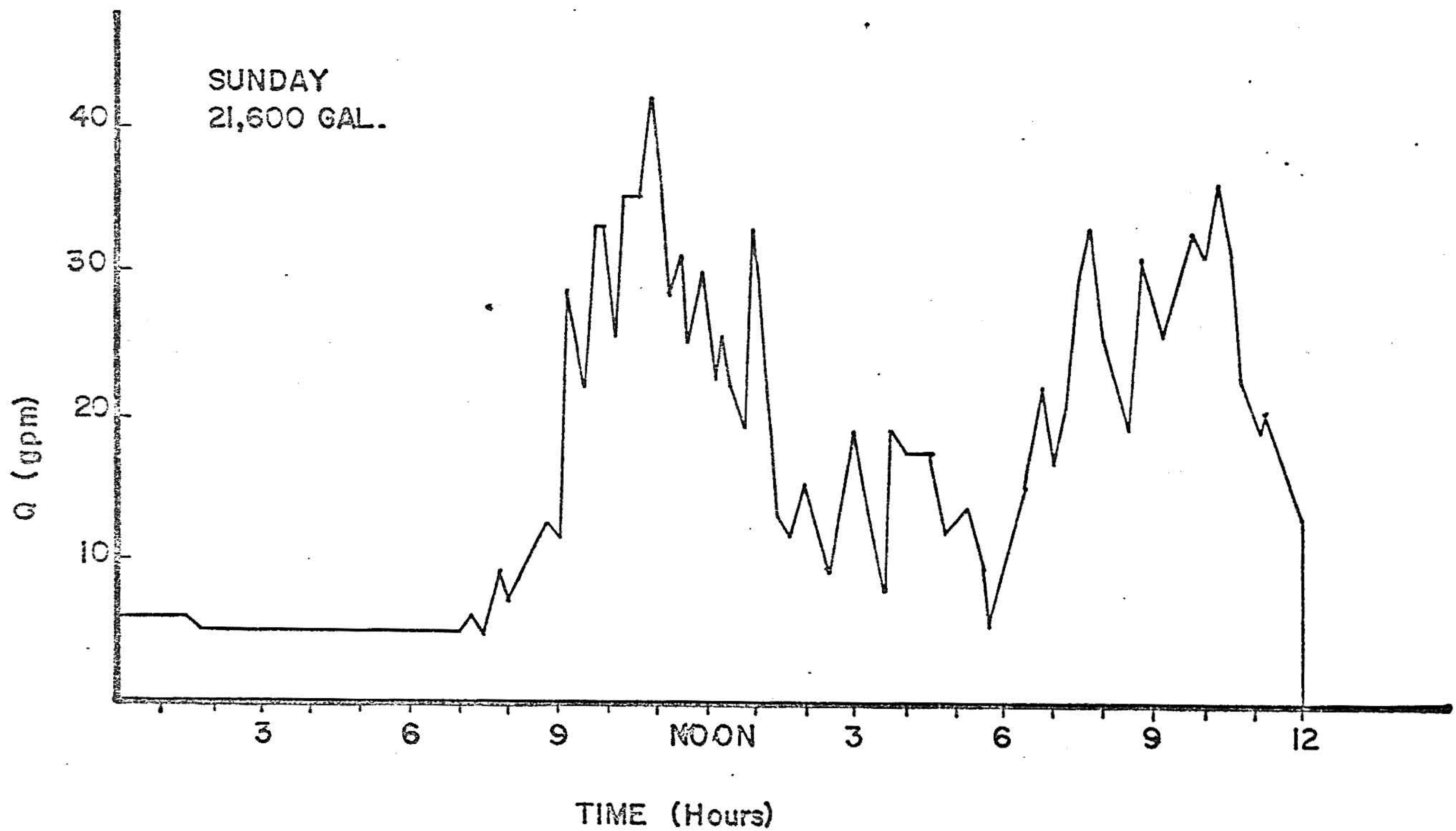


FIGURE IX. PLANT INFLOW

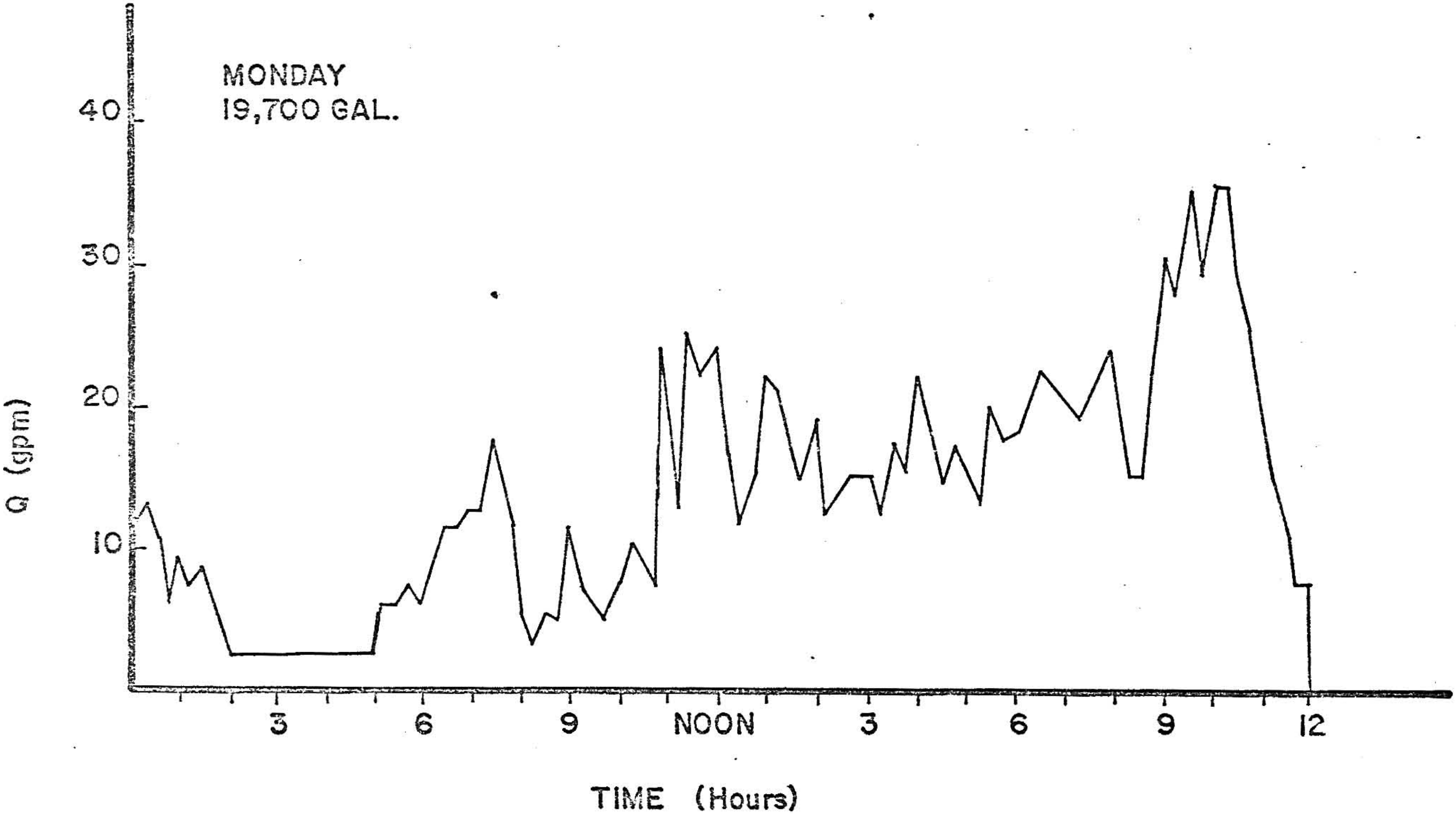


FIGURE X. PLANT INFLOW

representation of the waste for a 24 hour period. Values of COD, BOD_5 and suspended solids (SS) are tabulated for each hour of the day in Tables III, IV and V in the Appendix. A summary of these values is contained in Table I.

Traditionally, wastewater strength and flow rate, when considered with time, vary diurnally. Waste strength follows the living habits of man, lowest values during early morning hours, with peaks around dawn, during meal preparation and late evening hours. This characteristic was exhibited quite clearly for wastewater quantity, but for values of COD, BOD_5 and SS the trend is more difficult to discern.

A possible explanation for this is the smallness of Walnut Grove Mobile Home Park. During early morning hours when flow rates are low, a discharge from one home would not attain a great deal of dilution. If a sample was collected when this discharge reached the treatment plant, high values could be obtained. Perhaps a continuous sampling technique would solve this problem.

By considering all samples obtained, averages of 720, 375 and 317 mg/l are obtained for COD, BOD_5 and SS, respectively. Applying these averages to the average daily flow of 18,800 gallons, and assuming 300 people, values of COD, BOD_5 and SS in pounds per capita per day are 0.38, 0.20 and 0.16. Generally accepted design values for BOD_5 and SS are 0.2 and 0.23 pounds per capita per day. Wastewater treatment plants are not usually designed on the basis of COD. Applying the same average concentrations to the maximum daily flow of 24,300 gallons gives values of 0.49, 0.26 and 0.21, respectively.

Table I
Summary of Wastewater Strength

Date	Daily Average, mg/l		
