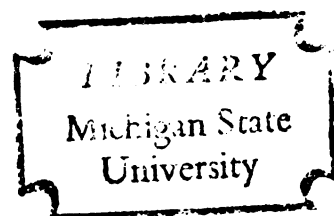
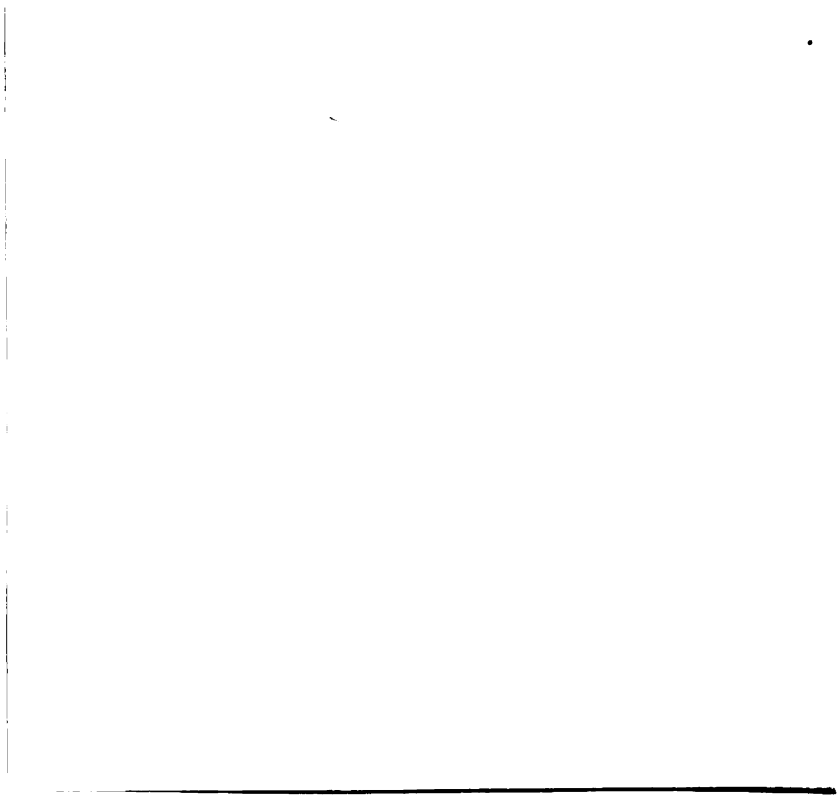


SPECIFIC AND OVERALL OXYGEN
CONSUMPTION RATES IN ACTIVATED SLUDGE
MIXED LIQUOR

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
Clarence John Cole Jr.
1972





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ABSTRACT

SPECIFIC AND OVERALL OXYGEN CONSUMPTION RATES IN ACTIVATED SLUDGE MIXED LIQUOR

By

Clarence John Cole Jr.

This thesis deals with the overall and specific oxygen consumption rates as determined from various batches of mixed liquor. The mixed liquor batches were made of return sludge and primary effluent in the ratios of 1:4, 1:3, 1:2, and 1:1. Four different activated sludge wastewater treatment plants were tested for this data. Each plant was tested on five different days for the four mixed liquor batches as described above.

The suspended solids concentration of the primary effluent and the return sludge was determined so as to be able to compute the initial suspended solids concentration of the various batches of mixed liquor. Also, the overall and specific oxygen consumption rates of the primary effluent and the return sludge were determined in order to calculate the initial oxygen consumption rates in the mixed liquor. A dissolved oxygen meter with a temperature sensitive electrode placed in the stoppered 250 ml

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Erlenmeyer flask containing the sample was used to determine the overall oxygen consumption rates. The dissolved oxygen meter was then connected to an electric recorder which plotted dissolved oxygen concentration versus time. And the overall oxygen consumption rate was determined by finding the slope of this line. The specific oxygen consumption rate was found by the equation:

$$r_r = k_r \times SS$$

r_r = overall oxygen consumption rate (mg O₂/l/hr)

k_r = specific oxygen consumption rate (mg O₂/gm SS/hr)

SS = suspended solids concentration (gm/l)

The data obtained from these tests resulted in high initial overall and specific oxygen consumption rates. An increase in suspended solids concentration resulted in an increase in the overall oxygen consumption rate but a decrease in the specific oxygen consumption rate. Theoretically, the rate of supply of oxygen in the aeration tank of an activated sludge treatment plant should be greater than or equal to the sum of the overall oxygen consumption rate and the endogenous respiration rate. From the literature, the value of 22.5 mg O₂/l/hr was the rate of oxygen supply in a typical activated sludge treatment plant. This value fell far below the overall oxygen consumption rates which were found in the plants tested. And from the wastewater treatment plants tested,

Clarence John Cole Jr.

it appeared obvious that the typical aeration equipment used in such plants could not provide the necessary dissolved oxygen required by the microorganisms to maintain their maximum respiration rates. Therefore, it seems reasonable to predict that in most typical activated sludge treatment plants, the process is oxygen dependent.

SPECIFIC AND OVERALL OXYGEN
CONSUMPTION RATES IN ACTIVATED SLUDGE
MIXED LIQUOR

By

Clarence John Cole Jr.

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Civil and Sanitary Engineering

1972

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ACKNOWLEDGMENTS

I wish to express my gratitude to the personnel at the Grandville, East Lansing, Mason, and Lansing Wastewater Treatment Plants for their friendliness, helpfulness, and courteousness while working in their laboratories in gathering the data for this thesis. Without their fully appreciated cooperation, this work would have been much more difficult. Also, I would like to express my gratitude to Dr. Schulze for his help in the preparation of this thesis.

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LIST OF LABORATORY EQUIPMENT USED,
SYMBOLS AND NOMENCLATURE

Laboratory Equipment

Dissolved Oxygen Meter with temperature sensitive
electrode-Yellow Springs Instrument Co., Inc., Model 54

Electric Recorder-Bausch and Lomb

Wide Mouth 250 ml Erlenmeyer Flask

Filter Paper and Filtering Apparatus

Hot Plate

Magnetic Stirrer

Thermometers, C

Drying Oven

Metric Balance

Air Diffusers

Assorted Glassware

Symbols and Nomenclature

r_r	Overall oxygen consumption rate (mg O_2 /l/hr)
k_r	Specific oxygen consumption rate (mg O_2 /gm SS/hr)
SS	Suspended solids
MLSS	Mixed liquor suspended solids
t	Time
DO	Dissolved oxygen
PE	Primary effluent
RS	Return sludge
ML	Mixed liquor

INTRODUCTION

The purpose of this research is to determine the overall oxygen consumption rate (r_r) and the specific oxygen consumption rate (k_r) of various concentrations of mixed liquor in an activated sludge wastewater treatment plant. The data were obtained at four such treatment plants. Specifically, the plants were located at Grandville, East Lansing, Mason, and Lansing. Each plant was tested on five different days to get a representative sampling for the determination of r_r and k_r values. Four different ratios of return sludge to primary effluent were used in preparing the mixed liquor batches. They were: 1:4, 1:3, 1:2, 1:1. This represented recycle ratios of 25%, 33%, 50%, and 100%.

Theory of Dissolved Oxygen Electrode

A brief discussion of the theory of the dissolved oxygen electrode used for this research is appropriate. The dissolved oxygen meter works on the basis of the measurement of the current induced by the reactions at the electrode. This current is directly proportional to the partial pressure of the oxygen, see Figure 1. The electrodes are separated from the surrounding solution by

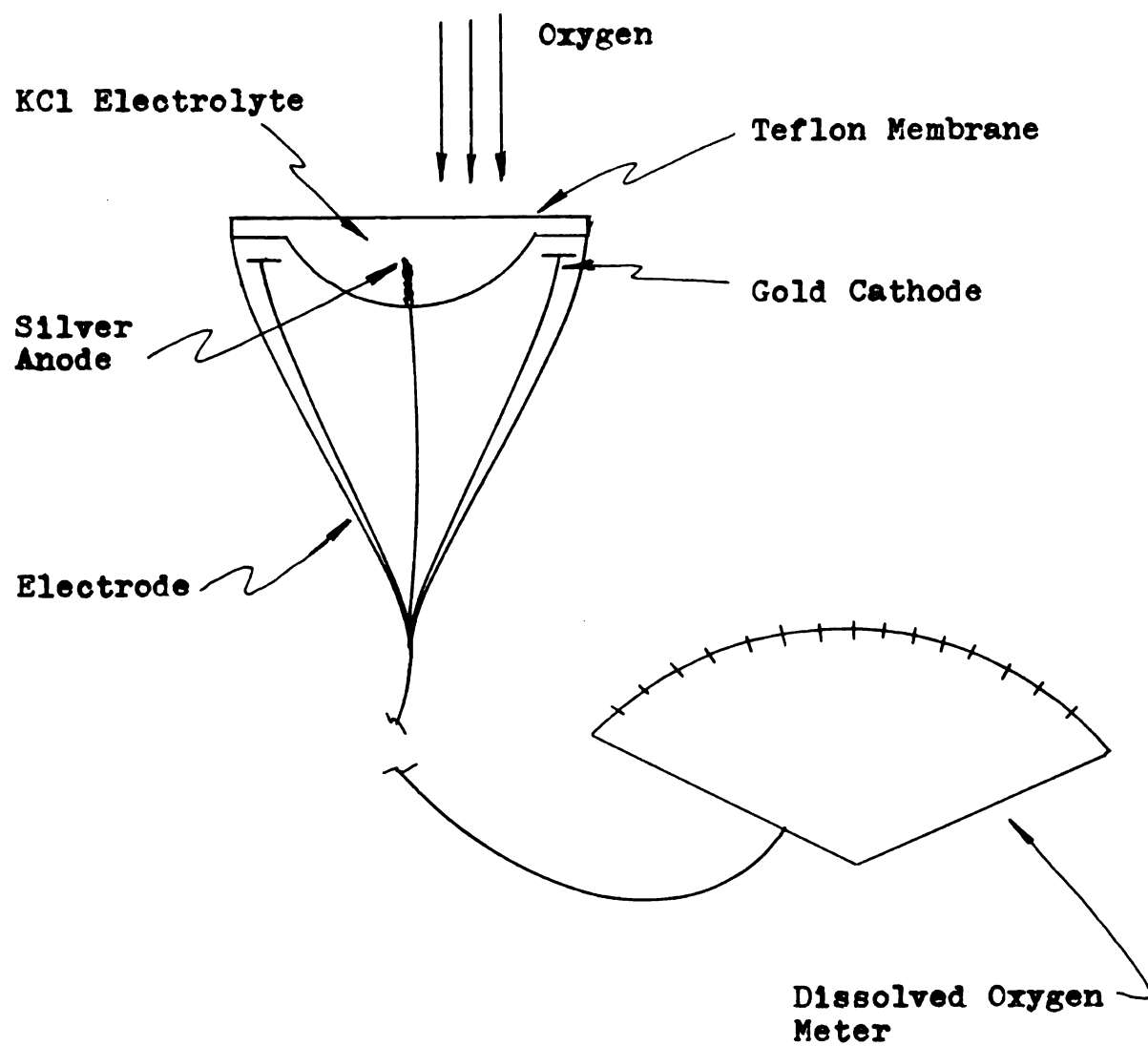


Figure 1. Electrode Schematic

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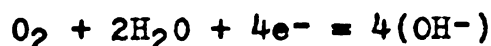
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a semipermeable teflon membrane and are immersed in a $\frac{1}{2}$ N KCl solution. The membrane is permeable for dissolved oxygen and the KCl solution serves as an electrolyte. The reaction produced at the anode is:



And the reaction produced at the cathode is:



A flow of water must be provided past the membrane to maintain the concentration gradient between the outside solution and the electrolyte. For the measurement of the oxygen consumption rates r_T and k_T , the dissolved oxygen meter was connected to an electric recorder which plotted dissolved oxygen concentration versus time.

Theoretical Considerations

The operation of an activated sludge wastewater treatment plant hinges on the operation of its aeration tank. And the primary purpose of the aeration tank is to provide the necessary oxygen for the microorganisms in order that they may oxidize the organic matter contained in the wastewater. Theoretically, the supply of oxygen provided should be equal to the demand of oxygen by the microorganisms. The oxygen required by the microorganisms is measured by the overall oxygen consumption rate, r_T . As early as 1939, Sawyer and Nichols (1) showed that the overall

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oxygen consumption rate is temperature dependent, and that at any given temperature, the rate of oxygen consumption is dependent on two factors; the sewage concentration or strength measured as BOD or COD and the amount of activated sludge or suspended solids in the mixed liquor. McKinney (6) has stated that generally the rate of microorganism growth doubles with every 10°C increase in temperature, up to a limiting temperature. The two processes occurring are the increased rate of reaction due to an increase in temperature and the denaturation of specific proteins at a definite temperature. The denaturation reaction is not significant at low temperatures and the increased rate of reaction dominates. However, as the temperature approaches 35°C , denaturation becomes significant resulting in a zero growth rate of the microorganisms.

In the activated sludge process, the return sludge is the source of the microorganisms which oxidize the organic matter. The most significant source of the organic matter is the primary effluent. Since the rate of oxygen consumption is temperature dependent, the samples of return sludge and primary effluent which were used to make up the mixed liquor batches were heated to 23°C and were then maintained at $23 \pm 1^{\circ}\text{C}$. The initial rate of oxygen consumption is primarily due to the oxidation of the carbonaceous material. The magnitude of the oxygen

consumption rate is expected to vary from plant to plant and from day to day within a single plant. This is because of the very complex and continuously changing characteristics of the sewage and return sludge at an operating plant.

Mathematical Relationship

Schulze and Kooistra (5) have stated that the specific oxygen consumption rate (k_r) of the bacteria is related to substrate concentration and that this relation can be expressed mathematically. Bacteria are the active ingredient of the sludge floc and therefore the specific oxygen consumption rate (k_r) can be used as a parameter to determine the physiological activity of the floc. The overall oxygen consumption rate of the mixed liquor is then dependent on the suspended solids concentration and the specific oxygen consumption rate.

$$r_r = k_r \times SS$$

r_r = overall oxygen consumption rate (mg O_2 /l/hr)

k_r = specific oxygen consumption rate (mg O_2 /gm SS/hr)

SS = suspended solids concentration (gm/l)

This mathematical relationship shows that r_r is affected by both the suspended solids concentration and the specific oxygen consumption rate.

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Using this formula, k_T can be calculated. The dissolved oxygen meter measures the dissolved oxygen concentration (mg/l) at a given time. As the dissolved oxygen concentration is recorded by means of an electric recorder, a straight line relationship will result for the length of time for each trial run (usually two to six minutes). From this curve, the slope will represent r_T in mg/l per unit time. And knowing the suspended solids concentration of the mixed liquor, the specific oxygen consumption rate (k_T) can then be calculated from the equation.

Oxidation of Organic Matter

The removal of organic matter by biological oxidation is a three phase process, as described by Eckenfelder (4). Initial removal of substrate as represented in particulate form is by means of adsorption and coagulation. Also, a portion of the soluble organic matter is initially removed by absorption and stored in the cell as a reserve food source. Secondary removal is described as the removal of dissolved organic matter during the aeration process. This results in the synthesis of sludge and the production of carbon dioxide and water. And final removal of organic matter is the oxidation of biological cellular material through endogenous respiration. Lijklema (8) describes endogenous respiration as that

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respiration of microorganisms which occurs in the absence of extracellular substrate. During this period, the microorganisms metabolize their own reserves. Generalized equations representing oxidation of the substrate are as follows:

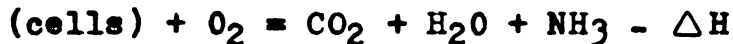
Organic matter oxidation



Cell material synthesis



Cell material oxidation



ΔH represents the heat of reaction.

From these equations, the important role played by oxygen is evident in the biological oxidation of the organic matter. For the best efficiency in an activated sludge treatment plant, the rate of oxygen supply should be equal to or greater than the rate of oxygen consumption or the process may become oxygen dependent.

The microbial growth curve is usually divided into three phases: logarithmic growth, declining growth, and stationary phase. During logarithmic growth, assuming there is an excess of substrate, the rate of metabolism and growth is only limited by the microorganisms ability to oxidize the organic matter. This represents their maximum growth rate and the maximum rate at which organic

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matter is being oxidized. However, often in activated sludge treatment plants, this maximum growth rate can not be attained due to limitations in substrate concentration and in the concentration of dissolved oxygen. The declining growth phase occurs due to the continual removal of organic matter. As this proceeds, the process becomes substrate dependent and therefore the rate of bacterial growth declines. No growth occurs when the substrate concentration becomes a minimum and the microorganisms begin to metabolize their own reserves. This is referred to as endogenous respiration as stated previously.

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METHODS AND PROCEDURE

Each of the four activated sludge treatment plants, as listed in the introduction, were tested on five different days. On each day, grab samples were taken of both the primary effluent and the return sludge. And from these, the various batches of mixed liquor were made. The temperature of both the primary effluent and return sludge was determined, and both samples were heated to 23°C, so as to maintain a constant temperature of the mixed liquor during the laboratory work. The size of each sample was approximately four liters to insure that there was enough primary effluent and return sludge to make up four batches of mixed liquor using ratios of return sludge to primary effluent of 1:4, 1:3, 1:2, and 1:1.

Suspended Solids Determination

Suspended solids of both the return sludge and primary effluent were determined by means of filtration of a known volume of sample as described in Standard Methods (7). This resulted in the weight of suspended solids per unit volume of sample filtered. Knowing the suspended solids of both the return sludge and the primary effluent, and

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the ratios of each in the various mixed liquor batches, it was possible to calculate the initial suspended solids in the mixed liquor.

Calibration of Dissolved Oxygen Meter

The dissolved oxygen meter was calibrated each day in air since the saturated dissolved oxygen concentration of the liquid is dependent on temperature and barometric pressure. From Fair, Geyer and Okun (14), C_s , the saturation values of dissolved oxygen in fresh water exposed to an atmosphere containing 20.9% oxygen under a pressure of 760 mm of mercury, were obtained for a given temperature. This value was then corrected for barometric pressure. The solubility of dissolved oxygen varies approximately as the ratio of the actual pressure to the standard pressure. As a control, the dissolved oxygen meter was also checked for residual current. This was accomplished by using a water solution saturated with Na_2SO_3 , which resulted in a zero dissolved oxygen concentration. The electrode was then placed in this solution which was being stirred by means of a magnetic stirrer. The reading obtained on the dissolved oxygen meter was then the result of residual current. The readings ranged from approximately 0.15 to 0.25 mg/l. If larger readings occurred, this was an indication to recharge the electrode.

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Oxygen Consumption Rates

After having taken the samples and heating them to 23°C and after calibrating and checking the dissolved oxygen meter for residual current, the primary effluent and the return sludge were checked separately for their overall oxygen consumption rates, r_T . The method used to determine overall oxygen consumption rate of the return sludge, primary effluent and the mixed liquor was the same. A 250 ml wide mouth Erlenmeyer flask was filled with the sample. The electrode was then placed in the flask through a rubber stopper to prevent contact with the atmospheric oxygen, and the sample was stirred by means of a magnetic stirrer to insure a flow of water past the electrode. An electric recorder was then connected to the dissolved oxygen meter which plotted dissolved oxygen concentration versus time. And r_T could then be calculated by finding the slope of that line; the units would be mg/l per unit time. See Figure 2 for diagram. Before placing the electrode in the samples, the samples were aerated for a short period of time to insure a sufficient dissolved oxygen concentration in the sample. Two trials were made on both the return sludge and primary effluent.

