

A CORRELATION OF CONTINUOUS MIXING
AND THE DISINFECTION OF DOMESTIC SEWAGE

by

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I. INTRODUCTION

Domestic sewage contains tremendous numbers of microorganisms, some of which are pathogenic to man. It is potentially a powerful vector of water-borne disease; therefore, it is necessary to destroy the pathogenic microorganisms prior to discharge to the environment of mankind. The destruction of pathogenic microorganisms is accomplished in a unit operation termed disinfection. The strict definition of disinfection is the complete destruction of all pathogenic organisms (?); however in the case of domestic sewage treatment, disinfection implies essentially complete destruction of pathogens because it is impractical to obtain complete destruction.

The unit operation of disinfection as practiced in sewage treatment involves the addition of chlorine to the sewage and passing the flow through a baffled contact tank with adequate residence time to allow the toxic chlorine compounds to destroy the susceptible microorganisms. The disinfection achieved is rarely complete because microorganisms differ widely in respect to their susceptibility to the action of the chlorine compounds and/or they may be imbedded in suspended matter which shields them from the action of the chemical agents. The shielding suspended matter may consist, for example, of aggregates of finely divided fecal material, fibers, garbage, greases, or clumps of microorganisms.

The object of this investigation was to determine if disruption of weakly bound aggregates by agitation would improve the degree of disinfection as a result of exposure of susceptible imbedded organisms to the action of the disinfectant.

II. REVIEW OF LITERATURE

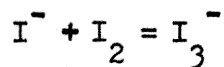
The practical method of plant scale disinfection of sewage or treated sewage effluents is by the addition of chlorine. The results obtained are affected by a myriad of variables, many of them uncontrollable, making rational investigation of the process tedious and difficult. Consequently, little information has been reported in the literature relative to the effect of mixing on disinfection of sewage.

Eliassen et al (4) have studied the effect of initial mixing on coliform kills in chlorinated filtered sewage. Samples of domestic sewage were filtered through absorbent cotton to remove suspended matter and were dosed with 40, 70, 100, 140, and 200 per cent of the chlorine demand of the sewage. Triplicate samples were used. Before mixing the samples were dosed to the prescribed percentages of the chlorine demand. The mixing was effected by either manual mixing (10 stirs @ 100 revolutions per minute) or rapid mechanical mixing for 15 seconds with an electric propeller mixer. Control samples for each dosage of chlorine were prepared by permitting the chlorine solution to flow from a pipette down the side of the beaker to minimize the mixing induced by the addition of the reagent. The coliform population of each sample was determined after 10 minutes of lapsed time by the multiple tube fermentation technique (12). The results were expressed in percentages of the coliform population of the control sample, for each chlorine dosage. The results showed a decrease in coliform population of approximately 50 per cent.

A comparison of the results indicated no effects attributable to differences in the mixing technique. Eliassen concluded that both methods of mixing accomplished complete blending of the chlorine solution with the sewage. The lack of quantitative expression of the intensity of mixing would make translation of the results to practical design difficult.

III. METHODS AND MATERIALS

Determination of adequate mixing for disinfection required the use of a disinfectant capable of producing approximately the same bactericidal products in the settled sewage for each application. Fair and Geyer (5) stated that chlorine in water releases hypochlorous acid (HOCl), hypochlorite ion (OCl^-), elemental chlorine (Cl_2), monochloramine (NH_2Cl), dichloramine (NHCl_2), nitrogen trichloride (NCl_3), and complex organic chloramines in sewage. Fair and Geyer (5) also stated the disinfecting power of the above chlorine species varied widely. The variance of the characteristics of the settled sewage to be used in this experiment made the use of chlorine impractical because of inherent differences in the composition of the active chemical agent. It was desirable to use a disinfectant which would produce a small number of active compounds in sewage and which would yield a reasonably stable residual. Chang (3) suggested the use of active iodine for disinfection and showed the forms of iodine in aqueous solution at pH values below 8.0 to be hypoiodous acid (HOI), elemental iodine (I_2), and tri-iodate (I_3^-). The disinfectant suggested was a solution containing crystalline iodine (I_2) and potassium iodine (KI). The reaction in aqueous solution is:



In dilute solutions with an iodine concentration greater than 0.5 ppm and pH less than 8.0 the elemental iodine will predominate (3) as

the sole active disinfectant. The use of active iodine solutions would probably yield reproducible concentration of iodine compounds in the settled sewage. The use of iodine eliminated many of the problems associated with control of the disinfectant dosage in chlorination.