	COD	BOD_5	SS
November 15	725	386	---
November 25	922	316	509
December 3	648	285	285
December 14	540	356	118
January 23	636	355	248
Average of All Samples	720	375	317

Plant Performance Prior to Modification

Before any changes were made in the plant, general observations were made on plant performance. Grab samples of the mixed liquor and effluent were taken and mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), sludge volume index (SVI) and effluent suspended solids (EFF SS) were determined. Also, spot checks of dissolved oxygen were made with a DO probe. This data is tabulated in Table VI. Mueldener (10) also supplied information on the performance of this plant.

Before modification, the plant was doing a very poor job of treating the waste. Dissolved oxygen was rarely above 0.0 mg/l. Odors were present on many visits to the plant, an indication of anaerobic conditions. Microscopic examination, however, indicated many aerobic protozoa. This may seem inconsistent, that is, aerobic organisms surviving in water with no dissolved oxygen, but the aeration system was running, and oxygen was being transferred to the liquid. The aerobes present were using the oxygen as quickly as it was transferred, allowing no dissolved oxygen to build up.

Microscopic examination of the mixed liquor quite often revealed filamentous growth. Photomicrographs of the mixed liquor were made (Figure XI) illustrating this condition. Figure XI shows the sludge the way it usually appeared. However, on many occasions the filamentous growths were much worse. The sludge was never found to be the type that develops in a well operating activated sludge treatment system. Visual observations of the aeration tank revealed a light, watery brown color instead of the rich, deep chocolate brown normally found in a healthy system.