The various batches of the mixed liquor were tested for overall oxygen consumption rates in the same manner as the primary effluent and the return sludge, utilizing a

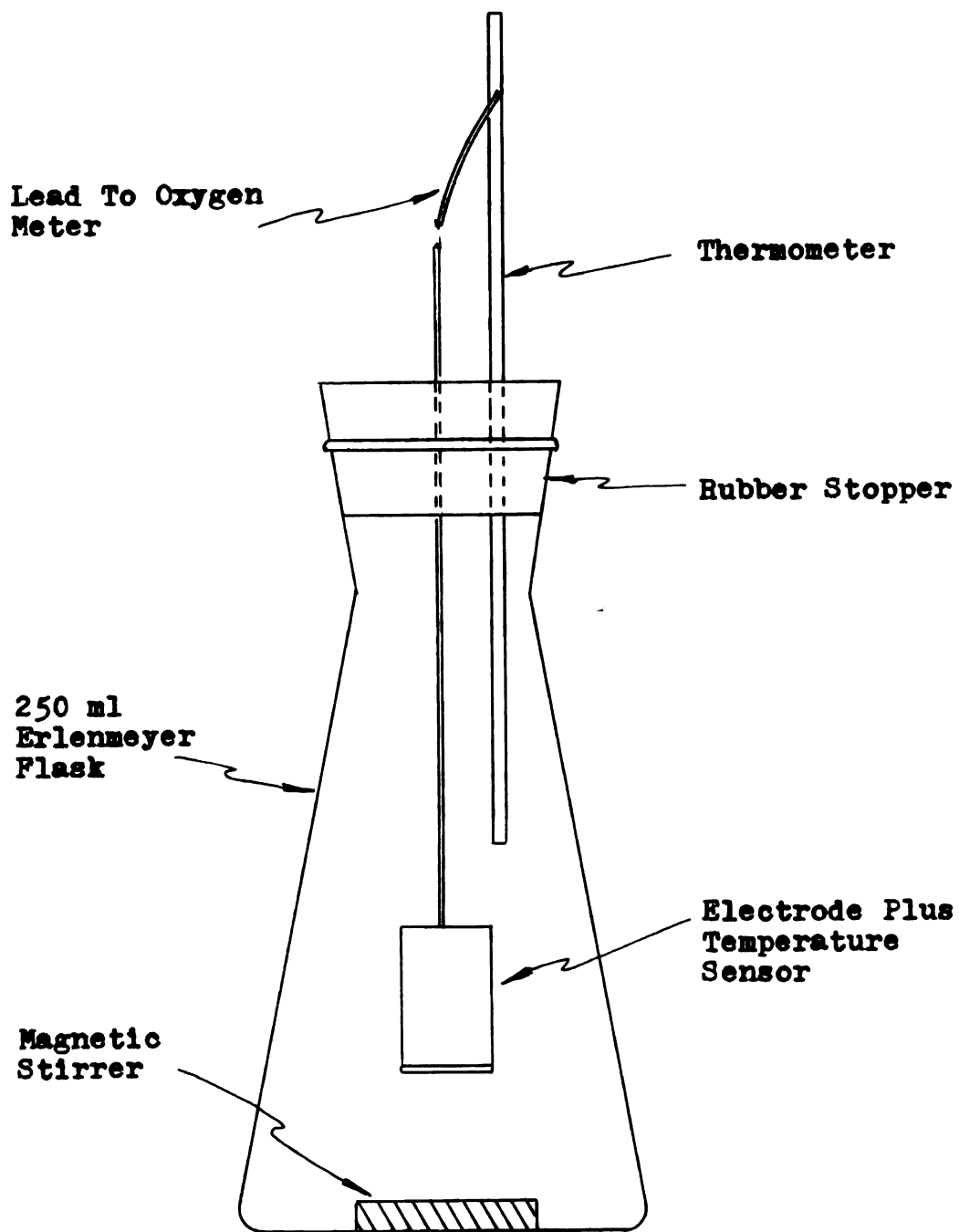


Figure 2. Apparatus to measure mixed liquor oxygen consumption rates.

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stoppered 250 ml Erlenmeyer flask. Eckenfelder (4) points out that the bacterial respiration is independent of oxygen concentration when the dissolved oxygen concentration in the mixed liquor is maintained at a minimum of 0.2 to 0.5 mg/l. Therefore, during the trial runs of dissolved oxygen depletion as to time for the various mixed liquor batches, the sample drawn off for a particular trial run was not allowed to go beyond this minimum dissolved oxygen concentration. Each mixed liquor batch consisted of a one liter volume. The various volumes of primary effluent and return sludge used to make up these batches were as described in Table 1.

Table 1. Return sludge to primary effluent ratios of the various batches of mixed liquor.

<u>Mixed Liquor ratio RS:PE</u>	<u>Vol RS (ml)</u>	<u>Vol PE (ml)</u>	<u>Vol ML (ml)</u>
1:4	200	800	1000
1:3	250	750	1000
1:2	333	667	1000
1:1	500	500	1000

For each batch of mixed liquor, first the primary effluent was added, and then the return sludge. The time of mixing was designated as time zero. All time measurements for that particular mixed liquor batch were measured from that time zero. The mixed liquor batch

was aerated continuously, and at a rate to insure a sufficient dissolved oxygen concentration so that the process was not oxygen dependent. At various time intervals (usually nine trials during thirty minutes), a sample of mixed liquor was drawn off the continuously aerated batch and placed in the 250 ml Erlenmeyer flask and checked for overall oxygen consumption rate. Between each trial run, the electrode was placed in a sample of primary effluent which was not aerated, resulting in a very low dissolved oxygen concentration. When the electrode was then placed in the sample of mixed liquor, a definite breaking point existed where the instrument showed a beginning decrease in dissolved oxygen concentration. The recorded curve of dissolved oxygen concentration versus time showed this very clearly. For each mixed liquor batch, approximately nine r_T values were determined within a thirty minute time interval. This resulted in a fairly well represented curve when plotting overall oxygen consumption rates versus time. For each of the nine trials, the time the sample was drawn off the continuously aerated mixed liquor batch and the length of the time for the trial run were noted. From these times, the average time was used in plotting the overall oxygen consumption rate versus time. The average time being defined as:

$$t \text{ (ave)} = t_1 + (t_T/2)$$

t (ave) = average time

t_1 = initial time, the time the sample was drawn
from the mixed liquor

t_r = length of time for trial run

All mixed liquor batches from the four wastewater treatment plants were aerated for about thirty minutes which was the elapsed time for the overall oxygen consumption rate determinations. Thirty minutes appeared to be an appropriate time period for the test since after that time the r_r values began to approach a stable value.

Four Hour Aeration Time

A separate mixed liquor batch made up of return sludge and primary effluent from the East Lansing plant was allowed to run for four hours. And from this mixed liquor, oxygen consumption rates were determined. The ratio of return sludge to primary effluent was 1:3. The four hour aeration time made it possible to demonstrate the shape of the r_r and k_r curves over a four hour aeration time as compared to the normal thirty minutes. Again, suspended solids concentration and r_r values were determined separately on the return sludge and the primary effluent in order to calculate the suspended solids concentration and the initial r_r value of the mixed liquor at the time of mixing. The overall oxygen consumption rates for the return sludge, primary effluent and the mixed liquor were determined as before

by finding the slope of the line produced by plotting dissolved oxygen concentration versus time. For this experiment, the return sludge, primary effluent and mixed liquor were again maintained at approximately 23°C so as to be able to compare the r_T values with those of the previous tests.

Approximately eighteen samples were taken for the overall oxygen consumption rate determinations during the four hour aeration time. This resulted in a fairly well represented curve when plotting oxygen consumption rates versus time.

DATA AND RESULTS

Since all the data collected from the various plants proved to be similar, although varying in magnitude, one typical example is given to represent the calculations and the curves necessary to illustrate the results. The remaining data are presented as tables and curves in the appendix.

Data obtained at the East Lansing Wastewater Treatment Plant on January 19, 1972 are used as the example. Also illustrated will be that sample of the East Lansing plant for which a four hour aeration period was used. The date of this test was June 6, 1972.

Data Obtained on January 19, 1972

Samples taken: 2:15 p.m.

Temperature of samples: 16°C

Samples heated to 23°C

Calibration of Dissolved Oxygen Meter

Temperature = 24°C

$C_s = 8.3 \text{ mg/l at } 760 \text{ mm Mercury}$

$C_s = 8.3 \times 740/760 = 8.07 \text{ mg/l}$

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Residual Current

Using Na_2SO_3 , residual current = 0.2 mg/l

Suspended Solids Determinations

Return Sludge

	<u>Trial No. 1</u>	<u>Trial No. 2</u>
Filter + SS	224.3 mg	224.8 mg
Filter	102.3 mg	101.8 mg
Volume	<u>20 ml</u>	<u>20 ml</u>
	122.0 mg/20 ml	123.0 mg/20 ml
Trial No. 1: SS	$= 122.0 \text{ mg}/20 \text{ ml} \times 1000 \text{ ml/l} \times \text{gm}/1000 \text{ mg}$ $= 6.10 \text{ gm/l}$	
Trial No. 2: SS	$= 123.0 \text{ mg}/20 \text{ ml} \times 1000 \text{ ml/l} \times \text{gm}/1000 \text{ mg}$ $= 6.15 \text{ gm/l}$	

SS ave. = 6.12 gm/l

Primary Effluent

	<u>Trial No. 1</u>	<u>Trial No. 2</u>
Filter + SS	104.8 mg	105.5 mg
Filter	103.5 mg	104.7 mg
Volume	<u>20 ml</u>	<u>20 ml</u>
	1.3 mg/20 ml	0.8 mg/20 ml
Trial No. 1: SS	$= 1.3 \text{ mg}/20 \text{ ml} \times 1000 \text{ ml/l} \times \text{gm}/1000 \text{ mg}$ $= .065 \text{ gm/l}$	
Trial No. 2: SS	$= 0.8 \text{ mg}/20 \text{ ml} \times 1000 \text{ ml/l} \times \text{gm}/1000 \text{ mg}$ $= .040 \text{ gm/l}$	

SS ave. = .053 gm/l

Suspended Solids of Mixed Liquor

Sample Calculation of 1:4 Mixture

$$\text{RS } .2 \times 6.12 \text{ gm/l} = 1.224 \text{ gm}$$

$$\text{PE } .8 \times .035 \text{ gm/l} = \underline{0.042 \text{ gm}}$$

$$1.0 \qquad \qquad \qquad 1.266 \text{ gm}$$

$$\text{MLSS} = 1.266 \text{ gm/l}$$

Calculation of r_r and k_r

Note: A sample calculation of r_r and k_r for trial No. 1 of the return sludge will be illustrated in detail. All other r_r and k_r values will be tabulated since they were found in the same manner.

Table 2. Dissolved oxygen concentration compared to time for trial number one of RS sample.

<u>Time (min)</u>	<u>DO Conc. (mg/l)</u>
0	4.4
1	3.5
2	2.6
3	1.7

From Figure No. 3, $r_r = x/y$

$$r_r = (3.9 - 1.9)/(0.5 - 2.75) = .89 \text{ mg/l/min}$$

$$r_r = .89 \text{ mg/l/min} \times 60 \text{ min/hr} = 53.4 \text{ mg/l/hr}$$

$$r_r = k_r \times \text{SS}$$

$$k_r = r_r/\text{SS}$$

$$k_r = (53.4 \text{ mg/l/hr})/(6.12 \text{ gm/l})$$

$$k_r = 8.7 \text{ mg/gm SS/hr}$$

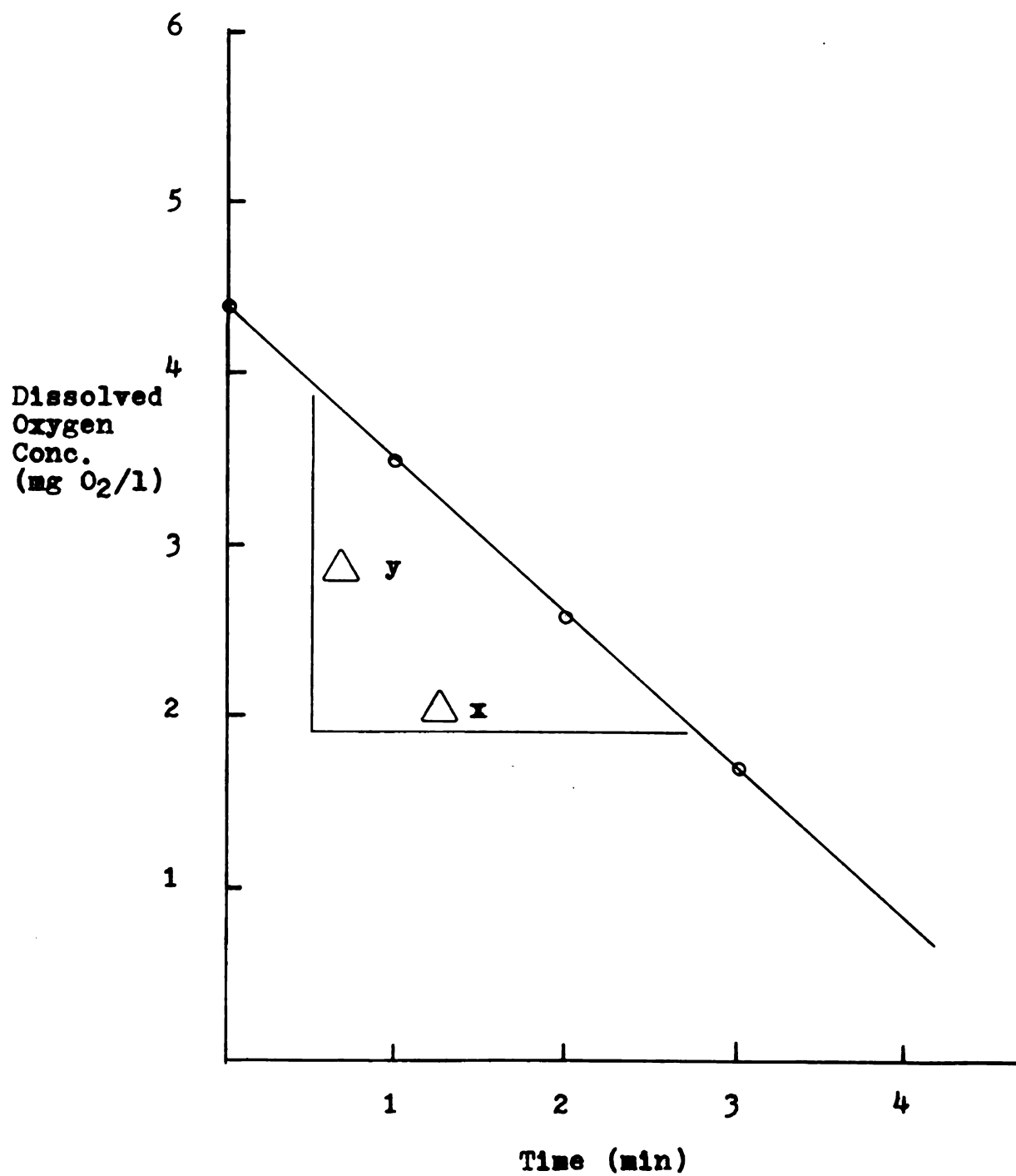


Figure 3. Dissolved oxygen concentration versus time for return sludge, trial number 1.

Table 3. r_r and k_r values of primary effluent and return sludge.

	<u>Trial No.</u>	<u>r_r(mg O_2/l/hr)</u>	<u>k_r(mg O_2/gm SS/hr)</u>
PE	1	4.2	79.2
	2	4.8	90.6
RS	1	53.4	8.7
	2	43.0	7.0

Primary effluent: r_r ave. = 4.5 mg O_2 /l/hr

k_r ave. = 84.9 mg O_2 /gm SS/hr

Return sludge: r_r ave. = 48.2 mg O_2 /l/hr

k_r ave. = 7.9 mg O_2 /gm SS/hr

Calculation of initial r_r and k_r values at time zero.

Note: A sample calculation for initial r_r and

k_r values will be illustrated for the 1:4 mixture.

	<u>SS</u>	<u>k_r(ave)</u>	<u>r_r</u>
Return sludge:	.2 x 6.12 = 1.224	x 7.9	= 9.67
Primary Effluent:	.8 x .093 = .042	x 84.9	= <u>3.56</u>
	1.266		13.23

Initial r_r = 13.23 mg O_2 /l/hr

Initial k_r = 13.23 = 10.45 mg O_2 /gm SS/hr

1.266

Table 4. Initial r_r and k_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O_2/gm SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	1.266	10.45	13.23
1:3	1.569	9.83	15.43
1:2	2.054	9.23	18.96
1:1	3.086	8.57	26.44

Table 5. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O_2/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O_2/gm SS/hr)</u>
1:4	1	81.0	1:15	64.0
	2	69.0	3:08	54.5
	3	60.0	4:45	47.4
	4	63.0	6:52	49.8
	5	54.0	9:30	42.6
	6	45.0	12:00	35.5
	7	33.0	16:15	26.1
	8	30.0	21:15	23.7
	9	24.0	26:22	19.0
1:3	1	96.0	1:15	61.2
	2	84.0	3:22	53.5
	3	66.0	5:15	42.1
	4	60.0	7:30	38.2
	5	39.0	9:52	24.9
	6	39.0	11:30	24.9

Table 5 (con'd.)

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r</u> <u>(mg O₂/l/hr)</u>	<u>Ave. Time</u> <u>(min:sec)</u>	<u>k_r</u> <u>(mg O₂/gm SS/hr)</u>
1:3	7	36.0	16:55	23.0
	8	30.0	21:45	19.1
	9	27.0	26:52	17.2
1:2	1	111.0	1:15	54.0
	2	81.0	3:22	39.4
	3	60.0	5:30	29.2
	4	48.0	8:00	23.4
	5	36.0	10:30	17.5
	6	33.0	13:15	16.1
	7	30.0	16:15	14.6
	8	24.0	21:22	11.7
	9	24.0	26:22	11.7
1:1	1	123.0	1:15	39.9
	2	72.0	3:00	23.3
	3	63.0	5:00	20.4
	4	54.0	7:30	17.5
	5	36.0	10:00	11.7
	6	36.0	12:37	11.7
	7	33.0	16:07	10.7
	8	33.0	21:07	10.7
	9	30.0	26:15	9.7

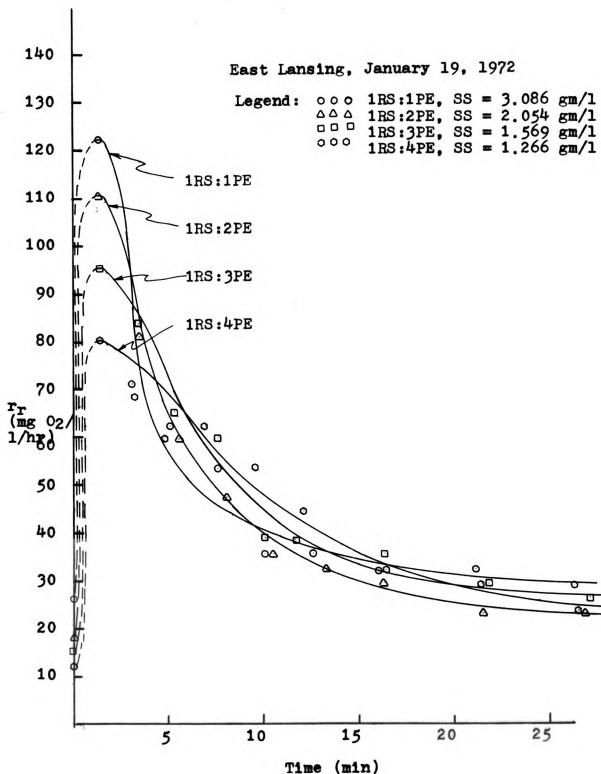


Figure 4. Overall oxygen consumption rates (r_r) versus time for various batches of mixed liquor.