The object of the investigation was to study the effect of mixing intensity on disinfection. Chicks law (5) formulates the rate of disinfection by the following equation:

$$dy/dt = k(N_0 - y)$$

where: y = number of organisms destroyed

N_0 = initial number of organisms present

k = constant

Integration of this relation gives a relation

$$\log N/N_0 = -kt^m \quad (5)$$

where: N = number organisms remaining

Recognizing that there is a finite time lapse before the disinfectant reaches all the organisms in the system, the plot of the number of microorganisms remaining would resemble Figure 1. (5)



Figure 1
Characteristic Disinfection Curve

To study the relation between mixing intensity and disinfection, it was necessary to determine the plot of the number of organisms versus time. The system was continuously mixed and samples removed at specified times for the determination of the coliform populations.

A. Design of Mixing System

The mixing system size was governed by the characteristics of the Chemineer, Inc. Mixer, Model ELB Experimental Agitator equipped with a conventional six bladed straight turbine impeller. The impeller blade was 2.5 inches in diameter and 0.3 inches in width. Parker (9) suggests a ratio of tank diameter to impeller diameter ranging from 3 to 6 for blending with multiple straight turbine impellers. Therefore, the mixing vessel selected was an 8-8 straight sided stainless steel beaker providing a tank diameter to impeller diameter ratio of 3.2.

The system was baffled with four galvanized steel plates providing a ratio of baffle width to tank diameter of 0.10 in accord with the recommendations of O'Connell (8). Four baffles 0.8 inches in width were equally spaced around the periphery of the mixing vessel. A sketch of the apparatus is shown in Figure 2.

The final characteristics of the system as designed were:

$$T/D = 3.2$$

$$W/D = .12$$

$$C/T = .094$$

$$z/T = 0.625$$

$$n_b = 4$$

$$w_b = T/10$$

$$n = 6$$

where: C = impeller clearance, inches

D = impeller diameter, inches

n = number of impellers

n_b = number of baffles

T = tank diameter, inches

w_b = baffle width, inches

Z = liquid depth, inches

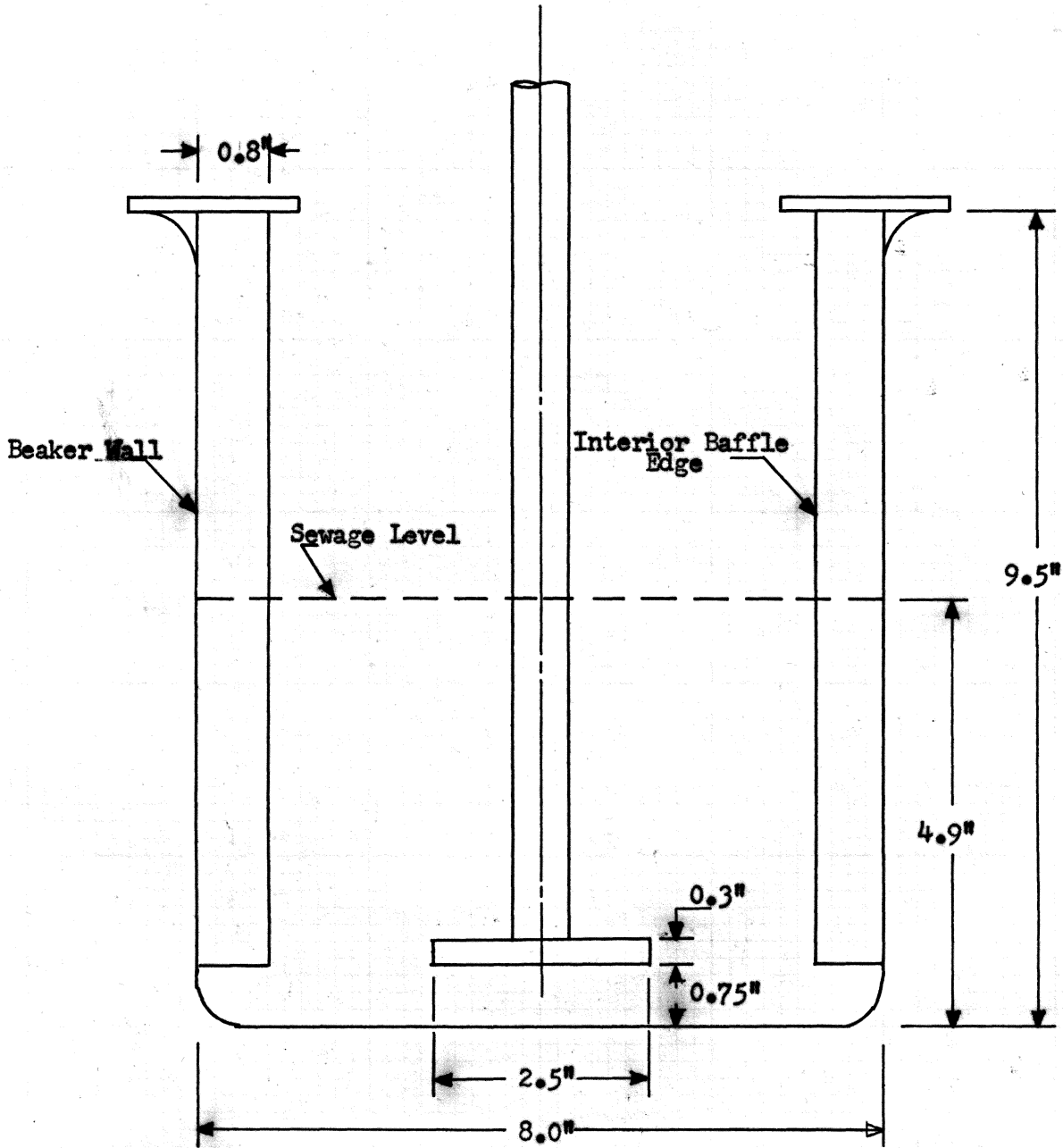


Figure 2

Mixing Apparatus

B. Experimental Methods

A sample of domestic sewage was obtained from the sewers of Blacksburg, Virginia. The settleable solids were separated from the sample by settling for one hour. One hundred milliliters of settled sewage were placed in each of ten 250 milliliters Erlenmeyer flasks and five of the flasks were dosed with 2.5, 3.0, 3.5, 4.0 and 4.5 milliliters respectively of 0.086 N. iodine solution. The flasks were swirled and checked for the presence of iodine at the end of a 10 minute contact period. A starch indicator was used and the appearance of a blue color taken as an indication of the presence of iodine. The remaining five flasks were inoculated with 0.1 milliliter increments of iodine solution in the range defined by the positive and negative flasks in the previous test. The dosage of iodine providing the minimum detectable residual was defined as the iodine demand of the sewage.

Four liters of the settled sewage were placed in the 8-8 stainless steel beaker and a sample withdrawn with a glass ladle to enable evaluation of the initial coliform population. The mixer was activated to the specified number of revolutions per minute and the settled sewage was dosed by dumping in a predetermined quantity of iodine solution from a beaker into the center of the beaker. The quantity of iodine solution added was determined by the iodine demand of the sample and the results of previous experiments. Following iodine addition, samples were withdrawn at 0.5, 1, 1.5, 2, 2.5, 3, 4, 6, 8, and 10 minutes of lapsed time and placed in beakers

containing 1 milliliter of 0.018 N. neutral sodium thiosulfate solution. The beakers were swirled to insure the destruction of the iodine.

At the end of 10 minutes the iodine residual was determined and if it was not within the range defined, all samples were discarded and the experiment repeated.

All samples were analyzed for the presence of organisms of the coliform group by the multiple-tube fermentation technique. Lactose broth and brilliant green bile broth were used as media in accordance with Standard Methods for the Examination of Water and Wastewater (12). Five tube replicates were used.

Iodine Residual

The iodine residual at the termination of the mixing operation was determined by titration of a 200 milliliter sample of sewage obtained from the mixing vessel with 0.018 N. neutral sodium thiosulfate in the presence of starch indicator solution. The disappearance of the blue color was taken as the end point.

C. Solutions

Iodine Solution (11)

The iodine solution used for disinfection was prepared by dissolving 40 grams of potassium iodide, reagent grade, in 25 milliliters of distilled water and then adding 13 grams of resublimed iodine, reagent grade. The solution was diluted 1:400 before use.

Sodium thiosulfate solution (10)

The sodium thiosulfate solution used for titration of the iodine was prepared by dissolving 25 grams of hydrated sodium thiosulfate ($\text{Na}_2\text{S}_2\text{O}_3 \cdot 5 \text{H}_2\text{O}$), reagent grade, in one liter of freshly boiled distilled water and diluting 1:4 before use.

Dichromate solution (10)

The dichromate solution used for standardization of sodium thiosulfate was prepared by drying powdered potassium dichromate, reagent grade, at 104°C . overnight and dissolving 4.904 grams by dry weight in one liter of distilled water.