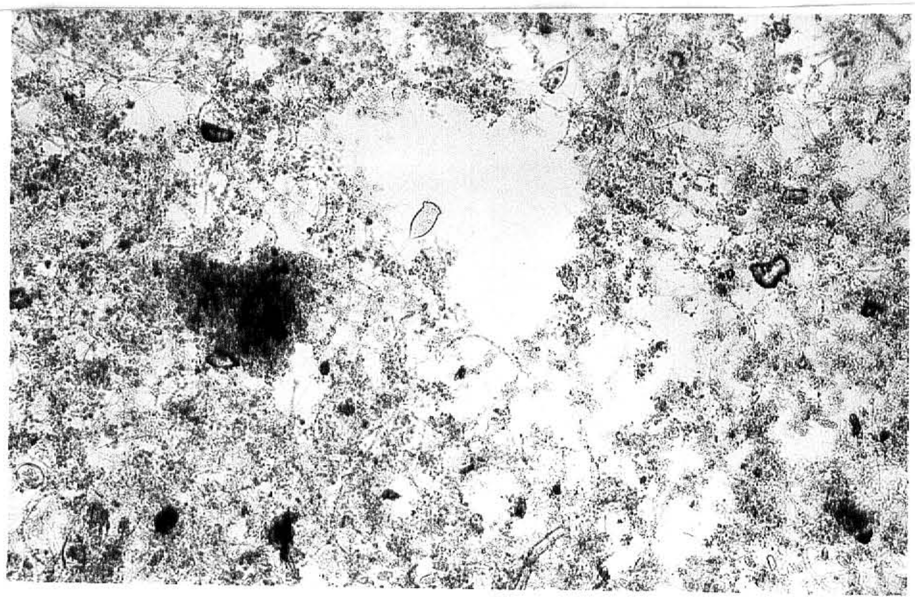


Figure XI. Photomicrograph of Sludge

Start of Study

Observations of the settling basin gave further indication of inefficient treatment. The floc appeared to be light and fluffy and the sludge layer was high in the tank. The sludge layer also was very unstable. The sludge layer would rise and fall, corresponding to a high or low flow rate into the plant. When influent flow rate exceeded 20 to 25 gallons per minute for a period of 20 to 30 minutes, as happened quite often, the sludge layer would rise to the top of the basin, resulting in heavy effluent suspended solids. The supernatant above the sludge layer was often cloudy from floc particles not trapped in the sludge layer. These particles also contributed to effluent suspended solids.

Many times sludge would float to the top and form a four to five inch thick crust. Figure I shows this condition at its worst. Scum was continuously present on the basin surface, although not always as bad as Figure I indicates. Part of the problem of the plant losing solids to the effluent can be attributed to the foam collection on the aeration tank. Foam would interfere with the natural skimming action of the settling tank, and it was necessary to install a hose spray to hold the foam back. This created upflow currents in the settling basin and caused further problems with sludge separation.

Figure XII shows the instability of the plant. The SVI from late June to late November showed no tendency to stabilize, ranging from 150 to well over 600. Effluent suspended solids are illustrated in Figure XIII. On occasions, the plant did produce an effluent with a low SS concentration, but it was excessive on numerous occasions also.

Another indication that the plant was upset is the variation in MLSS. This variation is very similar to the up and down cycle shown by the SVI in Figure XII and was therefore not shown graphically. Table VI, Appendix, gives MLSS concentrations for various sampling dates.