East Lansing, January 19, 1972

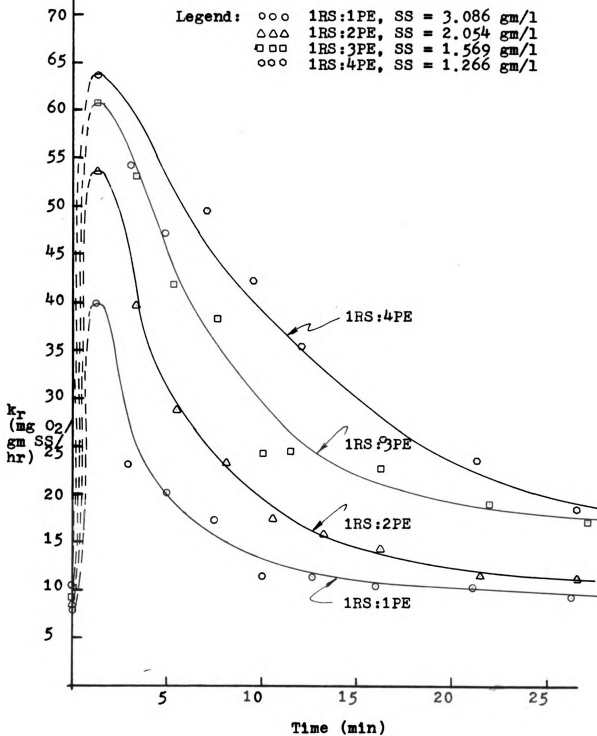


Figure 5. Specific oxygen consumption rates (k_r) versus time for various batches of mixed liquor.

East Lansing, January 19, 1972

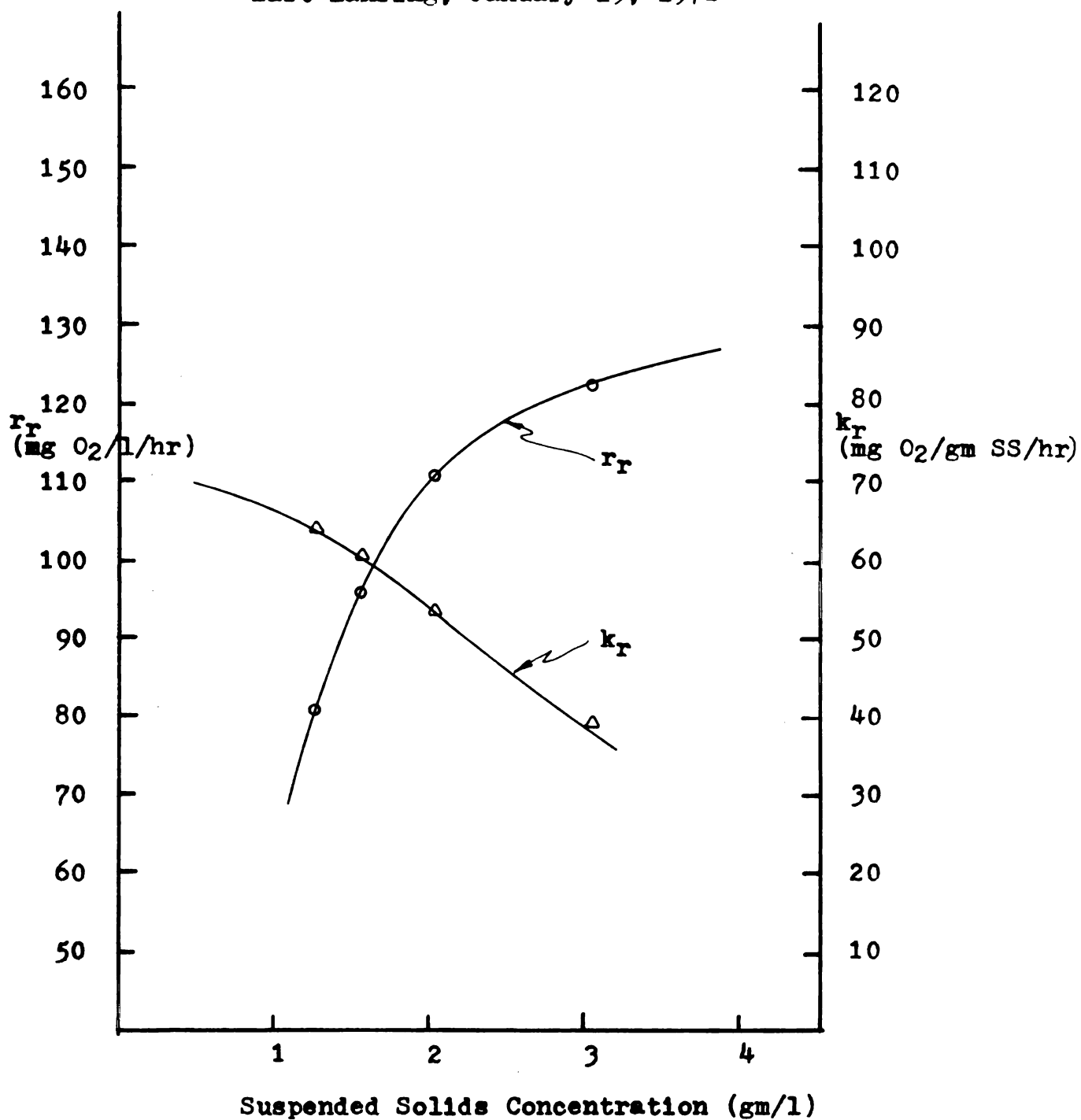


Figure 6. Maximum overall (r_r) and specific (k_r) oxygen consumption rates versus suspended solids concentration.

As mentioned previously, the data given are for one day's test at the East Lansing plant. The data for the other day's tests and for the other plants are presented in the appendix.

Data Obtained for the Four Hour Aeration Time, June 6, 1972

The following data are for the mixed liquor sample from the East Lansing Wastewater Treatment Plant which was aerated for four hours. The methods used to evaluate r_r , k_r and suspended solids are as previously illustrated, so the details will be omitted.

Samples taken 4:00 p.m.

Temperature of samples: 22°C

Samples heated to 23°C

Calibrate DO Meter: $C_s = 7.49$ mg/l

Residual Current = 0.2 mg/l

Return Sludge: SS Ave. = 8.04 gm/l

Primary Effluent: SS Ave. = 0.028 gm/l

Table 6. r_r and k_r values of primary effluent and return sludge for the four hour aerated sample.

	<u>Trial No.</u>	<u>r_r(mg O₂/l/hr)</u>	<u>k_r(mg O₂/gm SS/hr)</u>
PE	1	0.6	21.4
	2	0.6	21.4
RS	1	27.0	3.2
	2	27.0	3.2

3-20-68

Primary Effluent: r_r ave. = 0.6 mg O_2 /l/hr

k_r ave. = 21.4 mg O_2 /gm SS/hr

Return Sludge: r_r ave. = 27.0 mg O_2 /l/hr

k_r ave. = 3.2 mg O_2 /gm SS/hr

The mixed liquor batch was made of a ratio of return sludge to primary effluent of 1:3.

MLSS = 2.03 gm/l

Initial r_r = 6.86 mg O_2 /l/hr

Initial k_r = 3.38 mg O_2 /gm SS/hr

Table 7. r_r and k_r values for the mixed liquor aerated for four hours.

<u>Trial No.</u>	<u>r_r (mg O_2/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O_2/gm SS/hr)</u>
1	99.0	1:22	48.8
2	87.0	3:45	42.9
3	63.0	6:30	31.0
4	45.0	9:30	22.2
5	36.0	13:15	17.7
6	36.0	16:45	17.7
7	33.0	20:45	16.3
8	27.0	26:00	13.3
9	27.0	46:00	13.3
10	18.0	64:00	8.9
11	15.0	82:30	7.4
12	15.0	96:30	7.4
13	15.0	104:00	7.4

Table 7 (con'd.)

<u>Trial No.</u>	<u>r_r</u> <u>(mg O₂/l/hr)</u>	<u>Ave. Time</u> <u>(min:sec)</u>	<u>k_r</u> <u>(mg O₂/gm SS/hr)</u>
14	15.0	126:00	7.4
15	15.0	153:30	7.4
16	12.0	187:00	5.9
17	9.0	215:15	4.4
18	9.0	245:30	4.4

The above data for the r_r and k_r values as listed in Table 7 are presented graphically in Figure 7.

Legend: $\circ \circ \circ$ r_r values
 $\Delta \Delta \Delta$ k_r values
 Mixed Liquor Suspended Solids = 2.03 gm/l

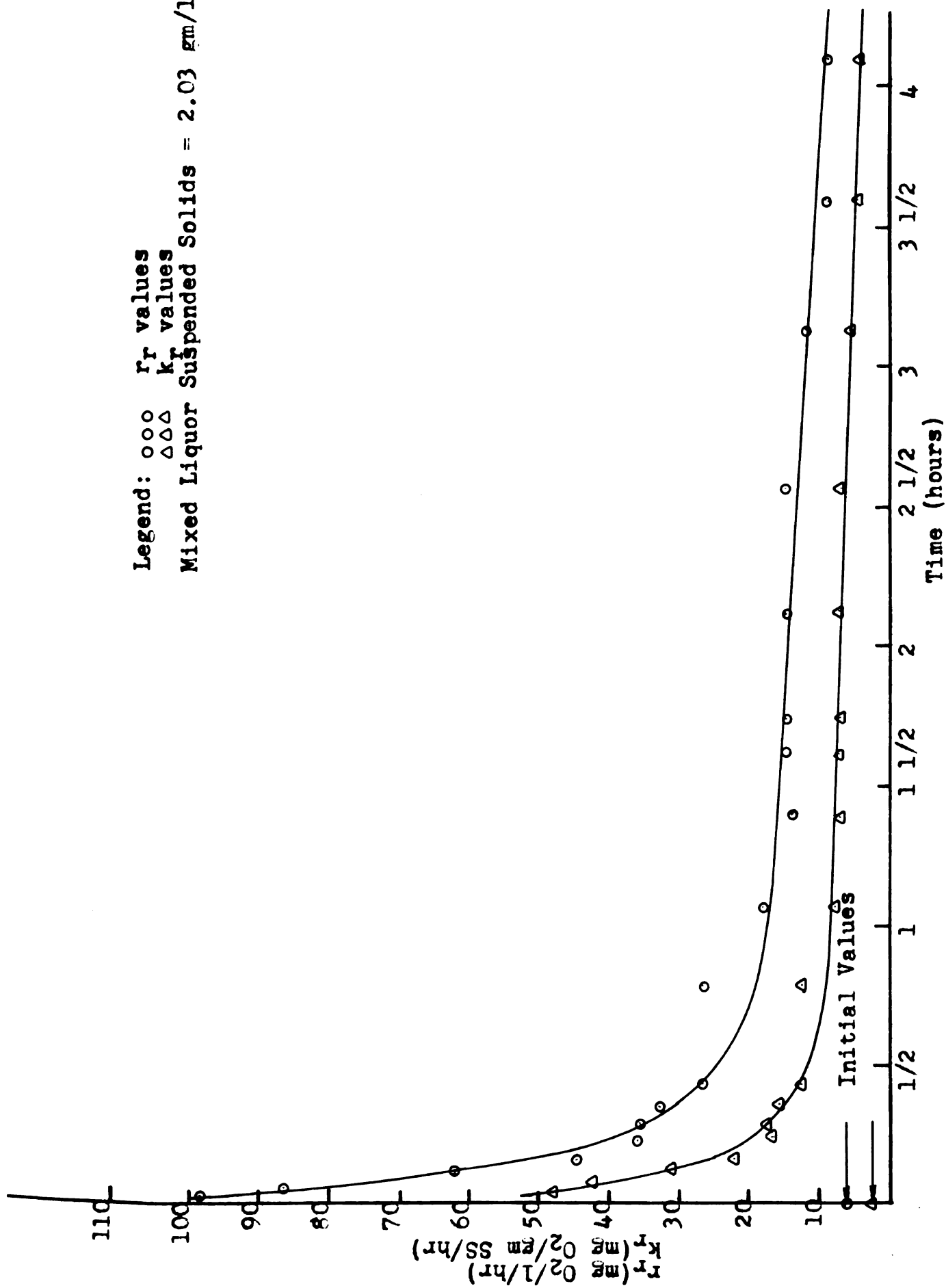


Figure 7. Specific (k_r) and overall (r_r) oxygen consumption rates versus time for mixed liquor batch, lRS:3PE.

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DISCUSSION

The graphs of specific and overall oxygen consumption rates versus time indicate the situation in the mixed liquor. From the data it is evident that the r_T value of the primary effluent increased from trial number one to trial number two. This is due to the relatively large amount of substrate in the primary effluent and the small number of bacteria. As time passed, the number of bacteria increased and therefore also, the overall oxygen consumption rate, r_T . The opposite is true for the return sludge where r_T decreases from trial number one to trial number two. This is because of the low concentration of substrate and the large concentration of bacteria. Food soon becomes a limiting factor and therefore causes a decrease in r_T .

Sludge growth and substrate removal are based on the mass transfer of essential foods into the microbial cell and the utilization of these foods for energy. The graphs of r_T and k_T show that the initial respiration rates are high. The r_T curve represents the overall oxygen consumption rate and the k_T curve represents the physiological activity of the sludge floc which

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contains the bacteria utilized in the oxidation of the organic matter. From all the various tests, the range of the r_r and k_r values for each mixed liquor batch from the four treatment plants are as follows:

Table 8. Range of maximum r_r and k_r values in the various batches of mixed liquor.

<u>Mixed Liquor RS:PE Ratio</u>	<u>SS (gm/l) Range</u>	<u>Max.r_r Range (mg O_2/l/hr)</u>	<u>Max.k_r Range (mg O_2/gm SS/hr)</u>
1:4	1.01-2.94	39-120	18.4-80.4
1:3	1.24-3.66	51-138	20.4-80.2
1:2	1.63-4.80	48-162	15.8-66.4
1:1	2.44-7.22	57-189	12.3-57.8
<u>Mixed Liquor RS:PE Ratio</u>	<u>SS (gm/l) Range</u>	<u>Max.Ave.r_r (mg O_2/l/hr)</u>	<u>Max.Ave.k_r (mg O_2/gm SS/hr)</u>
1:4	1.01-2.94	89.7	51.0
1:3	1.24-3.66	100.2	46.6
1:2	1.63-4.80	112.3	39.9
1:1	2.44-7.22	133.1	31.5

Table 8 lists the range of maximum r_r and k_r values and the averages for the four treatment plants tested on the various days. The average values are a result of all the maximum values obtained during the tests, not just an average of the range. The wide range of maximum r_r and k_r values indicates the many differences found from plant to plant and the differences within each plant on a day to day basis. The most significant

reasons for this wide range are the suspended solids concentration on each particular day and the amount of substrate available for oxidation. Figure 6 indicates the effect of suspended solids concentration on the maximum r_r and k_r values. A higher mixed liquor suspended solids concentration indicates a higher recycle ratio which means more dilution of the primary effluent with the return sludge. And an increase in mixed liquor suspended solids results in an increase in the overall oxygen consumption rates (r_r) with a corresponding decrease in the specific oxygen consumption rate (k_r). The equation $r_r = k_r \times SS$ holds. Since temperature was kept constant (± 1 C), it did not greatly affect the results.

r_r And k_r As Affected by Recycle Ratio

Since the inflow of sewage is variable in terms of hydraulics and materials concentration, wide differences in r_r values for a given mixed liquor ratio can be expected from grab samples of return sludge and primary effluent. The sample graphs of r_r and k_r versus time (as shown in Figures No. 4 and 5) indicate the relationship between r_r and k_r as affected by the suspended solids concentration or recycle ratio. The specific and overall oxygen consumption rates will vary with the time of aeration. The magnitude of these values depends on the concentration

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of the suspended solids in the mixed liquor and on the concentration of the substrate. Initially the substrate concentration is at its maximum and correspondingly at this point, the maximum r_T or k_T value is reached. The magnitude of this maximum r_T value is clearly shown to be dependent on the suspended solids concentration. The reason for this is the fact that the mass of bacteria are contained in the suspended solids and an increase in suspended solids results in an increase in bacteria. As stated previously, the most significant factor determining the suspended solids concentration of the mixed liquor is the amount of return sludge employed in making up the batch of mixed liquor. Therefore, for high concentrations of suspended solids, the overall oxygen consumption rate is high due to the oxidation of the organic matter. As the sludge concentration decreases (1:4 mixture), the overall oxygen consumption rate decreases due to a smaller number of bacteria available to oxidize the organic matter. However, the opposite is true of the specific oxygen consumption rate, k_T . As the suspended solids concentration is increased up to the 1:1 mixture, the maximum k_T values decrease. The reason for this decrease is the fact that k_T measures the physiological activity of the bacteria. And as the concentration of the suspended solids increases, the initial substrate

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concentration of the mixed liquor decreases, resulting in a decrease of the physiological activity of the bacteria.

Effects of Aeration Equipment

From Table 8 showing the average maximum r_T and k_T values for the various batches of mixed liquor, it is obvious that the aeration equipment in most of the existing treatment plants can not meet the overall oxygen consumption rates as required for maximum efficiency. Schulze and Kooistra (5) indicate the maximum rate of oxygen supply for diffused aeration equipment at the East Lansing Plant was 22.5 mg O_2 /l/hr. This value falls far short of the average value of 89.7 mg O_2 /l/hr for the overall oxygen consumption rate found for the various plants using a 1RS:4PE ratio for the mixed liquor. It even falls short of the minimum value obtained for this same mixed liquor batch. And the mixed liquor batch of 1RS:4PE represents a recycle ratio of 25% which is certainly not excessive in most treatment plant operations. As the recycle ratio is increased, a rate of oxygen supply of 22.5 mg O_2 /l/hr becomes farther removed from the overall oxygen consumption rate which theoretically should be met. Therefore, it is evident that many if not most of the existing activated sludge treatment plants

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are operating under insufficient rates of oxygen supply. If this is the case, dissolved oxygen concentration becomes the limiting factor and vastly reduces the oxygen consumption rates and therefore also decreases the rate of removal of the substrate.

Basic "Rates" in an Activated Sludge Plant

Lijklema (8) states that the oxygen necessary for wastewater purification is the sum of the overall oxygen consumption rate or substrate respiration rate and the endogenous respiration rate. From Figures 4 and 5 showing r_T and k_T values versus time, it is seen that within thirty minutes the process becomes fairly stable as the microorganisms approach the endogenous respiration level. This is more clearly shown in Figure 7 where curves for a four hour aeration time are shown. This curve demonstrates that after four hours, the r_T and k_T values are below 10.

In general, the activated sludge process is primarily concerned with the respiration and metabolism of aerobic bacteria as they decompose the organic matter in solution. The process consists of the transfer of nutrients, both carbonaceous and inorganic compounds required for cell growth found in the substrate and of dissolved oxygen to the bacterial cell for removal of waste products.

Oxygen is dissolved in the waste liquid from the atmosphere or from other sources such as diffusers. The microorganisms tend to floc into masses many times the size of individual bacterial cells thus causing the separation of the cells from the treated waste liquid as required in the final settling tank. The bacteria respiration, the transfer of nutrients, and the dissolution of oxygen into the waste liquid should all be considered as rates. In an activated sludge plant, man has no control over the natural maximum attainable respiration rates of bacteria and therefore this should be designed as the limiting factor in a treatment plant. If the transfer of nutrients and the dissolution of oxygen can be maintained at rates sufficient to meet the high respiration rates of bacteria as indicated from the graphs, the activated sludge process would be more efficient in substrate removal and require less time for treatment. Kalinske (10) states that often the transfer of nutrients through bacterial matrices of floc is by molecular diffusion and can be quite slow, thus becoming the controlling rate in the process. But he states that the disintegration of these matrices can be attained by agitation. This controlled agitation produces micro-turbulence which is essential for obtaining maximum transfer rates of oxygen and nutrients to the cell surface.