D. Mixing Parameters

The parameters selected to express the mixing applied to the system during experimentation were as follows:

a) Mean temporal velocity gradient -- G -- This parameter was suggested by Camp (2) to express flocculation in chemical treatment of wastes. The expression in use is

$$G = \sqrt{P / (v V)}$$

where: P = power, foot pounds per second

v = viscosity, pound seconds per square foot

V = tank volume, cubic feet

b) Power Number -- N_p -- White and Brenner (13) proposed the parameter characterizing the basic flow pattern in impeller agitation of liquids. The expression is $N_p = P g / (w S^3 D^5) =$

$$K \left[\frac{d S D^2}{v} \right]^a \left[\frac{S^2 D^2}{g} \right]^b \left[\frac{T}{D} \right]^c \left[\frac{Z}{D} \right]^d \left[\frac{C}{D} \right]^e \left[\frac{P}{D} \right]^f \left[\frac{W}{D} \right]^g \left[\frac{L}{D} \right]^h \left[\frac{S_2}{S_1} \right]^i$$

where: d = density, slugs per cubic foot

g = gravitational constant, 32.2 feet per second per second

K = constant

L = blade length, inches

S = impeller speed, revolutions per minute

W = impeller width, inches

c) Power to Volume Ratio -- P/V -- The intensity of mixing in the system was expressed in a P/V ratio as suggested by Parker (9).

d) Pumping Rate -- Q -- The intensity of mixing was also expressed by the pumping rate which was defined as follows for the Chemineer, Inc. ELB Experimental mixer in cubic inches per minute:

$$Q = 0.62 S D^3$$

E. Calculation of mixing parameters

Bates (1) simplified the expression for Power Number by stipulation of geometric similiarity and a non-swirling system. The simplification resulted in the following equation:

$$N_p = P g / (w S^3 D^5) = K (N_{Re})^a$$

where: $N_{Re} = (dS D^2/v)$ is the Reynolds number.

Bates (1) gives a plot of Reynolds Number versus Power Number for a Chemineer Mixer Model ELB equipped with a straight bladed impeller. The value of Reynolds Number for the mixing systems used in the experiment was calculated and the corresponding Power Number determined from Bates' plot. The Power Number thus selected was used to calculate the impeller power by solving the expression for Power Number as follows:

$$P = (w N_p S^3 D^5)/g$$

Knowing the power applied to the system, the mean temporal velocity gradient was calculated from the expression $G = \sqrt{P/(vV)}$.

The P/V ratio was also determined as a parameter to express the intensity of mixing in the system.

IV EXPERIMENTAL RESULTS

It was recognized that the minimum degree of mixing for efficient disinfection would be that required to effect complete blending of the disinfectant with the sewage. It was considered conceivable that improved disinfection might be achieved through application of adequate mixing to effect disruption of floccules present in domestic sewage.

The initial experiment, Experiment 1, was to determine the value of the exponent "m" as defined by Fair and Geyer (5). A 4-liter sample of settled domestic sewage was placed in the stainless steel beaker and a sample withdrawn with a glass ladle to enable evaluation of the initial coliform population in accord with the procedures described in the Methods Section. The mixer was activated to 100 revolutions per minute. The 4-liters of settled sewage was dosed with 120 milliliters of 0.0086 N. iodine solution amounting to 107 per cent of the iodine demand. Samples for the multiple tube fermentation determination of the coliform population were withdrawn at 1, 2, 3, 4, 6, 8, and 10 minutes of lapsed time. These samples were placed in beakers containing one milliliters of 0.018 N. neutral sodium thiosulfate and swirled to insure destruction of the iodine. The iodine residual was determined at the end of 10 minutes and found to be approximately 0.48 milligrams per liter. The complete results of the experiment are tabulated in Table 1 and the data are illustrated in Figure 3. Figure 3 was obtained by the trial plotting of the data varying the power of the exponent of time until the data traced a

straight line on semi-logarithmic paper. The value of the exponent "m" was found to be approximately $1/3$. The slope of the line plotted in Figure 1 is -1.8.

The next experiment, Experiment 2, was designed to determine if increased agitation would improve disinfection. The mixer speed was increased to 255 revolutions per minute and the previous experiment was repeated. The 4-liters of settled sewage were dosed with 180 milliliters of iodine solution. This dosage was 107 per cent of the iodine demand. Samples were taken at the same time-intervals used in Experiment 1. The 10-minute iodine residual was 0.48 milligrams per liter. The data obtained is tabulated in Table 2 and summarized in Figure 4. The bacterial disinfection data traces a straight line with a slope of -2.0. The slope of the line in Figure 4 is very similar to the slope of the line in Figure 3. No effect of the additional agitation was evident.