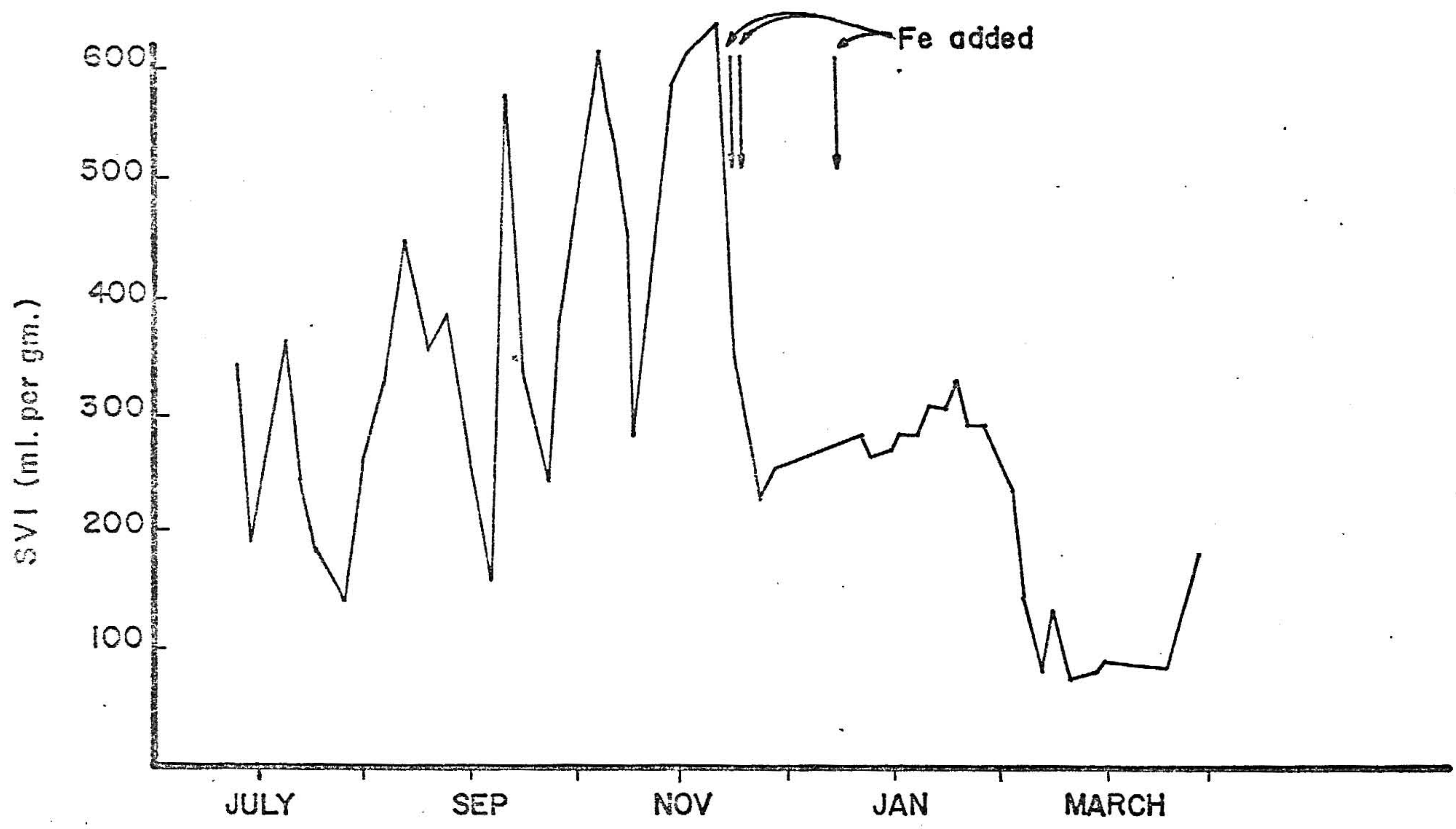


FIGURE XII. SVI vs. TIME

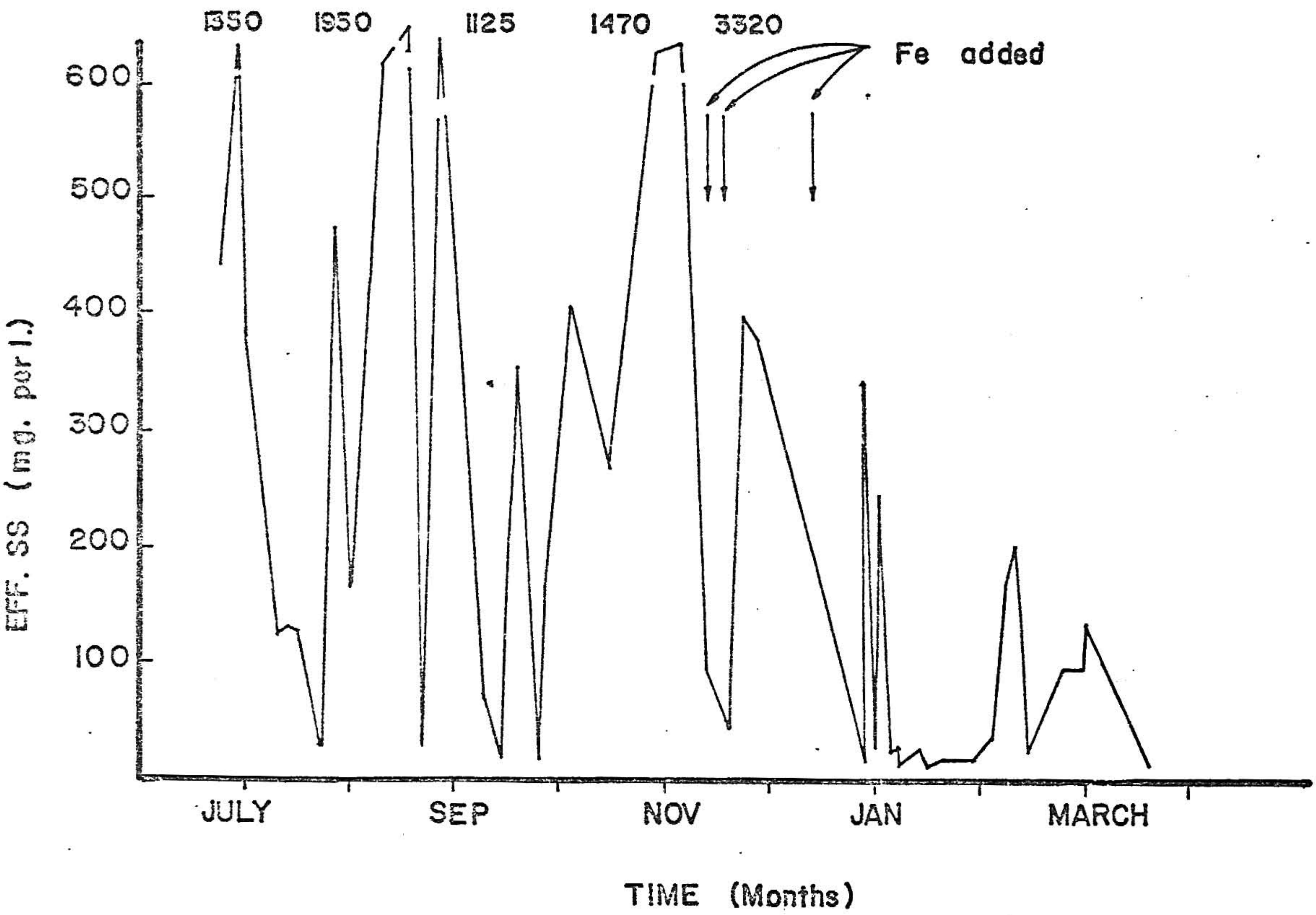


FIGURE XIII. EFF. SS vs. TIME

Plant Modification and Evaluation

Since dissolved oxygen (DO) was rarely observed to be greater than zero, it was natural to suspect that the aeration system was unable to supply the oxygen needed for satisfactory treatment. The aeration system was evaluated on four occasions, July 25, August 8, August 14 and August 16. Modifications were made to the system on September 9, and the revised system was reevaluated on October 16, October 18 and January 17. Table II summarizes the evaluations made on the system.

Initially, air was supplied to the aeration tank through 14 one-inch open ended pipes. On September 9, the system was modified by attaching a 24 inch diffuser to the bottom of each of the 14 pipes, forming a "tee." Each diffuser was a piece of one inch plastic pipe with 48 holes, 1/4 inch in diameter, drilled along its length. The intent was to increase oxygen transfer by reducing bubble size and increasing bubble-liquid interface area. This was the only physical change made for the entire treatment plant.

The modification in the aeration system improved oxygen transfer efficiency by 18 percent as measured by the increase in K_{La}, the oxygen transfer coefficient. The K_{La} before the change was 1.20 hr^{-1}, the average of the trials on August 14 and 16. The K_{La} after the change was 1.41 hr^{-1}, the average of the trials on October 16 and 18 and January 17. A sample calculation is provided in the Appendix.

The trials on July 25 and August 8 were disregarded in the determination of K_{La} before the aeration system was modified. This was done because the DO in the aeration tank was zero. Since the tank DO was zero, then it could not be certain that r, the oxygen demand by the bacteria, was being satisfied. The r values of 26.6 and 27.3 on July 25

Table II - Summary of Aeration System Evaluation

Date	Temp. (C)	MLSS mg/l	r mg/l/hour	C_s mg/l	C mg/l	K_{La} hr^{-1}
July 25	25	1,860	26.6	6.9	0.0	---
August 8	26	1,525	27.3	6.6	0.0	---
August 14	24	1,150	11.0	7.2	0.2	1.30
August 16	24	1,100	8.4	7.3	1.0	1.10
Plant Modifications Performed						
October 16	20	1,180	12.0	8.5	1.4	1.69
October 18	20	1,100	7.0	8.5	2.6	1.20
January 17	11	1,670	8.0	9.6	0.6	1.35

Note: r is the O_2 uptake rate, mg/l per hour

C_s is saturated O_2 value of mixed liquor in mg/l

C is aeration tank DO in mg/l