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APPENDICES

APPENDIX A

City of Grandville

**Tested on five different days between the dates
of December 10, 1971 and December 30, 1971.**

Appendix A-1

City of Grandville

December 10, 1971

Time Samples Taken: 12:30 p.m.

Temperature of Samples: 23 C

 $C_s = 8.07 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 9.52 gm/l

Primary Effluent, SS Ave. = 0.36 gm/l

Table A-1-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O₂/gm SS/hr)</u>	<u>Initial r_r (mg O₂/l/hr)</u>
1:4	2.19	12.2	26.8
1:3	2.65	11.7	31.1
1:2	3.38	11.1	37.7
1:1	4.94	10.0	49.0

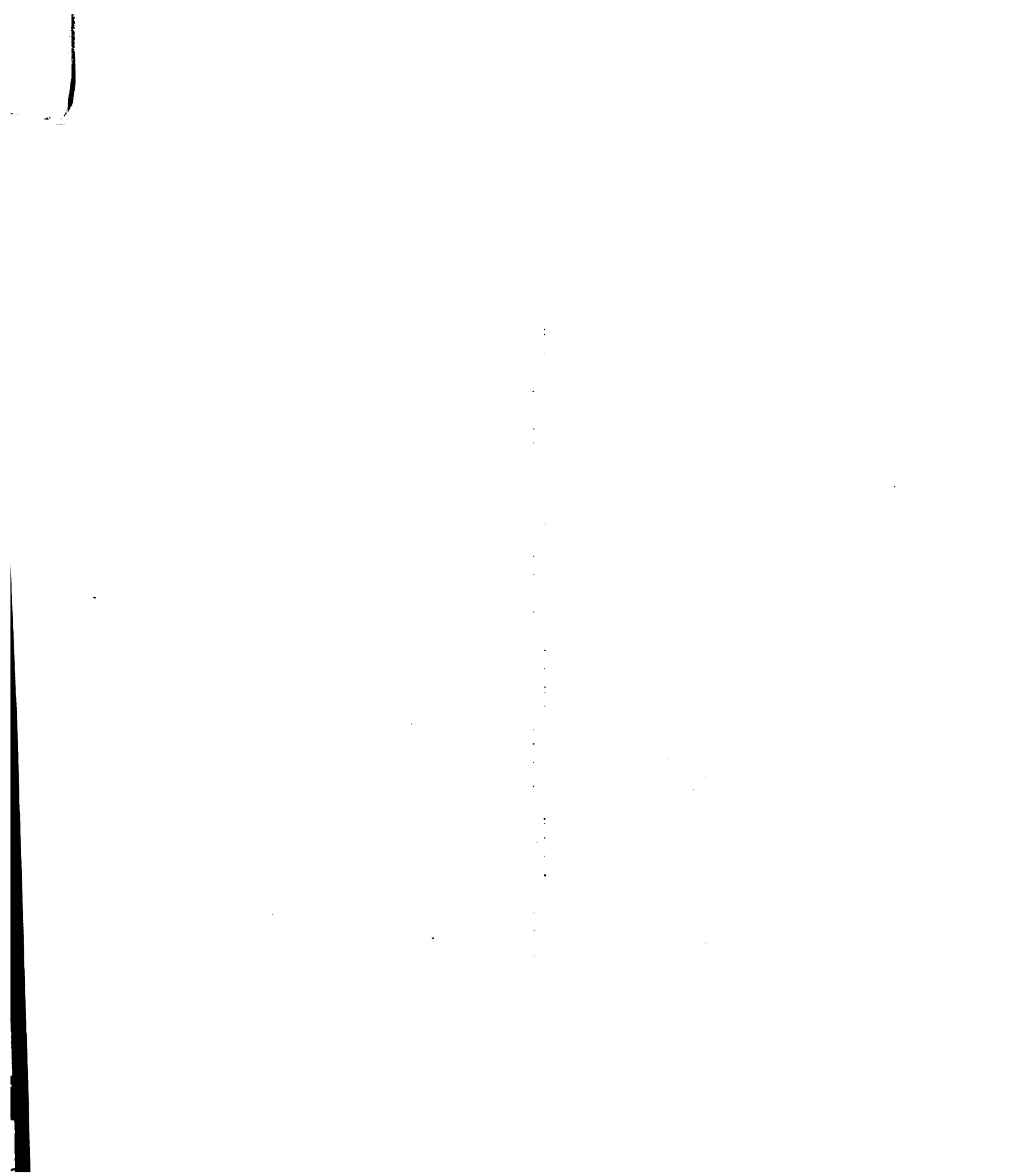
Table A-1-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O₂/l/hr)</u>	<u>k_r(mg O₂/gm SS/hr)</u>
PE	1	9.6	26.6
	2	10.4	28.9
RS	1	102.0	10.7
	2	87.0	9.1

Appendix A-1

Table A-1-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O_2/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O_2/gm SS/hr)</u>
1:4	1	63.0	1:37	28.7
	2	57.0	3:07	26.5
	3	48.0	5:56	21.9
	4	51.0	7:52	23.3
	5	36.0	10:17	16.4
	6	36.0	12:35	16.4
	7	30.0	16:15	13.7
	8	30.0	21:30	13.7
1:3	1	66.0	1:30	28.7
	2	66.0	3:55	28.7
	3	54.0	6:22	20.4
	4	45.0	9:07	17.0
	5	39.0	11:37	14.7
	6	30.0	16:07	11.4
	7	30.0	21:17	11.4
	8	30.0	26:22	11.4
1:2	1	75.0	1:45	22.2
	2	72.0	3:45	21.3
	3	51.0	5:50	15.08
	4	48.0	8:20	14.2
	5	39.0	10:45	11.5
	6	36.0	13:40	10.6
	7	42.0	17:07	12.4
	8	33.0	23:45	9.8
1:1	1	93.0	1:15	18.8
	2	69.0	3:25	14.0
	3	72.0	5:22	14.6
	4	51.0	7:50	10.3
	5	57.0	10:15	11.5
	6	57.0	12:52	11.5
	7	48.0	15:30	9.7
	8	45.0	19:22	9.1
	9	30.0	26:25	6.1



Appendix A-1

Grandville, December 10, 1971

Legend: $\circ \circ \circ$ 1RS:1PE
 $\Delta \Delta \Delta$ 1RS:2PE
 $\square \square \square$ 1RS:3PE
 $\circ \circ \circ$ 1RS:4PE

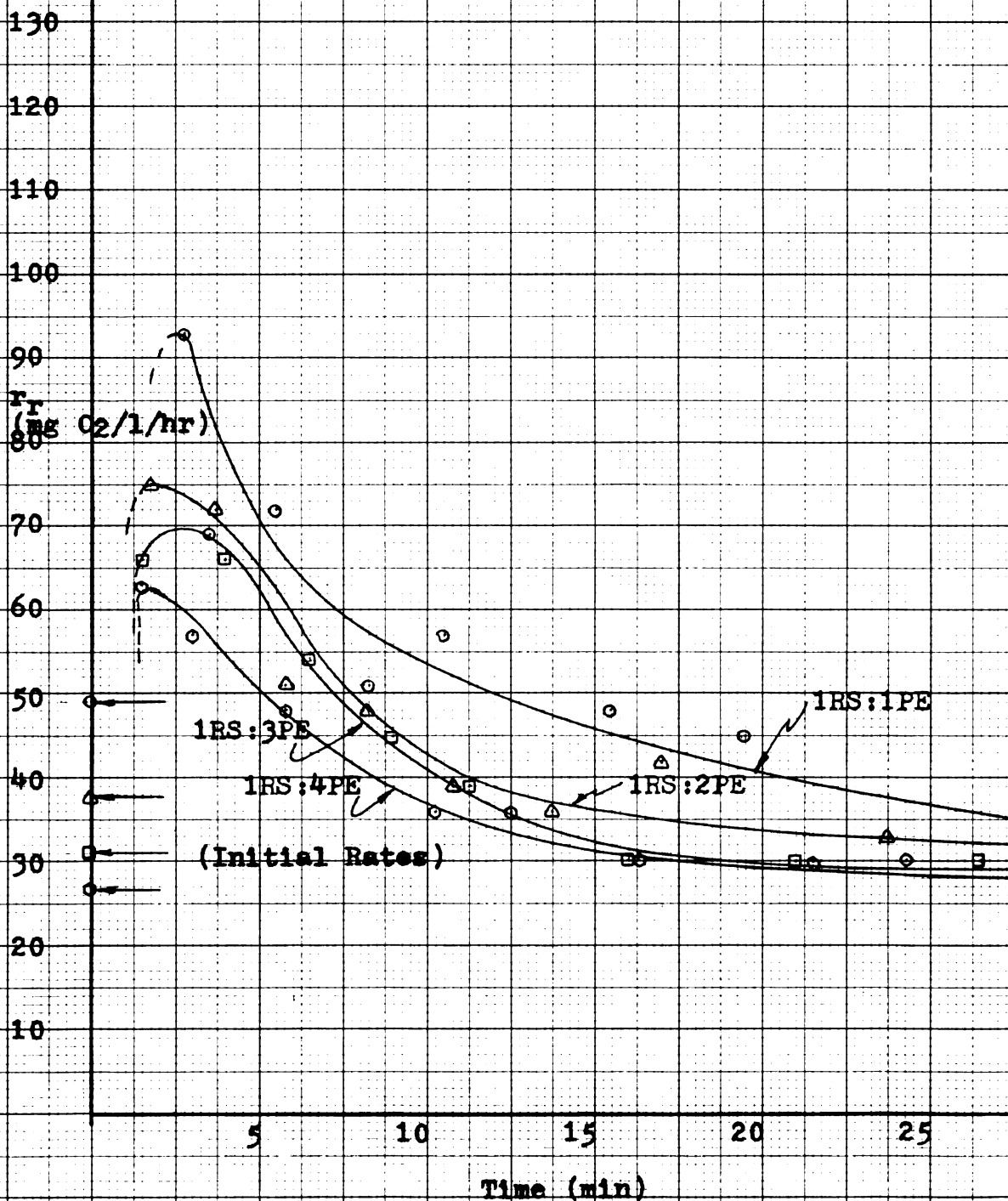
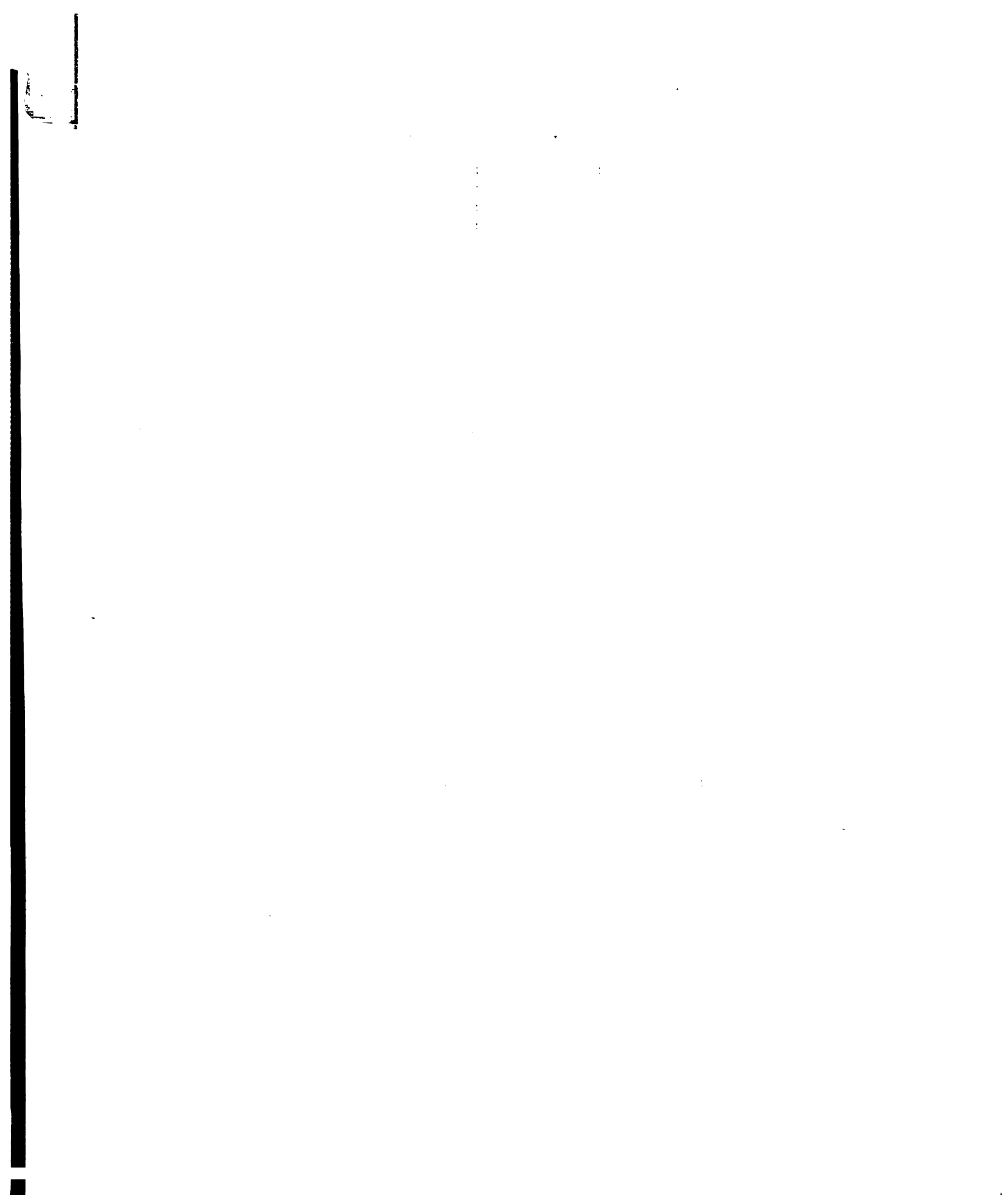


Figure A-1-1. Overall oxygen consumption rates (r_T) versus time for various batches of mixed liquor.



Appendix A-2

City of Grandville

December 13, 1971

Time Samples Taken: 11:30 a.m.

Temperature of Samples: 23 C

 $C_s = 8.17 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 10.42 gm/l

Primary Effluent, SS Ave. = 0.21 gm/l

Table A-2-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS (gm/l)</u>	<u>Initial k_r (mg O₂/gm SS/hr)</u>	<u>Initial r_r (mg O₂/l/hr)</u>
1:4	2.24	10.8	24.4
1:3	2.75	10.4	28.6
1:2	3.57	10.1	35.9
1:1	5.31	9.6	51.0

Table A-2-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r (mg O₂/l/hr)</u>	<u>k_r (mg O₂/gm SS/hr)</u>
PE	1	6.6	31.42
	2	7.8	31.14
RS	1	99.0	9.5
	2	93.0	8.9

Appendix A-2

Table A-2-3. k_r and r_r values for various batches of mixed liquor.

Mixture	Trial No.	r_r (mg O ₂ /l/hr)	Ave. Time (min:sec)	k_r (mg O ₂ /gm SS/hr)
1:4	1	66.0	1:37	29.5
	2	75.0	3:15	33.5
	3	72.0	5:00	32.1
	4	51.0	7:07	22.8
	5	42.0	9:22	18.7
	6	39.0	13:52	17.4
	7	33.0	21:22	14.7
1:3	1	66.0	1:07	24.0
	2	81.0	2:45	29.4
	3	66.0	4:45	24.0
	4	51.0	6:52	18.5
	5	48.0	9:17	17.4
	6	42.0	13:00	15.3
	7	33.0	15:52	12.0
	8	30.0	23:07	10.9
1:2	1	90.0	1:07	25.2
	2	75.0	2:52	21.0
	3	60.0	4:52	16.8
	4	66.0	6:52	18.5
	5	48.0	8:37	13.4
	6	51.0	12:52	14.3
	7	45.0	19:45	12.6
	8	36.0	23:00	10.1
1:1	1	108.0	1:07	20.3
	2	96.0	2:52	18.1
	3	66.0	4:45	12.4
	4	72.0	6:37	13.5
	5	69.0	8:45	13.0
	6	63.0	10:45	11.9
	7	69.0	12:38	13.0
	8	48.0	16:00	9.0
	9	51.0	21:00	9.6
	10	48.0	26:00	9.0

Appendix A-2

Grandville, December 13, 1971

Legend: ○○○ 1RS:1PE
 △△△ 1RS:2PE
 □□□ 1RS:3PE
 ○○○ 1RS:4PE

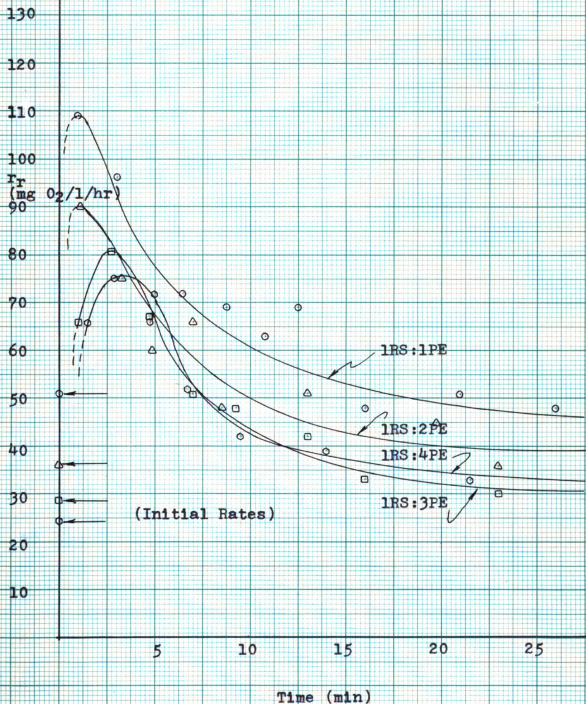


Figure A-2-1. Overall oxygen consumption rates (r_r) versus time for various batches of mixed liquor.

Appendix A-3

City of Grandville

December 22, 1971

Time Samples Taken: 11:30 a.m.