K_{La} is the O_2 transfer coefficient converted to a 20^o C value and August 8 were measured when the bacteria were exposed to the waste in an oxygen rich liquor, an environment not available in the aeration tank. Therefore a K_{La} based on these two trials would be erroneously high.

Also, to be on an equal basis for comparison, the K_{La} values were changed to an equivalent K_{La} at 20° C.

Plant Performance Following Modification

Immediately following the aeration modification, measurements of DO with the probe indicated that oxygen was present. Only once (November 15) was DO observed to be 0.0 mg/l. This was not enough to bring the plant completely around to stable operating conditions, however. Examination of Figures XII and XIII shows the SVI and effluent SS continuing to fluctuate after September 9, when the modification was made.

Conditions were much the same as they were prior to modification, with the exception that DO was being maintained. The foam remained on the aeration tank, necessitating the continued use of the hose spray. Scum was still present on top of the sedimentation basin, with a crust forming on occasion. Microscopic examination revealed many aerobic protozoa, but filamentous conditions were still evident. In general, it appeared that changing the aeration system alone was not going to do the job. The sludge layer in the sedimentation basin was still very fluffy, and solids discharge in the effluent was frequent.

On November 15, six pounds of ferric sulfate, $Fe_2(SO_4)_3$ were added to the aeration tank. Three days later six more pounds were added. The effect was immediate and obvious, as can be observed from Figures XII and XIII. The SVI immediately stabilized around the 280 to 300 level.

Effluent SS also dropped, although they still tended to fluctuate. This appeared to be what the plant needed. On December 15, six more pounds of ferric sulfate were added.

The beneficial effect of the ferric sulfate was due to the divalent iron cation. The iron had a flocculating effect on the sludge flocs, aiding in sedimentation. In addition to the flocculating effect, the iron probably had a weighting action; that is, it increased sedimentation by adding its own weight to the floc particles. It is also possible that the iron satisfied a nutrient deficiency. The potable water supply at Walnut Grove contains no iron, and the filamentous sludge conditions did improve slowly from late December on.