Temperature of Samples: 23 C

 $C_s = 8.07 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 10.15 gm/l

Primary Effluent, SS Ave. = 0.12 gm/l

Table A-3-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O₂/gm SS/hr)</u>	<u>Initial r_r (mg O₂/l/hr)</u>
1:4	2.12	11.0	23.3
1:3	2.65	10.6	28.0
1:2	3.42	10.1	34.5
1:1	5.13	9.5	48.9

Table A-3-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O₂/l/hr)</u>	<u>k_r(mg O₂/gm SS/hr)</u>
PE	1	6.6	55.0
	2	6.6	55.0
RS	1	99.0	9.75
	2	84.0	8.27

Appendix A-3

Table A-3-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O₂/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O₂/gm SS/hr)</u>
1:4	1	39.0	1:15	18.4
	2	39.0	3:22	18.4
	3	36.0	5:22	17.0
	4	33.0	7:55	15.6
	5	33.0	10:07	15.6
	6	30.0	13:15	14.1
	7	30.0	16:07	14.1
	8	27.0	21:30	12.7
	9	24.0	26:15	11.3
1:3	1	54.0	1:25	20.4
	2	48.0	3:52	18.1
	3	36.0	5:52	13.6
	4	36.0	8:00	13.6
	5	36.0	10:45	13.6
	6	30.0	13:30	11.3
	7	30.0	16:15	11.3
	8	24.0	21:52	9.1
	9	24.0	26:30	9.1
1:2	1	54.0	1:25	15.8
	2	51.0	3:30	14.9
	3	48.0	6:00	14.0
	4	45.0	8:25	13.1
	5	45.0	11:07	13.1
	6	36.0	13:30	10.5
	7	36.0	16:07	10.5
	8	24.0	21:22	7.0
	9	27.0	26:45	7.9
1:1	1	63.0	1:30	12.3
	2	63.0	3:15	12.3
	3	54.0	5:30	10.5
	4	51.0	7:52	9.9
	5	42.0	10:00	8.2
	6	45.0	12:30	8.7
	7	36.0	16:22	7.0
	8	36.0	21:15	7.0
	9	36.0	26:37	7.0

Appendix A-3

Grandville, December 22, 1972

Legend: $\circ \circ \circ$ 1RS:1PE
 $\triangle \triangle \triangle$ 1RS:2PE
 $\square \square \square$ 1RS:3PE
 $\diamond \diamond \diamond$ 1RS:4PE

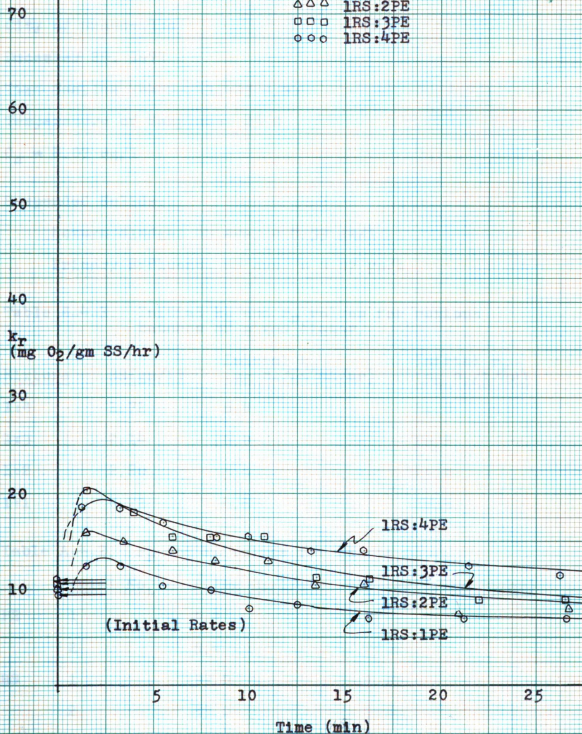


Figure A-3-2. Specific oxygen consumption rates (k_r) versus time for various batches of mixed liquor.

Appendix A-4

City of Grandville

December 29, 1971

Time Samples Taken: 11:15 a.m.

Temperature of Samples: 23 C

 $C_s = 8.07 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 8.39 gm/l

Primary Effluent, SS Ave. = 0.07 gm/l

Table A-4-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O_2/gm^r SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	1.72	6.4	11.0
1:3	2.14	6.0	12.8
1:2	2.80	5.4	15.0
1:1	4.22	4.8	20.3

Table A-4-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O_2/l/hr)</u>	<u>k_r(mg O_2/gm SS/hr)</u>
PE	1	5.4	77.1
	2	5.4	77.1
RS	1	39.0	4.64
	2	33.0	3.93

Appendix A-4

Table A-4-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O₂/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O₂/gm SS/hr)</u>
1:4	1	45.0	1:22	26.2
	2	39.0	3:15	22.7
	3	24.0	5:22	13.9
	4	30.0	7:30	17.4
	5	24.0	10:15	13.9
	6	21.0	13:15	12.2
	7	21.0	16:22	12.2
	8	21.0	21:30	12.2
	9	18.0	26:37	10.5
1:3	1	51.0	1:22	23.8
	2	33.0	3:22	15.4
	3	24.0	6:15	11.2
	4	21.0	8:37	9.8
	5	18.0	11:15	8.4
	6	21.0	13:37	9.8
	7	21.0	16:15	9.8
	8	18.0	21:52	8.4
	9	15.0	26:45	7.0
1:2	1	48.0	1:22	17.1
	2	36.0	3:37	12.8
	3	27.0	6:07	9.6
	4	21.0	8:37	7.5
	5	18.0	11:07	6.4
	6	15.0	13:37	5.4
	7	18.0	16:15	6.4
	8	18.0	21:30	6.4
	9	18.0	27:00	6.4
1:1	1	57.0	1:15	13.5
	2	39.0	3:37	9.2
	3	36.0	5:37	8.5
	4	27.0	8:15	6.4
	5	24.0	10:37	5.7
	6	27.0	13:15	6.4
	7	24.0	16:52	5.7
	8	15.0	22:07	3.6
	9	15.0	27:13	3.6

Appendix A-4

Grandville, December 29, 1971

Legend: ○○○ 1RS:1PE
 △△△ 1RS:2PE
 □□□ 1RS:3PE
 ○○○ 1RS:4PE

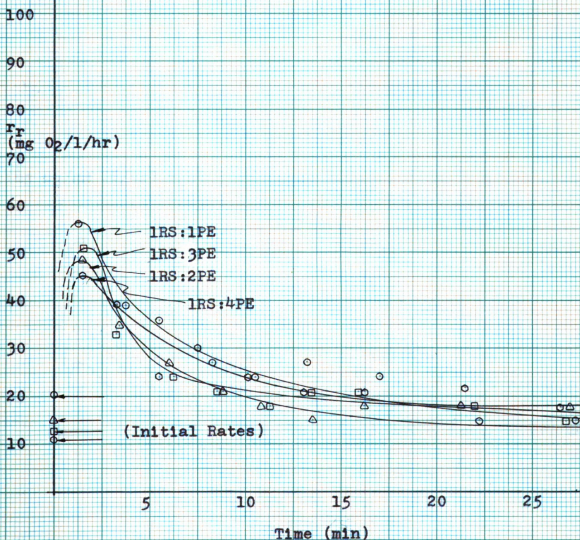


Figure A-4-1. Overall oxygen consumption rates (r_F) versus time for various batches of mixed liquor.

Appendix A-5

City of Grandville

December 30, 1971

Time Samples Taken: 12:00

Temperature of Samples: 23 C

 $C_s = 8.07 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 9.71 gm/l

Primary Effluent, SS Ave. = 0.24 gm/l

Table A-5-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS (gm/l)</u>	<u>Initial k_r (mg O_2/gm SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	2.13	11.1	23.6
1:3	2.60	10.5	27.3
1:2	3.36	9.9	33.3
1:1	4.97	9.3	46.0

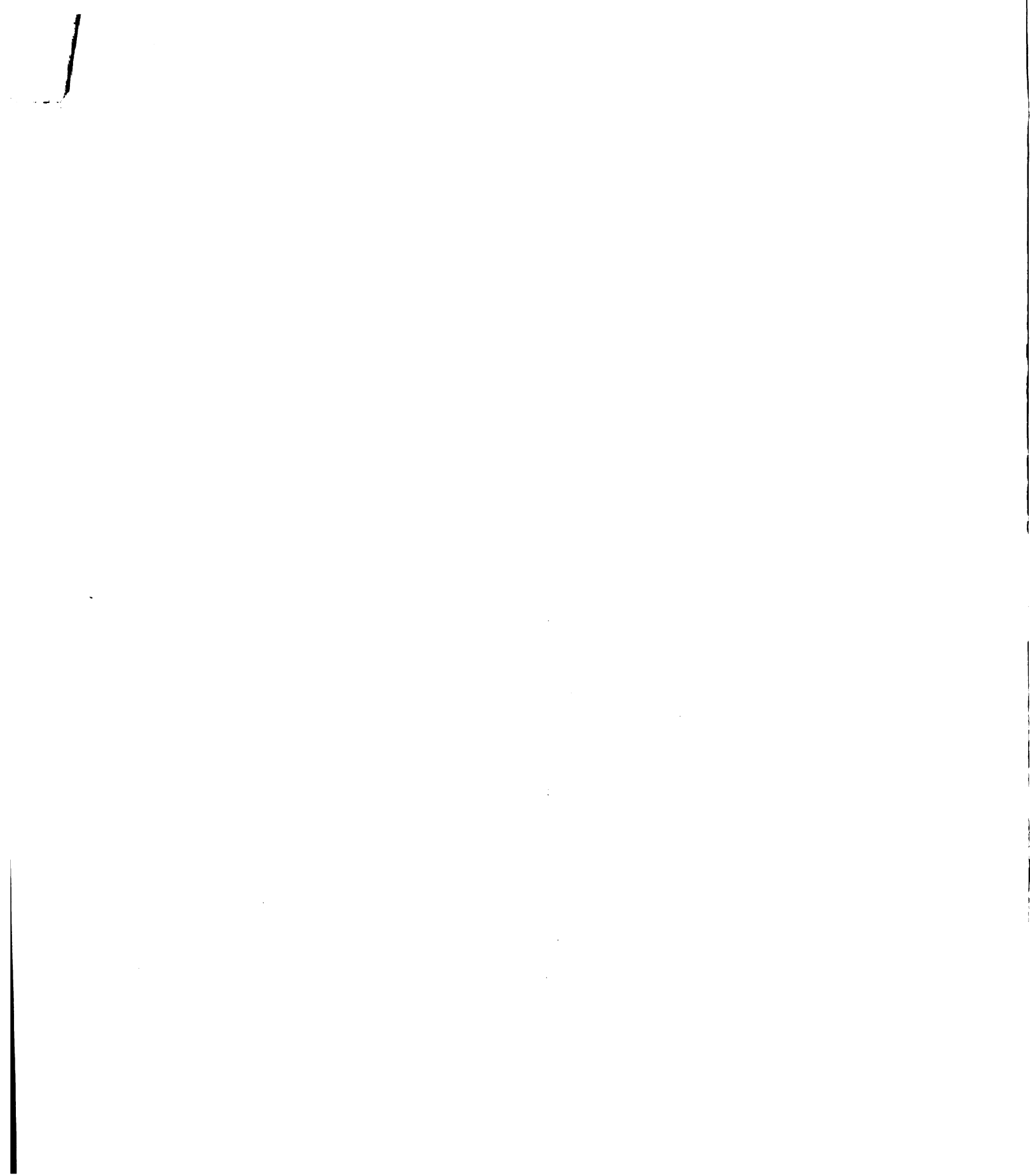
Table A-5-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r (mg O_2/l/hr)</u>	<u>k_r (mg O_2/gm SS/hr)</u>
PE	1	8.4	35.0
	2	9.0	37.5
RS	1	87.0	8.9
	2	81.0	8.3

Appendix A-5

Table A-5-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O_2/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O_2/gm SS/hr)</u>
1:4	1	66.0	1:22	31.0
	2	48.0	3:22	22.5
	3	42.0	5:22	19.7
	4	39.0	7:37	18.3
	5	33.0	10:07	15.5
	6	30.0	12:37	14.1
	7	30.0	16:30	14.1
	8	24.0	21:37	11.3
	9	24.0	26:30	11.3
1:3	1	63.0	1:15	24.2
	2	54.0	3:22	20.8
	3	36.0	5:37	13.8
	4	30.0	8:00	11.5
	5	27.0	10:37	10.4
	6	30.0	13:07	11.5
	7	27.0	16:22	10.4
	8	27.0	21:37	10.4
	9	24.0	26:37	9.2
1:2	1	63.0	1:15	18.7
	2	54.0	3:30	16.1
	3	42.0	5:37	12.5
	4	33.0	8:07	9.8
	5	27.0	10:37	8.0
	6	30.0	13:07	8.9
	7	30.0	16:22	8.9
	8	24.0	21:37	7.1
	9	24.0	26:45	7.1
1:1	1	69.0	1:22	13.9
	2	48.0	3:30	9.6
	3	45.0	5:52	9.1
	4	39.0	8:30	7.8
	5	33.0	11:37	6.6
	6	33.0	14:15	6.6
	7	33.0	16:52	6.6
	8	36.0	21:30	7.2
	9	27.0	26:45	5.4



Appendix A-5

Grandville, December 30, 1971

Legend: $\circ \circ \circ$ 1RS:1PE
 $\triangle \triangle \triangle$ 1RS:2PE
 $\square \square \square$ 1RS:3PE
 $\diamond \diamond \diamond$ 1RS:4PE

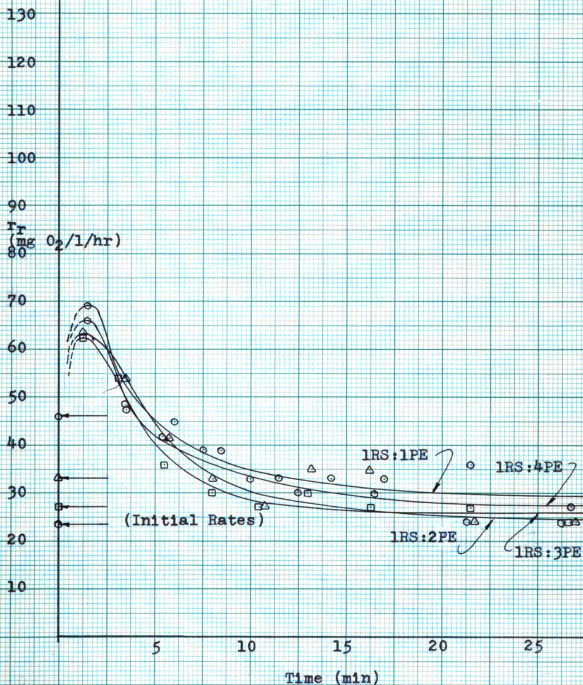


Figure A-5-1. Overall oxygen consumption rates (r_o) versus time for various batches of mixed liquor.

APPENDIX B

City of East Lansing

Tested on five different days between the dates
of January 19, 1972 and February 2, 1972.

Appendix B-1

City of East Lansing

January 19, 1972

Time Samples Taken: 2:15 p.m.

Temperature of Samples: 23 C

 $C_s = 8.07 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 6.12 gm/l

Primary Effluent, SS Ave. = 0.053 gm/l

Table B-1-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O₂/gm SS/hr)</u>	<u>Initial r_r (mg O₂/l/hr)</u>
1:4	1.266	10.47	13.3
1:3	1.569	9.83	15.4
1:2	2.054	9.23	19.0
1:1	3.086	8.57	26.4

Table B-1-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O₂/l/hr)</u>	<u>k_r(mg O₂/gm SS/hr)</u>
PE	1	4.2	79.24
	2	4.8	90.57
RS	1	54.0	8.82
	2	43.0	7.03

Appendix B-1

Table B-1-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O₂/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O₂/gm SS/hr)</u>
1:4	1	81.0	1:15	64.0
	2	69.0	3:08	54.5
	3	60.0	4:45	47.4
	4	63.0	6:52	49.8
	5	54.0	9:30	42.6
	6	45.0	12:00	35.5
	7	33.0	16:15	26.1
	8	30.0	21:15	23.7
	9	24.0	26:22	19.0
1:3	1	96.0	1:15	61.2
	2	84.0	3:22	53.5
	3	66.0	5:15	42.1
	4	60.0	7:30	38.2
	5	39.0	9:52	24.9
	6	39.0	11:30	24.9
	7	36.0	16:15	23.0
	8	30.0	21:45	19.1
	9	27.0	26:52	17.2
1:2	1	111.0	1:15	54.0
	2	81.0	3:22	39.4
	3	60.0	5:30	29.2
	4	48.0	8:00	23.4
	5	36.0	10:30	17.5
	6	33.0	13:15	16.1
	7	30.0	16:15	14.6
	8	24.0	21:22	11.7
	9	24.0	26:22	11.7
1:1	1	123.0	1:15	39.9
	2	72.0	3:00	23.3
	3	63.0	5:00	20.4
	4	54.0	7:30	17.5
	5	36.0	10:00	11.7
	6	36.0	12:37	11.7
	7	33.0	16:07	10.7
	8	33.0	21:07	10.7
	9	30.0	26:15	9.7

Appendix B-2

City of East Lansing

January 25, 1972

Time Samples Taken: 3:00 p.m.

Temperature of Samples: 23 C

 $C_s = 8.07 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 6.04 gm/l

Primary Effluent, SS Ave. = 0.090 gm/l

Table B-2-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O_2/gm SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	1.28	9.62	12.3
1:3	1.58	9.39	14.8
1:2	2.05	9.07	18.6
1:1	3.06	8.72	26.7

Table B-2-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O_2/l/hr)</u>	<u>k_r(mg O_2/gm SS/hr)</u>
PE	1	2.4	26.67
	2	3.0	33.33
RS	1	54.0	8.94
	2	48.0	7.95

Appendix B-2

Table B-2-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O₂/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O₂/gm SS/hr)</u>
1:4	1	96.0	1:22	75.0
	2	90.0	3:15	70.3
	3	78.0	5:52	60.9
	4	66.0	8:00	51.6
	5	63.0	10:30	49.2
	6	48.0	13:00	37.5
	7	45.0	16:15	35.2
	8	42.0	21:15	32.8
	9	36.0	26:22	28.1
1:3	1	99.0	1:22	62.7
	2	96.0	3:15	60.8
	3	84.0	5:30	53.2
	4	66.0	8:07	41.8
	5	45.0	10:37	28.5
	6	42.0	13:15	26.6
	7	39.0	16:15	24.7
	8	36.0	21:45	22.8
	9	30.0	26:30	19.0
1:2	1	117.0	1:22	57.1
	2	108.0	3:15	52.7
	3	84.0	5:15	41.0
	4	57.0	7:30	27.8
	5	54.0	10:07	26.3
	6	42.0	12:37	20.5
	7	33.0	16:45	16.1
	8	30.0	21:30	14.6
	9	30.0	26:22	14.6
1:1	1	150.0	1:22	49.0
	2	84.0	3:07	27.4
	3	69.0	5:30	22.5
	4	63.0	7:30	20.6
	5	54.0	10:07	17.6
	6	54.0	12:30	17.6
	7	45.0	16:22	14.7
	8	39.0	21:15	12.7
	9	39.0	26:30	12.7

Appendix B-2

East Lansing, January 25, 1972

Legend: $\circ \circ \circ$ 1RS:1PE
 $\triangle \triangle \triangle$ 1RS:2PE
 $\square \square \square$ 1RS:3PE
 $\circ \circ \circ$ 1RS:4PE

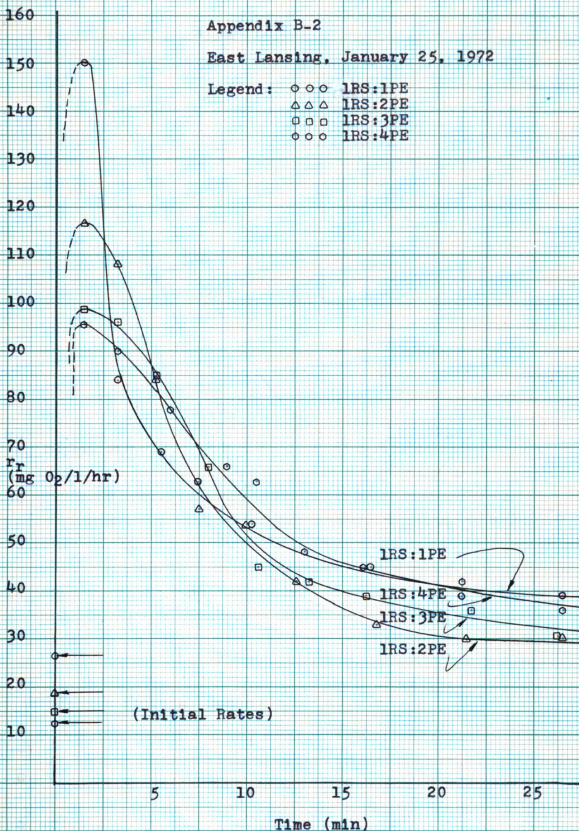


Figure B-2-1. Overall oxygen consumption rates (r_r) versus time for various batches of mixed liquor.

Appendix B-3

City of East Lansing

January 26, 1972

Time Samples Taken: 2:15 p.m.