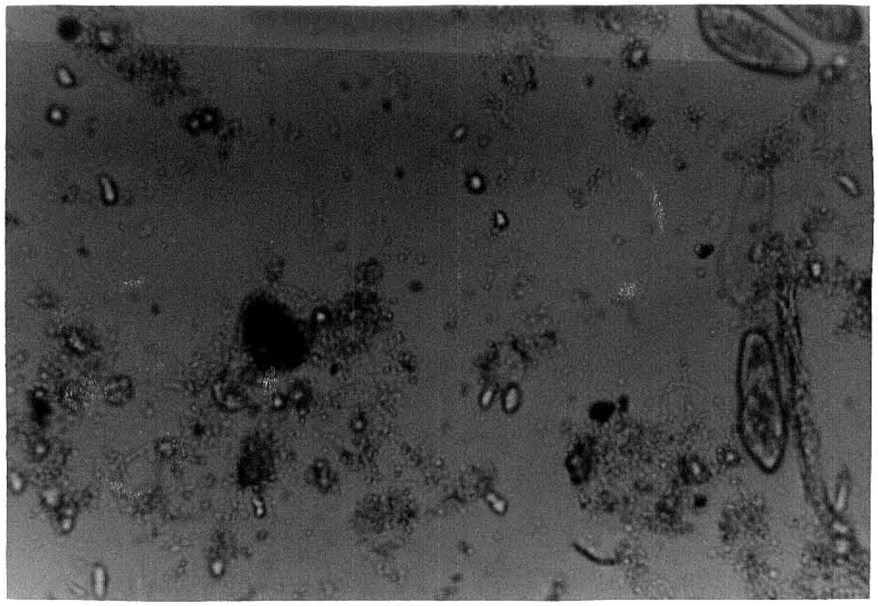
The foam on the aeration tank slowly decreased following the iron addition and disappeared completely on January 6. On this date the hose spray was also removed.

The SVI continued to hold steady, although it did exhibit a slight increase at the end of January. On the last few days in January and early in February, however, the SVI took another drop, this time stabilizing in the below 150 range, which is desirable. This was probably due to the sludge improving biologically. The initial stabilization was due to the flocculating and weighting effect of the iron. The iron, by keeping the SVI under control during December and January, enabled the MLSS to slowly build up, allowing the sludge to stabilize biologically. During late January effluent suspended solids dropped below the 30 mg/l mark and stayed there until February 7, when the system did start to lose more solids. This solids loss can probably be attributed to high flow rates to the plant.

SUMMARY

The aeration system for the Walnut Grove wastewater treatment plant was altered by attaching diffusers to the air supply pipes. This increased the oxygen transfer efficiency by 18 percent, but in itself was not enough to bring about improved treatment. Before the aeration system was changed, DO levels greater than zero were rarely found. Following the modification, DO levels greater than zero were observed, but the treatment plant still gave poor treatment to the waste. Changing the aeration system had no effect on electrical power requirements. Usage was about 1.75 kw/hr for both systems.

Ferric sulfate was added on three occasions, November 15, November 18 and December 15. An immediate improvement in sludge settleability was noticed. This was probably due to a flocculation and weighting effect the iron had on the sludge flocs. It is also possible that the iron satisfied a nutrient deficiency in the waste. By enabling the system to keep its solids, the iron also helped stabilize the sludge biologically. Before the addition of the iron, the MLSS would go through a constant cycle of increasing to the 1,800 to 2,500 mg/l level, reaching a point where the sludge would pass over the effluent weir and dropping to the 800 to 1,000 level, only to repeat the cycle. The sludge gradually improved biologically, forming the dense floc found in well operating activated sludge systems. The mixed liquor lost its watery brown look, and took on the deep chocolate brown color that is evident in a healthy treatment plant. Figure XIV is a photomicrograph of the sludge as it appeared from January on.



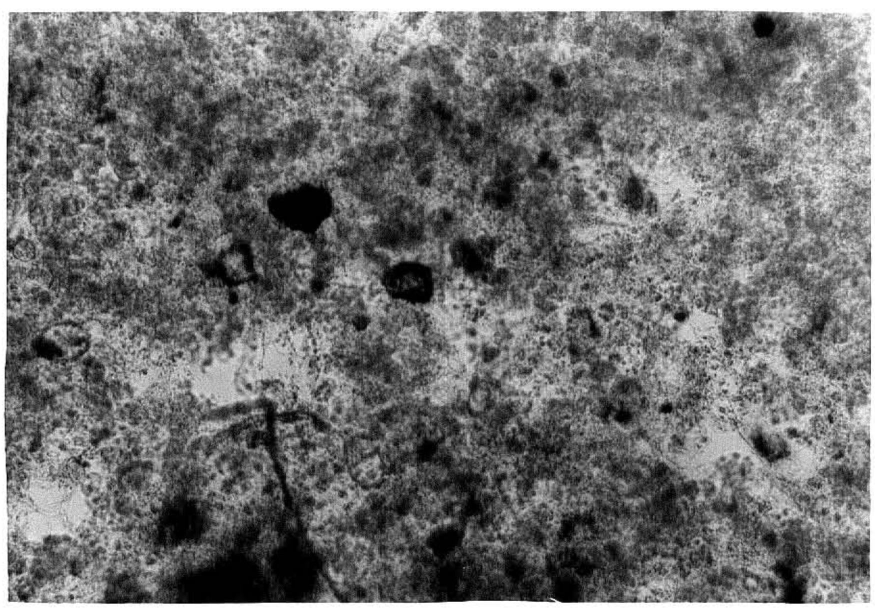


Figure XIV. Photomicrograph of Sludge

End of Study

This treatment plant still leaves a lot to be desired. The sedimentation tank is a poor design, with visual observation indicating an unstable sludge layer. The sedimentation tank is very susceptible to hydraulic overloading. It is possible to observe the sludge blanket slowly rising when the plant influent flow rate exceeds 20 gpm. Because of this, the plant will experience frequent, excessive effluent suspended solids concentrations. On the whole, however, the result of the aeration system change and the iron addition is a great improvement in treatment performance. It appears that ferric sulfate offers a good means of chemical control for bulking sludge in the Walnut Grove treatment plant.