Temperature of Samples: 23 C

 $C_s = 7.8 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 6.84 gm/l

Primary Effluent, SS Ave. = 0.02 gm/l

Table B-3-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O₂/gm SS/hr)</u>	<u>Initial r_r (mg O₂/l/hr)</u>
1:4	1.38	10.01	13.8
1:3	1.72	9.76	16.8
1:2	2.27	9.52	21.6
1:1	3.43	9.27	31.8

Table B-3-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O₂/l/hr)</u>	<u>k_r(mg O₂/gm SS/hr)</u>
PE	1	3.0	150.0
	2	4.2	210.0
RS	1	63.0	9.21
	2	57.0	8.33

Appendix B-3

Table B-3-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O_2/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O_2/gm SS/hr)</u>
1:4	1	111.0	1:15	80.4
	2	102.0	3:07	73.9
	3	81.0	5:22	58.7
	4	81.0	7:22	58.7
	5	63.0	9:30	45.6
	6	48.0	12:00	34.8
	7	42.0	16:07	30.4
	8	39.0	21:15	28.3
	9	36.0	26:15	26.1
1:3	1	138.0	1:15	80.2
	2	99.0	3:22	57.5
	3	87.0	5:07	50.6
	4	63.0	7:15	36.6
	5	54.0	9:37	31.4
	6	45.0	12:07	26.2
	7	42.0	16:15	24.4
	8	36.0	21:22	20.9
	9	33.0	26:22	19.2
1:2	1	144.0	1:15	63.4
	2	120.0	3:07	52.9
	3	66.0	5:15	29.1
	4	66.0	7:37	29.1
	5	54.0	10:07	23.8
	6	45.0	12:45	19.8
	7	39.0	16:15	17.2
	8	36.0	21:30	15.9
	9	30.0	26:22	13.2
1:1	1	168.0	1:15	49.0
	2	90.0	3:15	26.2
	3	69.0	5:30	20.1
	4	60.0	7:30	17.5
	5	66.0	10:30	19.2
	6	63.0	13:07	18.4
	7	51.0	16:15	14.9
	8	45.0	21:15	13.1
	9	45.0	27:00	13.1

Appendix B-3

East Lansing, January 26, 1972

Legend: $\circ \circ \circ$ IRS:1PE
 $\triangle \triangle \triangle$ IRS:2PE
 $\square \square \square$ IRS:3PE
 $\circ \circ \circ$ IRS:4PE

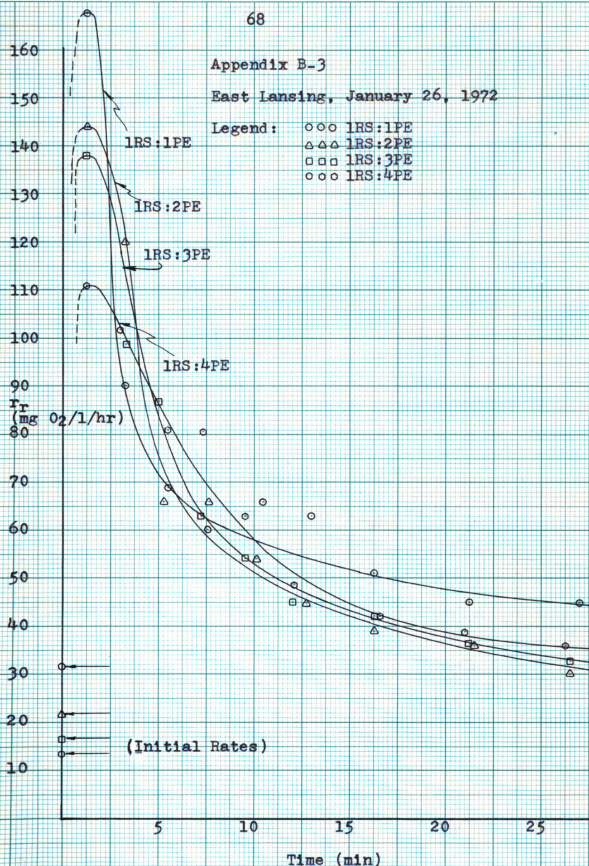


Figure B-3-1. Overall oxygen consumption rates (r_t) versus time for various batches of mixed liquor.

Appendix B-4

City of East Lansing

February 1, 1972

Time Samples Taken: 3:00 p.m.

Temperature of Samples: 23 C

 $C_s = 8.07 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 6.62 gm/l

Primary Effluent, SS Ave. = 0.038 gm/l

Table B-4-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O_2/gm^r SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	1.354	10.55	14.3
1:3	1.683	9.90	16.7
1:2	2.209	9.27	20.5
1:1	3.329	8.60	28.6

Table B-4-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O_2/l/hr)</u>	<u>k_r(mg O_2/gm SS/hr)</u>
PE	1	4.2	110.53
	2	5.4	142.10
RS	1	57.0	8.61
	2	48.0	7.25

Appendix B-4

Table B-4-3. k_r and r_r values for various batches of mixed liquor.

Mixture	Trial No.	r_r (mg O_2 /l/hr)	Ave. Time (min:sec)	k_r (mg O_2 /gm SS/hr)
1:4	1	108.0	1:22	79.8
	2	90.0	3:15	66.5
	3	90.0	5:07	66.5
	4	75.0	7:30	55.4
	5	75.0	10:00	55.4
	6	42.0	12:30	31.0
	7	39.0	16:22	28.8
	8	33.0	21:22	24.4
	9	27.0	26:22	19.9
1:3	1	132.0	1:22	78.4
	2	102.0	3:15	60.6
	3	96.0	5:30	57.0
	4	78.0	7:30	46.3
	5	60.0	10:00	35.6
	6	48.0	12:45	28.5
	7	42.0	16:22	24.9
	8	36.0	21:15	21.4
	9	33.0	26:37	19.6
1:2	1	144.0	1:15	65.2
	2	120.0	3:07	54.3
	3	102.0	5:15	46.2
	4	57.0	7:52	25.8
	5	45.0	10:37	20.4
	6	42.0	13:00	19.0
	7	42.0	16:15	19.0
	8	39.0	21:30	17.7
	9	36.0	26:22	16.3
1:1	1	171.0	1:22	51.4
	2	111.0	3:00	33.3
	3	72.0	5:00	21.6
	4	63.0	7:45	18.9
	5	57.0	10:30	17.1
	6	54.0	11:15	16.2
	7	48.0	16:22	14.4
	8	42.0	21:15	12.6
	9	45.0	26:45	13.5

Appendix B-4

East Lansing, February 1, 1972

Legend: ○○○ 1RS:1PE
 △△△ 1RS:2PE
 □□□ 1RS:3PE
 ○○○ 1RS:4PE

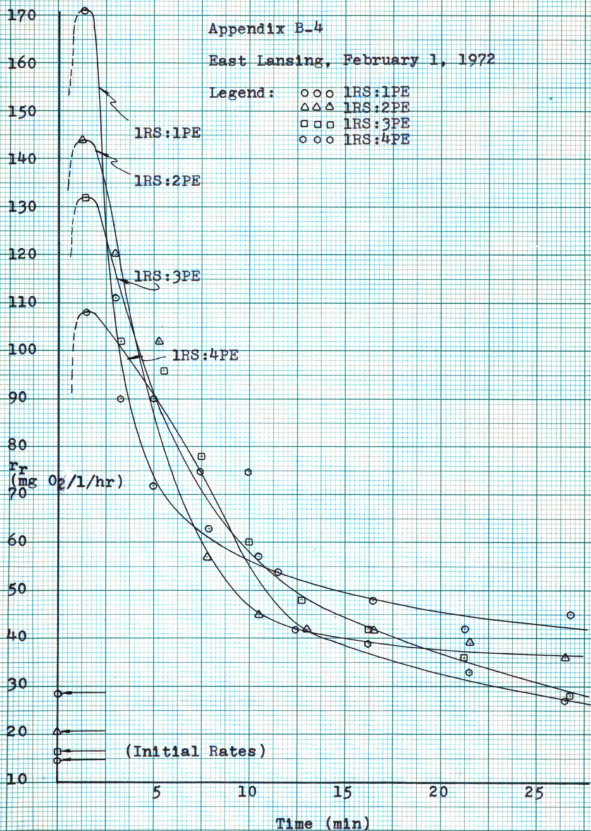


Figure B-4-1. Overall oxygen consumption rates (r_r) versus time for various batches of mixed liquor.

Appendix B-5

City of East Lansing

February 2, 1972

Time Samples Taken: 2:00 p.m.

Temperature of Samples: 23 C

 $C_s = 8.07 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 6.39 gm/l

Primary Effluent, SS Ave. = 0.037 gm/l

Table B-5-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O_2/gm SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	1.307	8.12	10.63
1:3	1.624	7.67	12.5
1:2	2.132	7.24	15.4
1:1	3.213	6.78	21.8

Table B-5-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O_2/l/hr)</u>	<u>k_r(mg O_2/gm SS/hr)</u>
PE	1	3.0	81.08
	2	3.6	93.30
RS	1	42.0	6.57
	2	39.0	6.10

Appendix B-5

Table B-5-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O₂/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O₂/gm SS/hr)</u>
1:4	1	84.0	1:30	64.2
	2	75.0	3:45	57.4
	3	63.0	6:07	48.2
	4	63.0	8:45	48.2
	5	45.0	11:15	34.4
	6	30.0	13:45	22.9
	7	30.0	18:00	22.9
	8	27.0	22:37	20.7
	9	24.0	26:37	18.4
1:3	1	93.0	1:37	57.3
	2	81.0	4:00	49.9
	3	75.0	6:45	46.2
	4	42.0	9:30	25.9
	5	36.0	12:45	22.2
	6	30.0	16:00	18.5
	7	27.0	18:45	16.6
	8	27.0	21:30	16.6
	9	27.0	24:45	16.6
1:2	1	120.0	1:30	56.3
	2	108.0	3:30	50.7
	3	48.0	6:07	22.5
	4	48.0	8:52	22.5
	5	33.0	11:22	15.5
	6	33.0	13:45	15.5
	7	33.0	17:07	15.5
	8	27.0	21:37	12.7
	9	27.0	26:52	12.7
1:1	1	150.0	1:22	46.7
	2	63.0	3:45	19.6
	3	57.0	6:00	17.7
	4	51.0	8:45	15.9
	5	42.0	11:37	13.1
	6	39.0	14:45	12.1
	7	39.0	18:07	12.1
	8	36.0	21:30	11.2
	9	30.0	27:00	9.3

Appendix B-5

East Lansing, February 2, 1972

Legend: $\circ \circ \circ$ 1RS:1PE
 $\triangle \triangle \triangle$ 1RS:2PE
 $\square \square \square$ 1RS:3PE
 $\circ \circ \circ$ 1RS:4PE

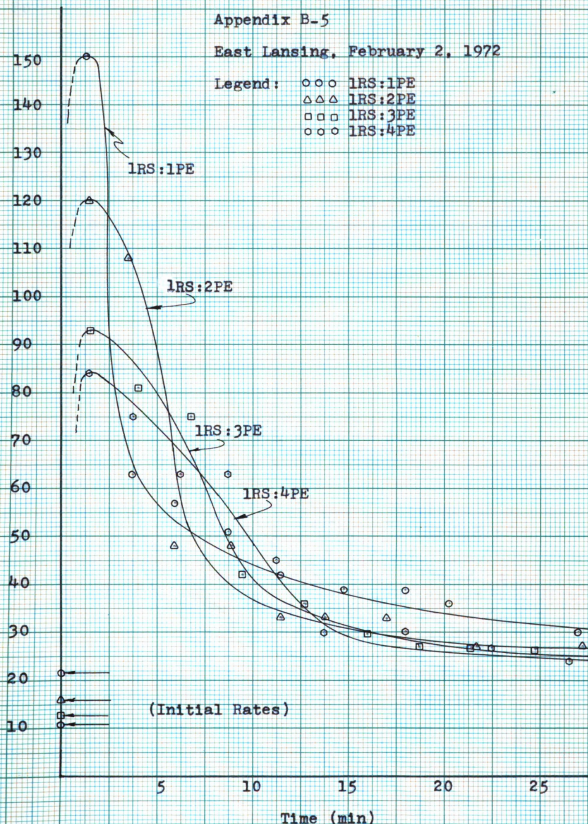


Figure B-5-1. Overall oxygen consumption rates (r_o) versus time for various batches of mixed liquor.

APPENDIX C

City of Mason

Tested on five different days between the dates
of February 16, 1972 and March 1, 1972.

Appendix C-1

City of Mason

February 16, 1972

Time Samples Taken: 2:00

Temperature of Samples: 23 C

 $C_s = 8.27 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 8.37 gm/l

Primary Effluent, SS Ave. = 0.030 gm/l

Table C-1-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS (gm/l)</u>	<u>Initial k_r (mg O_2/gm SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	1.698	15.11	25.66
1:3	2.114	14.70	31.07
1:2	2.782	14.16	39.40
1:1	4.200	13.55	56.94

Table C-1-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r (mg O_2/l/hr)</u>	<u>k_r (mg O_2/gm SS/hr)</u>
PE	1	5.4	180.0
	2	5.4	180.0
RS	1	114.0	13.62
	2	103.0	12.30

Appendix C-1

Table C-1-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O_2/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O_2/gm SS/hr)</u>
1:4	1	117.0	1:22	68.9
	2	99.0	3:22	58.3
	3	96.0	5:15	56.5
	4	93.0	7:15	54.8
	5	75.0	8:30	44.2
	6	63.0	12:15	37.1
	7	60.0	16:22	35.3
	8	48.0	21:30	28.3
	9	48.0	26:22	28.3
1:3	1	114.0	1:30	53.9
	2	120.0	3:22	56.8
	3	99.0	5:15	46.8
	4	66.0	7:30	31.2
	5	63.0	8:45	29.8
	6	63.0	12:37	29.8
	7	54.0	16:15	25.5
	8	54.0	21:37	25.5
	9	51.0	26:30	24.1
1:2	1	126.0	1:22	45.3
	2	141.0	3:15	50.7
	3	87.0	5:30	31.3
	4	84.0	8:07	30.2
	5	78.0	10:30	28.0
	6	69.0	13:07	24.8
	7	69.0	16:30	24.8
	8	72.0	21:22	25.9
	9	66.0	26:30	23.7
1:1	1	177.0	1:15	42.1
	2	108.0	3:15	25.7
	3	108.0	5:07	25.7
	4	99.0	7:37	23.6
	5	99.0	10:37	23.6
	6	93.0	13:07	22.1
	7	66.0	16:15	15.7
	8	57.0	21:45	13.6
	9	42.0	26:45	10.0

Appendix C-1

Mason, February 16, 1972

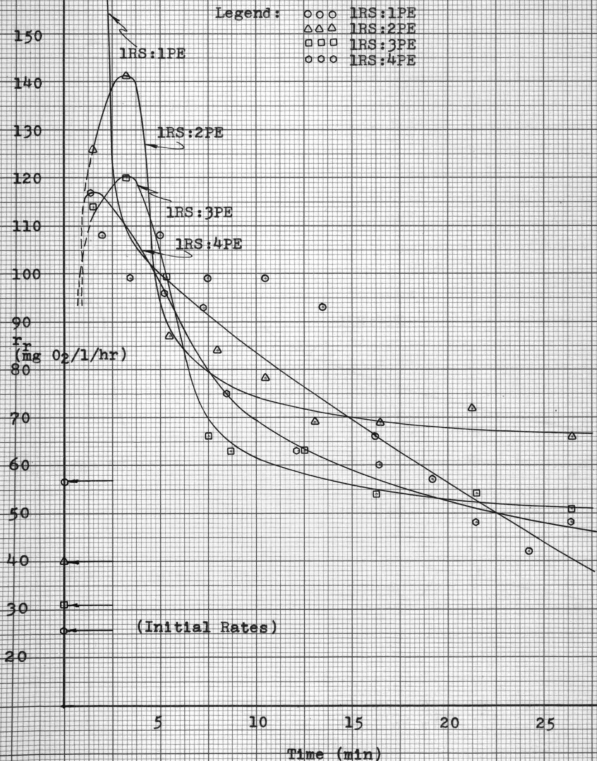


Figure C-1-1. Overall oxygen consumption rates (r_r) versus time for various batches of mixed liquor.

Appendix C-1

Mason, February 16, 1972

Legend: $\circ \circ \circ$ IRS:1PE
 $\triangle \triangle \triangle$ IRS:2PE
 $\square \square \square$ IRS:3PE
 $\circ \circ \circ$ IRS:4PE

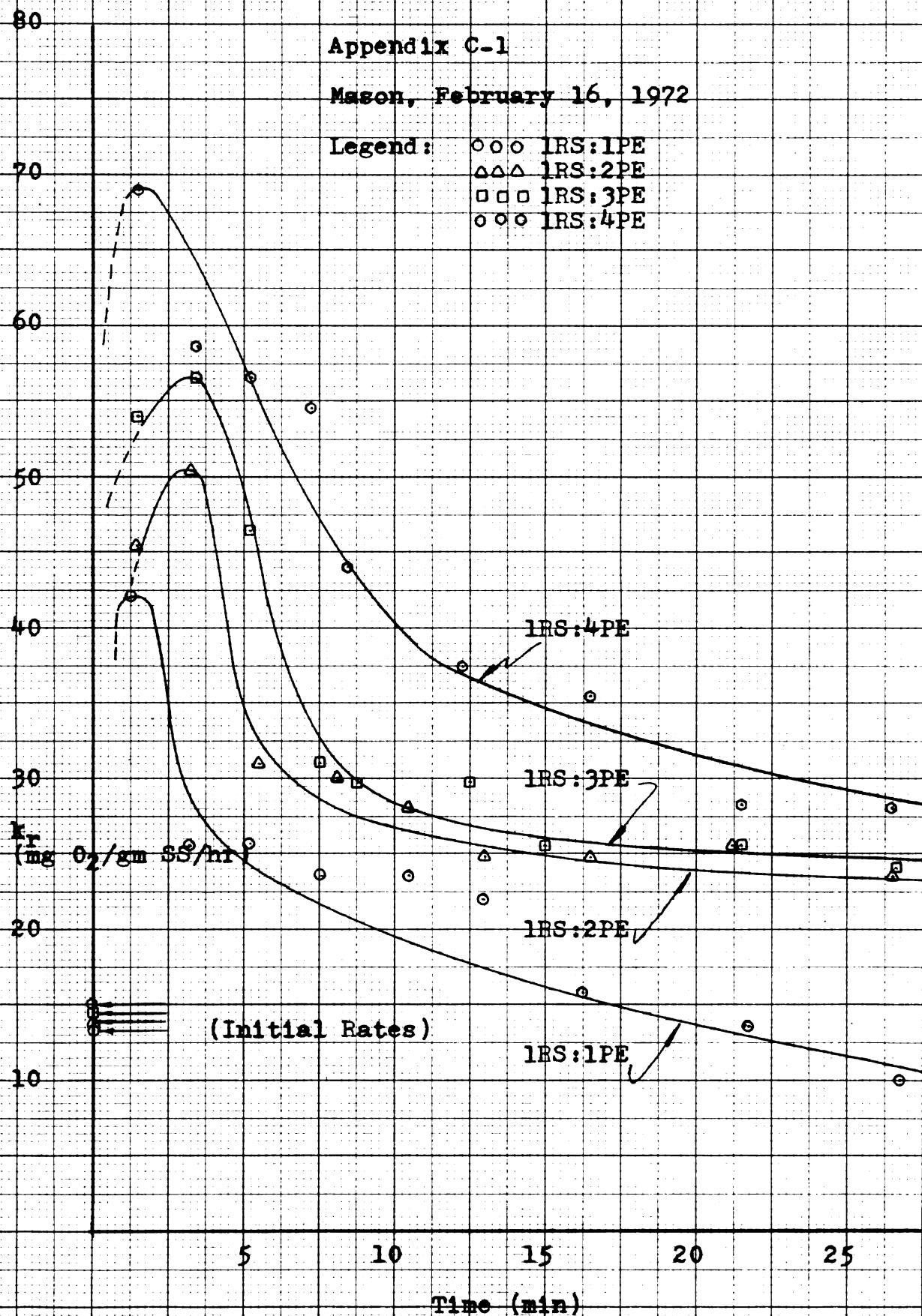


Figure C-1-2. Specific oxygen consumption rates (k_r) versus time for various batches of mixed liquor.

Appendix C-2

City of Mason

February 22, 1972

Time Samples Taken: 3:00

Temperature of Samples: 23 C

 $C_s = 8.46 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 4.83 gm/l

Primary Effluent, SS Ave. = 0.050 gm/l

Table C-2-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O_2/gm SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	1.006	18.30	18.41
1:3	1.244	17.37	21.61
1:2	1.627	16.48	26.82
1:1	2.440	15.54	37.93

Table C-2-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O_2/l/hr)</u>	<u>k_r(mg O_2/gm SS/hr)</u>
PE	1	4.8	96.0
	2	6.0	120.0
RS	1	72.0	14.90
	2	69.0	14.28

Appendix C-2

Table C-2-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O₂/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O₂/gm SS/hr)</u>
1:4	1	78.0	1:30	77.5
	2	75.0	4:00	74.5
	3	72.0	6:30	71.6
	4	66.0	9:07	65.6
	5	42.0	11:45	41.7
	6	42.0	14:30	41.7
	7	39.0	17:45	38.8
	8	33.0	21:30	32.8
	9	33.0	26:52	32.8
1:3	1	96.0	1:30	77.2
	2	81.0	4:00	65.1
	3	78.0	6:15	62.7
	4	48.0	8:52	38.6
	5	45.0	11:30	36.2
	6	42.0	14:30	33.8
	7	39.0	17:30	31.3
	8	42.0	21:30	33.7
	9	39.0	27:30	31.3
1:2	1	108.0	1:30	66.4
	2	90.0	3:45	55.3
	3	60.0	6:15	36.9
	4	42.0	8:30	25.8
	5	48.0	11:07	29.5
	6	45.0	13:37	27.7
	7	45.0	16:07	27.7
	8	36.0	21:30	22.1
	9	27.0	26:15	16.6
1:1	1	141.0	1:30	57.8
	2	72.0	3:30	29.5
	3	66.0	6:15	27.0
	4	54.0	8:37	22.1
	5	48.0	11:15	19.7
	6	42.0	13:45	17.2
	7	39.0	17:00	16.0
	8	36.0	21:30	22.1
	9	30.0	26:45	16.6

Appendix C-2

Mason, February 22, 1972

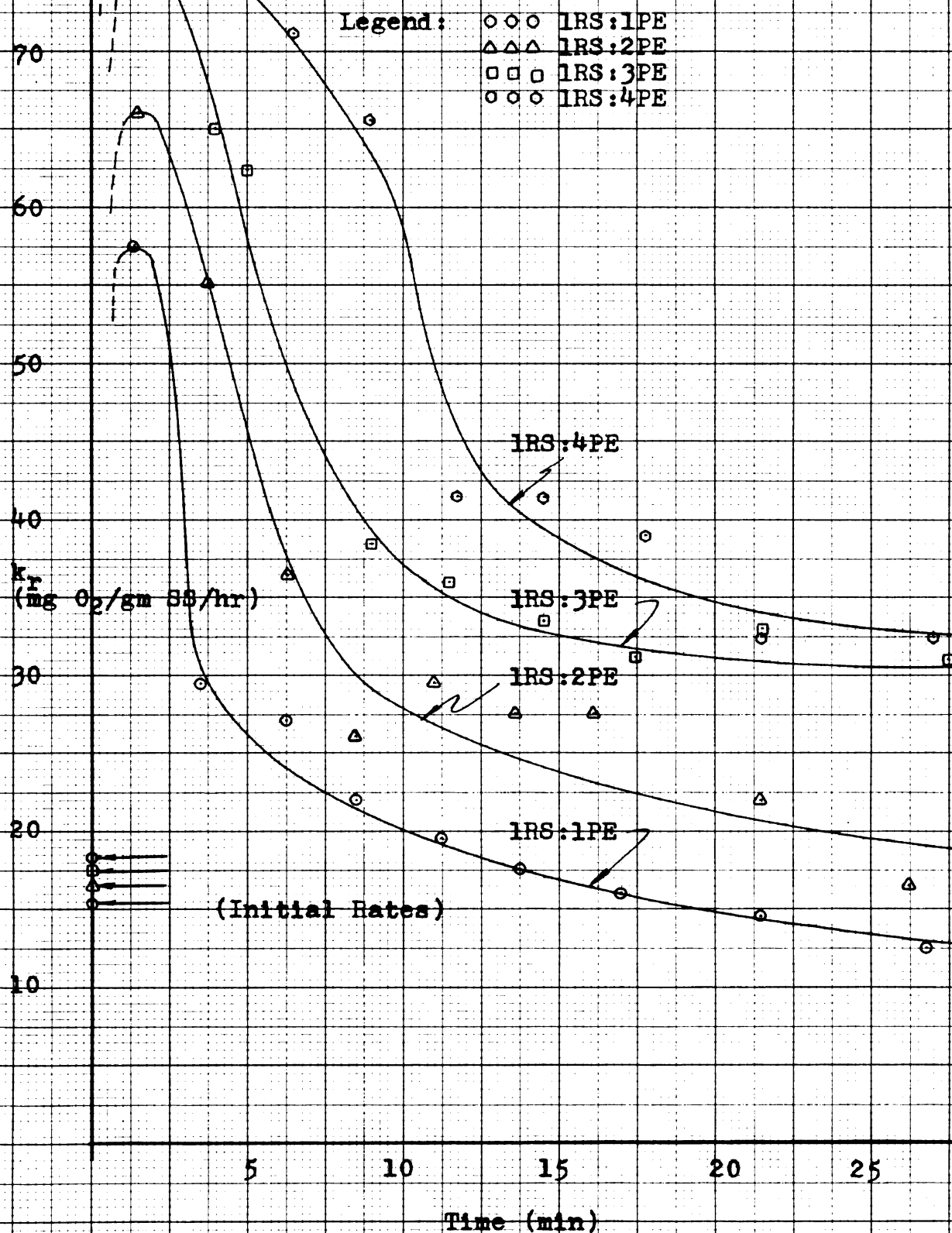


Figure C-2-2. Specific oxygen consumption rates (k_r) versus time for various batches of mixed liquor.

Appendix C-3

City of Mason

February 23, 1972

Time Samples Taken: 12:00

Temperature of Samples: 23 C

 $C_s = 8.76 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 5.61 gm/l

Primary Effluent, SS Ave. = 0.21 gm/l

Table C-3-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O_2/gm SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	1.290	18.04	23.28
1:3	1.559	16.34	25.48
1:2	1.99	15.68	31.21
1:1	2.910	14.93	43.44

Table C-3-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O_2/l/hr)</u>	<u>k_r(mg O_2/gm SS/hr)</u>
PE	1	6.6	31.42
	2	8.4	40.0
RS	1	84.0	14.97
	2	75.0	13.37

Appendix C-3

Table C-3-3. k_r and r_r values for various batches of mixed liquor.

Mixture	Trial No.	r_r (mg O_2 /l/hr)	Ave. Time (min:sec)	k_r (mg O_2 /gm SS/hr)
1:4	1	99.0	1:30	76.7
	2	81.0	4:00	62.8
	3	60.0	6:00	46.5
	4	51.0	8:45	39.5
	5	48.0	11:30	37.2
	6	45.0	14:15	34.9
	7	42.0	17:15	32.6
	8	42.0	21:22	32.6
	9	39.0	26:30	30.2
1:3	1	102.0	1:30	65.4
	2	78.0	3:30	50.0
	3	72.0	6:15	45.0
	4	57.0	8:45	35.6
	5	54.0	11:30	34.6
	6	51.0	14:45	32.7
	7	51.0	18:00	32.7
	8	48.0	22:30	30.8
	9	36.0	26:30	23.1
1:2	1	10.5	1:30	52.7
	2	63.0	3:52	31.6
	3	66.0	6:15	33.2
	4	63.0	9:15	31.6
	5	63.0	12:00	31.6
	6	63.0	14:45	31.6
	7	45.0	17:15	22.6
	8	39.0	21:15	19.6
	9	33.0	26:30	15.6
1:1	1	111.0	1:45	38.9
	2	111.0	3:52	38.9
	3	99.0	5:52	34.0
	4	75.0	8:00	25.8
	5	51.0	10:52	17.5
	6	48.0	13:30	16.5
	7	48.0	16:30	16.5
	8	39.0	22:30	13.4
	9	33.0	26:45	11.3

Appendix C-3

Mason, February 23, 1972

Legend: $\circ \circ \circ$ 1RS:1PE
 $\triangle \triangle \triangle$ 1RS:2PE
 $\square \square \square$ 1RS:3PE
 $\circ \circ \circ$ 1RS:4PE

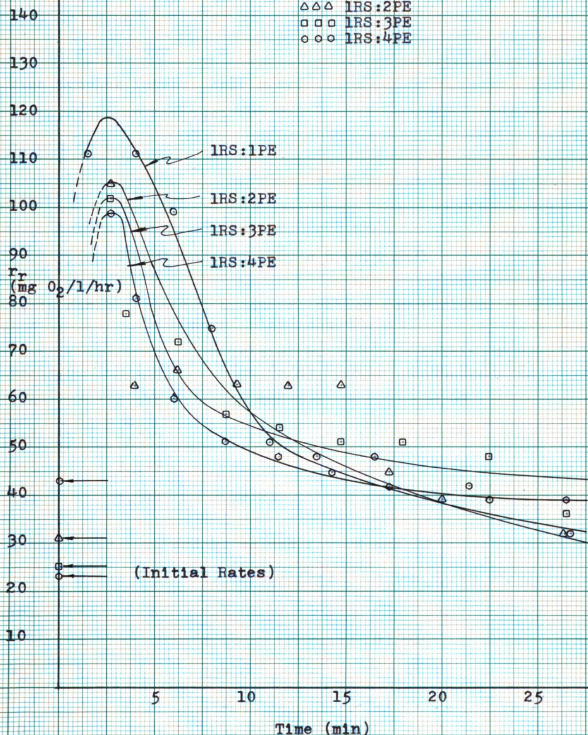


Figure C-3-1. Overall oxygen consumption rates (r_o) versus time for various batches of mixed liquor.

Appendix C-4

City of Mason

February 29, 1972

Time Samples Taken: 2:30 p.m.

Temperature of Samples: 23 C

 $C_s = 8.56 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 10.63 gm/l

Primary Effluent, SS Ave. = 0.0575 gm/l

Table C-4-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O_2/gm SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	2.172	14.03	30.48
1:3	2.714	13.65	37.06
1:2	3.549	13.26	47.05
1:1	5.344	12.83	68.58

Table C-4-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O_2/l/hr)</u>	<u>k_r(mg O_2/gm SS/hr)</u>
PE	1	4.8	83.47
	2	5.4	93.91
RS	1	144.0	13.55
	2	120.0	11.29

Appendix C-4

Table C-4-3. k_r and r_r values for various batches of mixed liquor.

Mixture	Trial No.	r_r (mg O_2 /l/hr)	Ave. Time (min:sec)	k_r (mg O_2 /gm SS/hr)
1:4	1	108.0	1:30	49.7
	2	99.0	3:30	45.5
	3	96.0	5:45	44.2
	4	90.0	8:00	41.4
	5	81.0	10:15	37.3
	6	60.0	13:15	27.6
	7	60.0	17:00	27.6
	8	54.0	21:30	24.9
	9	51.0	26:30	23.5
1:3	1	123.0	1:30	45.3
	2	120.0	3:15	44.2
	3	117.0	5:00	43.1
	4	78.0	7:00	28.7
	5	72.0	9:30	26.5
	6	63.0	12:30	23.2
	7	60.0	16:30	22.1
	8	45.0	21:30	16.6
	9	39.0	26:30	14.4
1:2	1	156.0	1:15	44.0
	2	132.0	3:15	37.2
	3	105.0	5:37	29.6
	4	90.0	8:15	25.4
	5	87.0	10:30	24.5
	6	69.0	13:30	19.4
	7	57.0	16:45	16.7
	8	54.0	21:45	15.2
	9	48.0	26:45	13.5
1:1	1	189.0	1:07	35.4
	2	153.0	2:15	28.6
	3	135.0	3:22	25.3
	4	102.0	5:07	19.1
	5	99.0	7:00	18.5
	6	75.0	9:45	14.0
	7	69.0	12:45	12.9
	8	63.0	21:30	11.8
	9	54.0	27:00	10.1

Appendix C-4

Mason, February 29, 1972

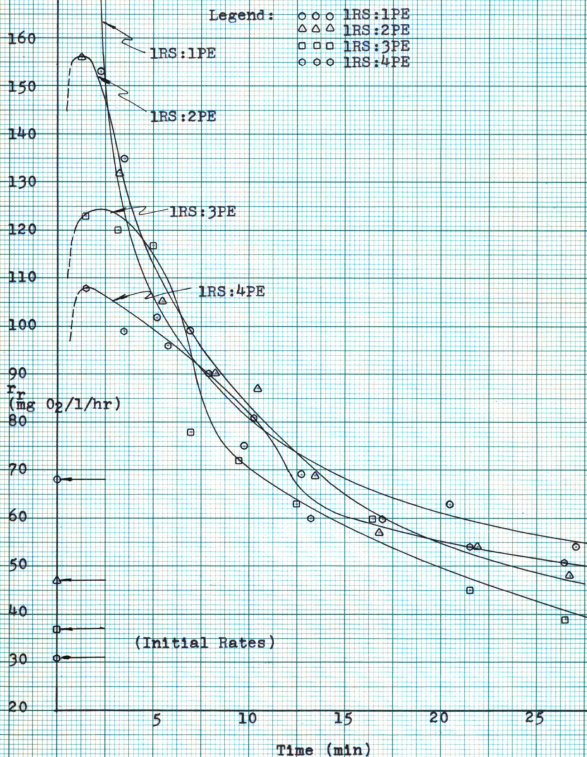


Figure C-4-1. Overall oxygen consumption rates (r_r) versus time for various batches of mixed liquor.

Appendix C-5

City of Mason

March 1, 1972

Time Samples Taken: 2:00 p.m.

Temperature of Samples: 23 C

 $C_s = 8.46 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 8.85 gm/l

Primary Effluent, SS Ave. = 0.277 gm/l

Table C-5-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O_2/gm^rSS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	1.99	15.02	29.90
1:3	2.420	14.96	36.20
1:2	3.105	14.89	46.24
1:1	4.563	14.82	67.61

Table C-5-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O_2/l/hr)</u>	<u>k_r(mg O_2/gm SS/hr)</u>
PE	1	4.8	17.32
	2	4.8	17.32
RS	1	132.0	14.91
	2	129.0	14.58

Appendix C-5

Table C-5-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O_2/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O_2/gm SS/hr)</u>
1:4	1	108.0	1:30	54.2
	2	78.0	3:30	39.2
	3	63.0	5:45	31.7
	4	63.0	8:15	31.7
	5	57.0	11:15	28.6
	6	57.0	14:00	28.6
	7	57.0	17:30	28.6
	8	42.0	21:30	21.1
	9	33.0	26:45	16.6
1:3	1	117.0	1:15	48.3
	2	75.0	3:22	31.0
	3	75.0	5:30	31.0
	4	66.0	8:22	27.3
	5	63.0	11:00	26.0
	6	66.0	13:30	27.3
	7	51.0	16:30	21.1
	8	42.0	21:45	17.3
	9	36.0	27:30	14.9
1:2	1	120.0	1:30	38.6
	2	90.0	3:45	29.0
	3	90.0	6:00	29.0
	4	87.0	8:15	28.2
	5	69.0	10:45	22.2
	6	48.0	13:45	15.5
	7	48.0	16:45	15.5
	8	42.0	22:00	13.5
	9	42.0	27:00	13.5
1:1	1	99.0	1:22	21.7
	2	114.0	3:30	25.0
	3	81.0	5:52	17.7
	4	69.0	8:30	15.1
	5	48.0	11:15	10.5
	6	48.0	14:30	10.5
	7	48.0	18:15	10.5
	8	45.0	21:30	9.9
	9	39.0	26:45	8.5

Appendix C-5

Mason, March 1, 1972

Legend: ○○○ 1RS:1PE
 △△△ 1RS:2PE
 □□□ 1RS:3PE
 ○○○ 1RS:4PE

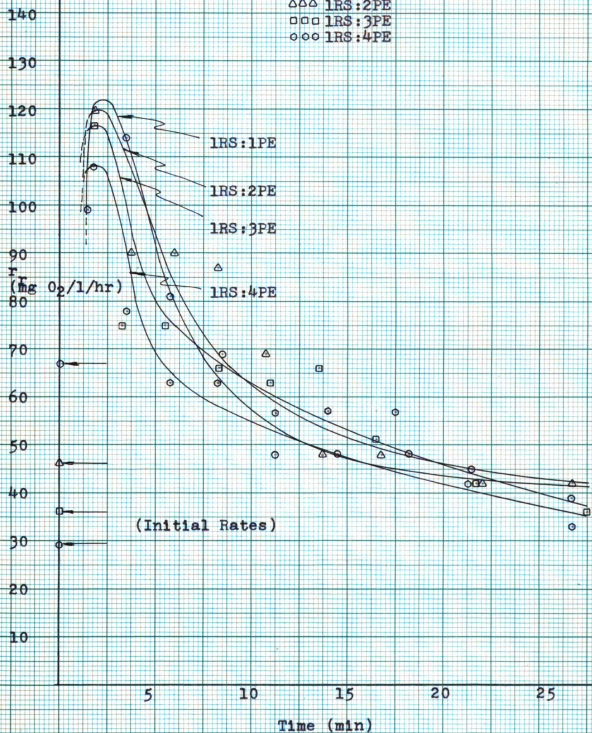


Figure C-5-1. Overall oxygen consumption rates (r_r) versus time for various batches of mixed liquor.

APPENDIX D

City of Lansing

Tested on five different days between the
dates of April 4, 1972 and April 17, 1972.

Appendix D-1

City of Lansing

April 4, 1972

Time Samples Taken: 11:45 a.m.

Temperature of Samples: 23 C

 $C_s = 8.27 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 14.35 gm/l

Primary Effluent, SS Ave. = 0.0925 gm/l

Table D-1-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS (gm/l)</u>	<u>Initial k_r (mg O_2/gm SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	2.94	6.09	17.90
1:3	3.66	6.05	22.13
1:2	4.80	6.02	28.89
1:1	7.22	5.99	43.30

Table D-1-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r (mg O_2/l/hr)</u>	<u>k_r (mg O_2/gm SS/hr)</u>
PE	1	0.9	9.72
	2	1.1	11.89
RS	1	93.0	6.48
	2	78.0	5.43

Appendix D-1

Lansing, April 4, 1972

Legend: ○○○ 1RS:1PE
 △△△ 1RS:2PE
 □□□ 1RS:3PE
 ○○○ 1RS:4PE

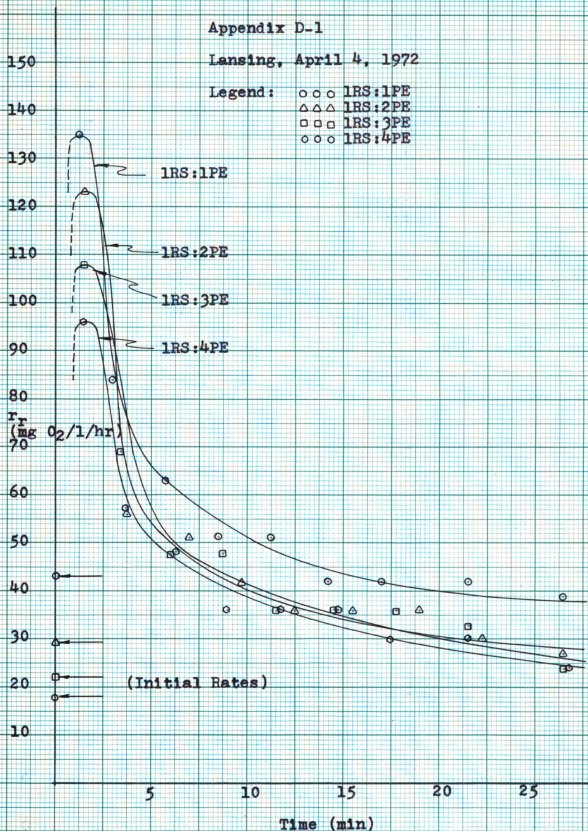


Figure D-1-1. Overall oxygen consumption rates (r_r) versus time for various batches of mixed liquor.