CONCLUSIONS

1. The modification of the aeration system improved oxygen transfer efficiency 18 percent, based on K_{La}, the oxygen transfer coefficient.

2. The treatment plant at Walnut Grove is not overloaded hydraulically on a daily basis. However, sustained peak flow rates are frequently reached which will overload the plant.

3. The treatment plant is not overloaded organically. However, it is loaded to its full capacity.

4. Ferric sulfate appears to be a good chemical for control of bulking sludge at this treatment plant. Addition of ferric sulfate allowed the plant to retain solids and develop a stable sludge.

5. This plant will still experience problems with solids loss to the effluent. The change in the aeration system along with the use of ferric sulfate when the sludge bulks should help to keep this problem confined to times of high plant influent.

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APPENDIX

ORGANIZED APPROACH TO SOLVING A BULKING PROBLEM (12)

1. Identify bulking as distinct from inadequate design, poor operation, deflocculated sludge, foam forming sludge, rising sludge, septic sludge, etc.

   Characteristics of bulking: sludge settles and leaves a clear supernatant but SVI is high (150 ml/gm); low solids concentration in the return sludge; and high sludge blanket in final settling tank.

   ↓

2. Identify if filamentous or non-filamentous bulking by microscopic examination of mixed liquor and return sludge. → Non-filamentous bulking → Chlorinate return sludge at 5 to 10 mg/l

   ↓

   Filamentous bulking

   ↓

3. Determine if filamentous organisms are bacteria or fungi → Fungal bulking → Look for industrial waste problem

   ↓

   Bacterial filamentous bulking; identify organism if possible

   ↓

4. Look for source of massive innoculum of filamentous bacteria in wastewater or process return flows → Massive innoculum of filamentous bacteria found → Use bactericide to eliminate innoculum

   ↓

   Filamentous bacteria growing in activated sludge

   ↓

5. Establish theory of treatment
   a. Kill sludge and start all over
   b. Use bactericide on return sludge
   c. Use flocculant or weighting agent to decrease SVI

   ↓

6. Establish objectives; minimum time, and control procedures for course of treatment

   ↓

7. Carry out course of treatment and collect data for evaluation of treatment

   ↓

8. Evaluate treatment results → Successful → Continue as needed

   ↓

Table III - Influent COD

Hour	Nov. 15	Nov. 25	Dec. 3	Dec. 14	Jan. 23
Midnight	1,800	498	--	585	453
1	1,800	260	--	--	234
2	1,800	2,950	710	820	242
3	313	237	660	--	1,300
4	313	--	--	618	550
5	843	180	--	--	880
6	843	600	--	556	341
7	1,050	375	560	--	470
8	1,270	1,087	--	810	--
9	--	923	380	--	1,475
10	460	4,200	470	220	312
11	460	700	--	--	1,600
Noon	460	329	--	660	614
1	460	1,120	266	256	363
2	780	330	1,325	390	219
3	415	--	220	--	--
4	415	1,200	255	520	--
5	415	345	--	--	--
6	257	226	--	619	--
7	820	200	495	490	--
8	--	360	--	--	--
9	403	520	530	547	--
10	290	402	1,740	--	--
11	--	3,260	820	490	758
Avg.	725	922	648	540	636

Table IV - Influent BOD_5

Hour	Nov. 15	Nov. 25	Dec. 3	Dec. 14	Jan. 23
Midnight	840	150	--	320	215
1	840	114	360	--	180
2	840	700	315	675	150
3	180	105	250	--	415
4	180	--	--	525	300
5	475	85	380	--	430
6	475	250	--	320	300
7	565	170	220	--	450
8	565	675	--	495	400
9	--	370	160	--	1,035
10	250	750	160	150	200
11	250	160	--	--	415
Noon	250	170	120	350	270
1	250	345	--	150	--
2	400	160	380	280	150
3	215	--	70	--	--
4	215	600	80	310	--
5	215	190	--	--	--
6	186	100	--	340	--
7	615	220	130	350	--
8	--	170	--	--	--
9	300	300	270	510	--
10	220	190	765	--	--
11	--	930	495	310	425
Avg.	386	316	285	356	355

Table V - Influent SS

Hour	Nov. 15	Nov. 25	Dec. 3	Dec. 14	Jan. 23
Midnight	--	110	--	166	120
1	--	95	--	--	12
2	--	1,275	770	154	52
3	--	117	450	--	35
4	--	--	--	76	65
5	--	45	--	--	98
6	--	330	--	76	17
7	--	75	170	--	520
8	--	1,770	--	364	--
9	--	78	83	--	780
10	--	1,860	105	20	100
11	--	290	--	--	740
Noon	--	75	90	92	420
1	--	950	--	74	515
2	--	85	800	56	60
3	--	--	150	--	--
4	--	795	45	168	--
5	--	80	--	--	--
6	--	55	--	42	--
7	--	60	250	92	--
8	--	134	--	--	--
9	--	273	45	188	--
10	--	146	1,315	--	--
11	--	2,500	35	86	190
Avg.	--	509	285	118	248

Table VI - Plant Performance Parameters

Date	30 min.	MLSS	SVI	DO	EFF SS	MLVSS/MLSS
6/24	840	2,500	336	---	445	.20
6/27	420	2,230	188	---	1,350	.58
7/ 1	380	1,500	253	0.0	380	.57
7/ 8	320	865	370	---	125	.32
7/11	200	840	238	---	135	.64
7/15	220	1,140	193	---	128	.70
7/22	260	1,525	170	0.0	26	.62
7/25	240	1,860	129	---	470	.54
8/ 1	400	1,500	267	---	168	.80
8/ 5	460	1,500	320	0.0	430	.49
8/ 8	510	1,525	334	---	620	.75
8/14	510	1,150	443			
8/16	310	1,100	282	0.0	1,950	.73
8/20	310	950	326	---	26	.52
8/26	470	1,205	390	0.0	1,125	.81
9/ 6	360	2,300	156	0.0	72	.65
9/11	960	1,670	575	0.2	16	.67
9/12	940	1,890	495	---	15	.73
9/16	740	2,220	334	0.3	360	.57
9/23	780	3,220	242	4.8	20	.34
9/25	640	1,680	382	0.2	165	.55
10/ 5	820	1,320	620	0.3	410	.67
10/15	490	1,080	450	1.6	265	---
10/18	310	1,110	280			
10/29	680	1,170	580	0.6	1,470	.67
11/ 6	700	1,155	605	---	3,320	.42
11/ 9	570	890	640	0.7	95	.56
11/15	430	1,230	350	0.0	42	.67
11/16	380	1,220	311	0.7	410	.53
11/20	320	1,420	226	---	400	.82
11/23	350	1,380	253	0.6	380	.68
12/24	420	1,460	288	1.0	12	---
12/26	445	1,660	268	1.1	340	---
12/27	420	1,500	280	1.0	285	---
12/30	410	1,550	265	0.8	26	---
12/31	410	1,560	263	1.2	276	---
1/ 3	380	1,330	285	1.4	22	---
1/ 6	330	1,180	279	0.8	33	---
1/ 7	350	1,320	265	0.3	7	---
1/ 9	420	1,535	274	0.2	13	---
1/10	410	1,390	295	1.6	17	---
1/13				---	27	---
1/14	480	1,540	312			
1/17	510	1,670	305	0.6	16	---
1/20	580	1,750	330	---	15	---
1/22	590	1,745	338	1.0	17	---

Table VI - Plant Performance Parameters (Continued)

Date	30 min.	MLSS	SVI	DO	EFF SS	MLVSS/MLSS
1/23	500	1,705	293	2.5	18	---
1/28	490	1,700	288	2.0	17	---
2/ 3	410	1,775	231	1.0	39	---
2/ 7	200	1,380	145	---	165	---
2/10	100	1,335	75	---	203	---
2/14	140	1,020	137	---	27	---
2/21	100	1,325	75	---	98	---
2/28	130	1,640	79	0.8	92	---
3/ 1	130	1,500	87	1.2	140	.70
3/17	180	2,170	83	0.6	18	.75
3/28	360	2,015	179	1.2	95	.80

Sample Calculation for Aeration Evaluation

Standard oxygen transfer equation:

$$\frac{dC}{dt} = K_{La}\,\alpha(\beta C_S - C)$$

$\frac{dC}{dt}$ = change in concentration with time

α = ratio of K_{La} mixed liquor to K_{La} standard conditions

β = ratio C_S of mixed liquor to C_S distilled water

K_{La} = oxygen transfer coefficient hr^{-1}

C_S = saturation level of DO

C = existing level of DO

at equilibrium conditions $\frac{dc}{dt} = r$, the uptake rate

lump K_{La} into one constant, K

also C_S in mixed liquor was measured

$$K = \frac{r}{C_S - C}$$

for January 17, $K = \frac{8}{9.6-0.6} = 0.89\ hr^{-1}$ at 11° C

$$K_T = K_{20}\,(1.047)^{T-20}$$

$$K_{20} = \frac{0.89}{(1.047)^{11-20}} = 1.35$$

PERFORMANCE IMPROVEMENT OF AN
EXTENDED AERATION TREATMENT PLANT

by

DAVID F. WALDO

B.S., Kansas State University, 1973

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1975

ABSTRACT

An extended aeration activated sludge treatment plant at Walnut Grove Mobile Home Park near Manhattan, Kansas, has had a history of poor performance. Odors, foam on the aeration tank and high effluent suspended solids were part of the problem.

Wastewater flow was analyzed both for quantity and strength. Flow quantity conformed to accepted design standards. Wastewater strength may be higher than accepted design standards on the basis of maximum daily flow and average BOD_5 concentration.

The aeration system was evaluated, changed and reevaluated, resulting in a 20 percent increase in oxygen transfer efficiency. This alone was not enough to improve treatment.

Ferric sulfate was found to be an efficient means of chemical control for bulking sludge in this treatment plant. It improved performance by a flocculating and weighting action and possibly satisfied a nutrient deficiency. Control of the bulking and maintenance of the solids within the aeration tank allowed a stable biological sludge to develop, further improving the plant performance.