Appendix D-2

City of Lansing

April 6, 1972

Time Samples Taken: 10:30 a.m.

Temperature of Samples: 23 C

 $C_s = 7.97 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 10.88 gm/l

Primary Effluent, SS Ave. = 0.117 gm/l

Table D-2-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS (gm/l)</u>	<u>Initial k_r (mg O_2/gm SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	2.27	8.27	18.78
1:3	2.81	8.16	22.95
1:2	3.67	8.07	29.63
1:1	5.50	7.96	43.81

Table D-2-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r (mg O_2/l/hr)</u>	<u>k_r (mg O_2/gm SS/hr)</u>
PE	1	1.8	15.38
	2	2.4	20.5
RS	1	87.0	8.00
	2	84.0	7.72

Appendix D-2

Lansing, April 6, 1972

Legend: ○○ 1RS:1PE
 △△ 1RS:2PE
 □□ 1RS:3PE
 ○○ 1RS:4PE

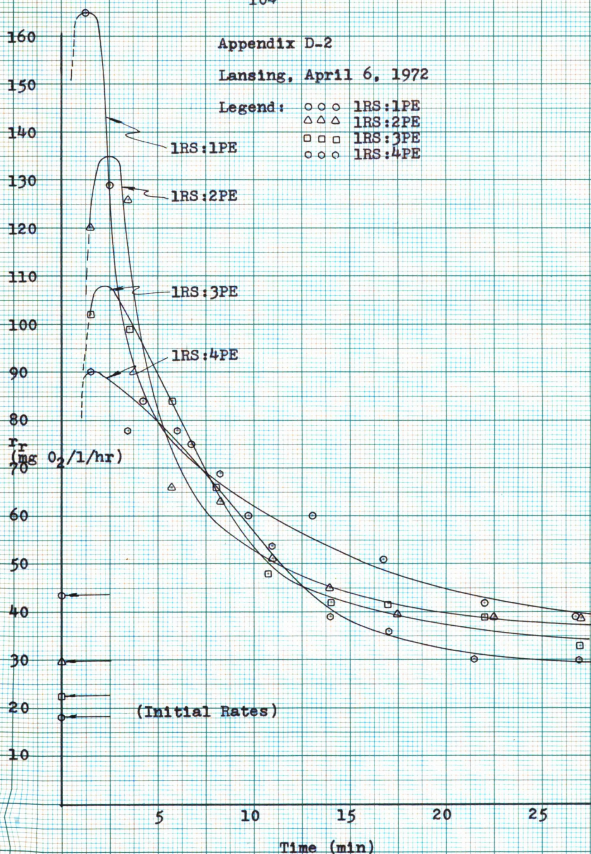


Figure D-2-1. Overall oxygen consumption rates (r_r) versus time for various batches of mixed liquor.

Appendix D-2

Lansing, April 6, 1972

Legend: ○○○ 1RS:1PE
 △△△ 1RS:2PE
 □□□ 1RS:3PE
 ○○○ 1RS:4PE

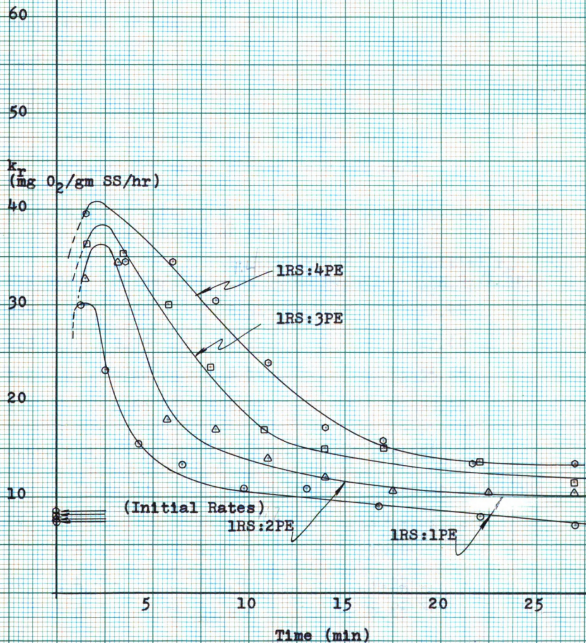


Figure D-2-2. Specific oxygen consumption rates (k_T) versus time for various batches of mixed liquor.

Appendix D-3

City of Lansing

April 11, 1972

Time Samples Taken: 12:00

Temperature of Samples: 23 C

 $C_s = 7.97 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 13.26 gm/l

Primary Effluent, SS Ave. = 0.062 gm/l

Table D-3-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O_2/gm^rSS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	2.70	8.31	22.44
1:3	3.36	8.21	27.60
1:2	4.42	8.11	35.86
1:1	6.66	8.01	53.38

Table D-3-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O_2/l/hr)</u>	<u>k_r(mg O_2/gm SS/hr)</u>
PE	1	1.8	29.0
	2	1.8	29.0
RS	1	111.0	8.37
	2	99.0	7.47

Appendix D-3

Table D-3-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O₂/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O₂/gm SS/hr)</u>
1:4	1	120.0	1:30	44.4
	2	72.0	3:30	26.7
	3	57.0	6:00	21.1
	4	45.0	9:00	16.7
	5	45.0	12:00	16.7
	6	39.0	15:15	14.4
	7	36.0	18:30	13.3
	8	30.0	21:30	11.1
	9	30.0	27:00	11.1
1:3	1	132.0	1:30	39.3
	2	66.0	3:45	19.6
	3	66.0	6:00	19.6
	4	48.0	8:30	14.3
	5	45.0	11:15	13.4
	6	39.0	14:00	11.6
	7	36.0	17:15	10.7
	8	36.0	22:00	10.7
	9	33.0	27:00	9.82
1:2	1	153.0	1:15	34.6
	2	84.0	4:15	19.0
	3	54.0	5:45	12.2
	4	51.0	8:15	11.5
	5	48.0	11:00	10.9
	6	39.0	14:00	8.8
	7	39.0	17:15	8.8
	8	36.0	22:00	8.1
	9	36.0	27:00	8.1
1:1	1	162.0	1:07	24.3
	2	96.0	2:30	14.4
	3	63.0	4:45	9.5
	4	63.0	7:45	9.5
	5	57.0	11:00	8.6
	6	51.0	14:45	7.7
	7	45.0	18:45	6.8
	8	45.0	23:00	6.8
	9	42.0	27:00	6.3

Appendix D-3

Lansing, April 11, 1972

Legend: ○○○ 1RS:1PE
 △△△ 1RS:2PE
 □□□ 1RS:3PE
 ○○○ 1RS:4PE

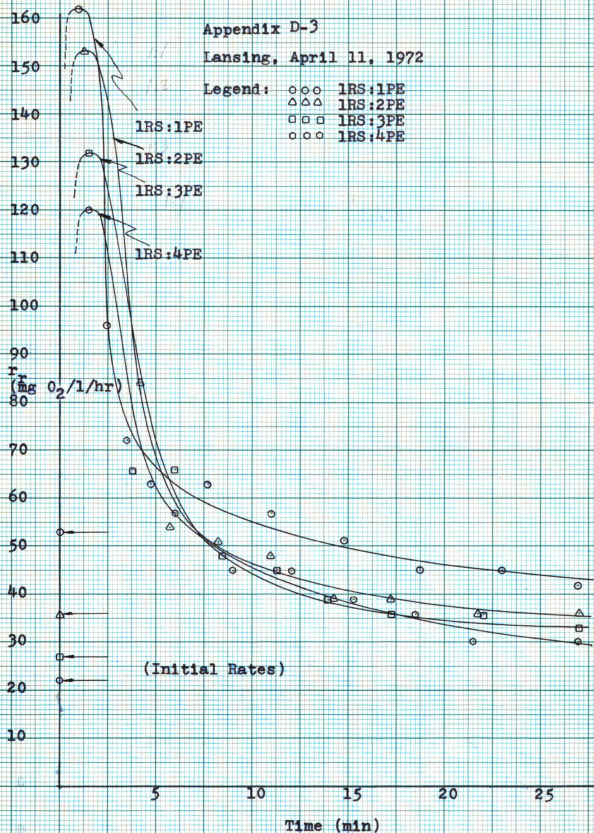


Figure D-3-1. Overall oxygen consumption rates (r_t) versus time for various batches of mixed liquor.

Appendix D-3

Lansing, April 11, 1972

Legend: ○○○ 1RS:1PE
 △△△ 1RS:2PE
 □□□ 1RS:3PE
 ○○○ 1RS:4PE

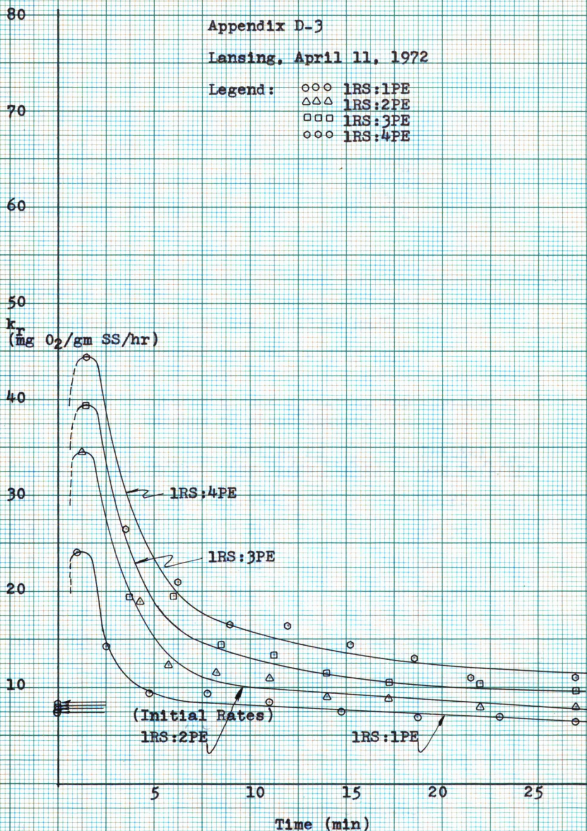


Figure D-3-2. Specific oxygen consumption rates (k_T) versus time for various batches of mixed liquor.

Appendix D-4

City of Lansing

April 13, 1972

Time Samples Taken: 10:15 a.m.

Temperature of Samples: 23 C

 $C_s = 8.07 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 13.96 gm/l

Primary Effluent, SS Ave. = 0.15 gm/l

Table D-4-1. Initial k_T and r_T values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS (gm/l)</u>	<u>Initial k_T (mg O_2/gm SS/hr)</u>	<u>Initial r_T (mg O_2/l/hr)</u>
1:4	2.91	7.98	23.21
1:3	3.60	7.89	28.39
1:2	4.71	7.81	36.77
1:1	7.05	7.71	54.38

Table D-4-2. r_T and k_T values for PE and RS

	<u>Trial No.</u>	<u>r_T (mg O_2/l/hr)</u>	<u>k_T (mg O_2/gm SS/hr)</u>
PE	1	2.4	16.0
	2	2.4	16.0
RS	1	111.0	7.95
	2	102.0	7.31

Appendix D-4

Table D-4-3. k_r and r_r values for various batches of mixed liquor.

Mixture	Trial No.	r_r (mg O_2 /l/hr)	Ave. Time (min:sec)	k_r (mg O_2 /gm SS/hr)
1:4	1	120.0	1:30	41.2
	2	102.0	3:45	35.0
	3	60.0	6:00	20.6
	4	42.0	8:45	14.4
	5	39.0	11:30	13.4
	6	33.0	15:15	11.3
	7	33.0	18:45	11.3
	8	27.0	22:00	9.3
	9	27.0	27:00	9.3
1:3	1	135.0	1:30	37.5
	2	93.0	3:15	25.8
	3	57.0	6:00	15.8
	4	39.0	8:45	10.8
	5	39.0	11:30	10.8
	6	36.0	14:30	10.0
	7	33.0	18:00	9.2
	8	30.0	22:00	8.3
	9	27.0	27:00	7.5
1:2	1	162.0	1:15	34.4
	2	117.0	3:00	24.8
	3	54.0	5:00	11.5
	4	51.0	7:30	10.8
	5	48.0	10:15	10.2
	6	36.0	13:30	7.6
	7	39.0	16:30	8.3
	8	39.0	22:00	8.3
	9	36.0	27:00	7.6
1:1	1	180.0	1:00	25.5
	2	117.0	2:30	16.6
	3	72.0	4:30	10.2
	4	57.0	7:15	8.1
	5	57.0	10:00	8.1
	6	51.0	14:15	7.2
	7	48.0	18:00	6.8
	8	48.0	21:45	6.8
	9	48.0	27:00	6.8

Appendix D-4

Lansing, April 13, 1972

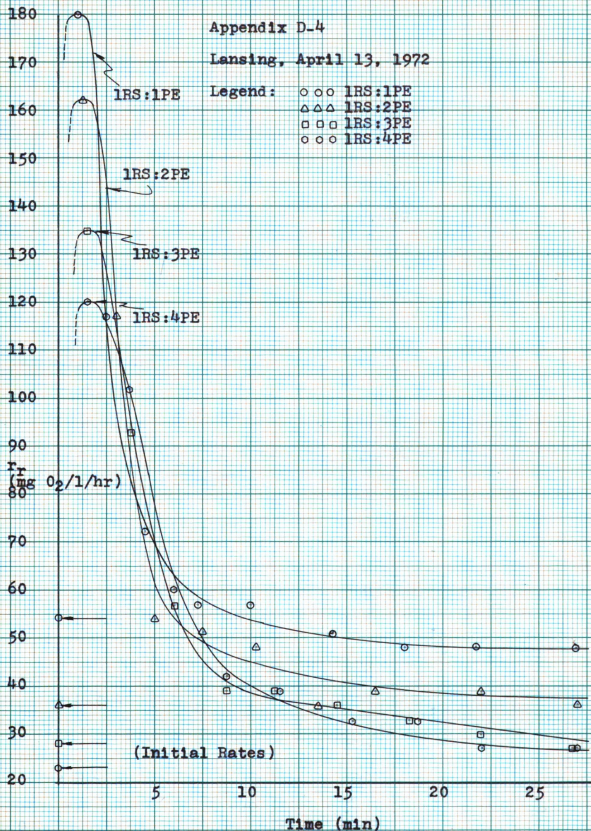


Figure D-4-1. Overall oxygen consumption rates (r_o) versus time for various batches of mixed liquor.

Appendix D-5

City of Lansing

April 17, 1972

Time Samples Taken: 12:00

Temperature of Samples: 23 C

 $C_s = 7.78 \text{ mg/l}$

Suspended Solids:

Return Sludge, SS Ave. = 12.77 gm/l

Primary Effluent, SS Ave. = 0.055 gm/l

Table D-5-1. Initial k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>SS(gm/l)</u>	<u>Initial k_r (mg O_2/gm SS/hr)</u>	<u>Initial r_r (mg O_2/l/hr)</u>
1:4	2.59	5.02	12.99
1:3	3.23	4.93	15.92
1:2	4.25	4.85	20.60
1:1	6.41	4.71	30.20

Table D-5-2. r_r and k_r values for PE and RS

	<u>Trial No.</u>	<u>r_r(mg O_2/l/hr)</u>	<u>k_r(mg O_2/gm SS/hr)</u>
PE	1	1.8	32.7
	2	1.8	32.7
RS	1	60.0	4.70
	2	57.0	4.46

Appendix D-5

Table D-5-3. k_r and r_r values for various batches of mixed liquor.

<u>Mixture</u>	<u>Trial No.</u>	<u>r_r (mg O_2/l/hr)</u>	<u>Ave. Time (min:sec)</u>	<u>k_r (mg O_2/gm SS/hr)</u>
1:4	1	90.0	1:30	34.7
	2	69.0	3:30	26.6
	3	54.0	6:00	20.8
	4	51.0	8:30	19.7
	5	42.0	11:00	16.2
	6	39.0	14:00	15.1
	7	33.0	17:00	12.7
	8	30.0	20:30	11.6
	9	27.0	27:00	10.4
1:3	1	96.0	1:30	29.7
	2	75.0	3:45	23.2
	3	63.0	6:00	19.5
	4	48.0	8:30	14.9
	5	42.0	10:45	13.0
	6	36.0	13:30	11.1
	7	27.0	17:00	8.4
	8	27.0	22:00	8.4
	9	27.0	27:00	8.4
1:2	1	117.0	1:30	27.5
	2	75.0	3:30	17.6
	3	63.0	6:00	14.8
	4	45.0	8:15	10.6
	5	45.0	10:45	10.6
	6	36.0	13:30	8.5
	7	36.0	17:00	8.5
	8	33.0	22:00	7.8
	9	30.0	27:00	7.1
1:1	1	126.0	1:30	19.7
	2	75.0	3:45	11.7
	3	63.0	6:00	9.8
	4	51.0	9:00	8.0
	5	48.0	12:15	7.5
	6	42.0	15:30	6.5
	7	36.0	18:45	5.6
	8	36.0	22:30	5.6
	9	36.0	27:00	5.6

Appendix D-5

Lansing, April 17, 1972

Legend: ○○○ 1RS:1PE
 △△△ 1RS:2PE
 □□□ 1RS:3PE
 ○○○ 1RS:4PE

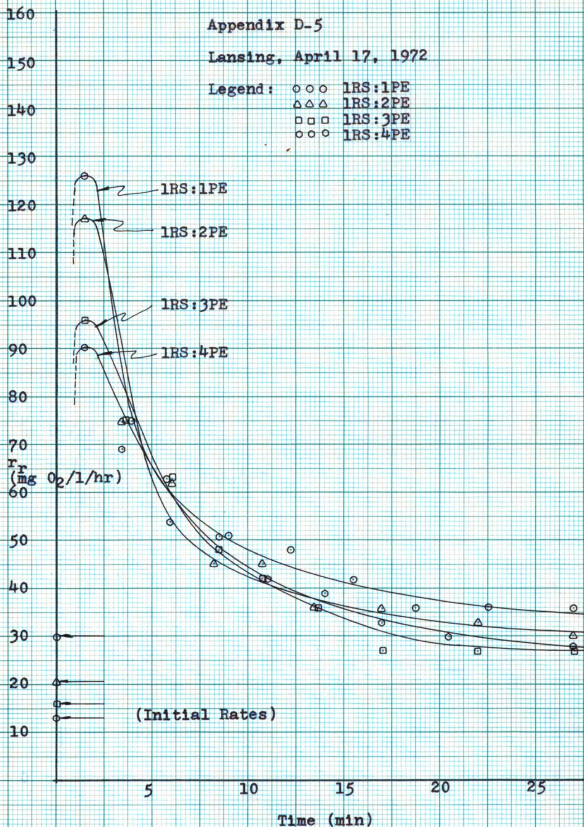


Figure D-5-1. Overall oxygen consumption rates (r_r) versus time for various batches of mixed liquor.

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