The two previous experiments had defined the effect of mixing and the third experiment was designed to decrease the intensity of agitation below that employed in previous experiments. The mixer was adjusted to its lowest speed of 32 revolutions per minute. The 4-liters of settled sewage were dosed with 110 milliliters of 0.0086 N. iodine solution amounting to 91.6 per cent of the iodine demand of the sewage. Samples were taken at 0.5, 1, 1.5, 2, 2.5, 3, 4, 6, 8 and 10 minutes of lapsed time. The iodine residual was 0.48 milligrams per liter after 10 minutes of contact time. Table 3 is a tabulation of the data obtained and Figure 5 is a plot of the

condensed data. The data traces a straight line with a slope of -2.0. The relation for disinfection was similar to Experiments 1 and 2. It appeared that adequate mixing had been provided throughout the contact period.

The next experiment, Experiment 4, was to determine if the turbulent addition of the iodine solution was sufficient to cause adequate mixing. The only mixing provided was that effected by the addition of 105 milliliters of iodine solution to 4-liters of settled sewage. Samples were taken from the top portion of the beaker with a glass ladle at 0.5, 1, 1.5, 2, 2.5, 3, 4, 6, 8 and 10 minutes. The iodine residual in the top portion after ten minutes was not detectible. The mixer was briefly activated at a high mixing rate and the iodine residual again determined. It was found to be approximately 0.49 milligrams per liter. Iodine was therefore present in the beaker throughout the entire contact period. Table 4 is a tabulation of the data for the experiment and Figure 6 is the graph of the condensed data. The line trace had a slope of -1.1. The disinfection achieved in this experiment was inferior to previous results and indicated that insufficient mixing was provided.

TABLE 1

Iodine Demand	2.8 milliliters per 100 milliliters sewage
Iodine added	120 milliliters
Iodine Residual	0.48 milligrams per liter
Impeller Speed	100 revolution per minute
G	61 per second
P/V	8.94 foot pounds per second per 1000 gallons
Q	0.0094 cubic feet per second
Temperature	78° F.

Time Minutes	Coliform Population per 100 milliliters	Per cent Remaining
0	13,000,000	
1	130,000	1.00
2	348,000	2.67
3	54,200	0.42
4	54,200	0.42
6	24,000	0.20
8	13,000	0.10
10	9,900	0.06

TABLE 2

Iodine Demand	4.2 milliliters per 100 milliliters sewage
Iodine Added	180 milliliters
Iodine Residual	0.48 milligrams per liter
Impeller Speed	255 revolutions per minute
G	251 per second
P/V	148 foot pounds per second per 1000 gallons
Q	0.0258 cubic feet per second
Temperature	78° F.

Time Minutes	Coliform Population per 100 milliliters	Per cent Remaining
0	130,000,000	
1	790,000	0.64
2	430,000	0.33
3	542,000	0.42
4	13,000	0.01
6	542,000	0.42
8	34,200	0.03
10	79,000	0.06

TABLE 3

Iodine Demand	3.0 milliliters per 100 milliliter sewage.
Iodine Added	110 milliliters
Iodine Residual	0.48 milligrams per liter
Speed	32 revolutions per minute
G	11 per second
P/V	0.294 foot pounds per second per 1000 gallons
Q	0.003 cubic feet per second

Time Minutes	Coliform Population per 100 milliliters	Per cent Remaining
0.0	2,210,000	
0.5	70,000	3.16
1.0	80,000	3.62
1.5	17,000	0.77
2.0	17,000	0.77
2.5	23,000	1.04
3.0	175,000	7.92
4.0	7,000	0.32
6.0	24,000	1.09
8.0	1,300	0.06
10.0	790	0.04

TABLE 4

Iodine Demand	3.0 milliliters per 100 milliliter sewage
Iodine Added	105 milliliters
Iodine Residual	0.49 milligrams per liter
Impeller Speed	0 (No agitation)
Temperature	78°F.

Time Minutes	Coliform Population per 100 Milliliters	Per cent Remaining
0.0	4,900,000	
0.5	490,000	10.00
1.0	330,000	6.73
1.5	240,000	4.90
2.0	348,000	7.10
2.5	348,000	7.10
3.0	790,000	16.10
4.0	348,000	7.10
6.0	130,000	2.65
8.0	240,000	4.90
10.0	79,000	1.61

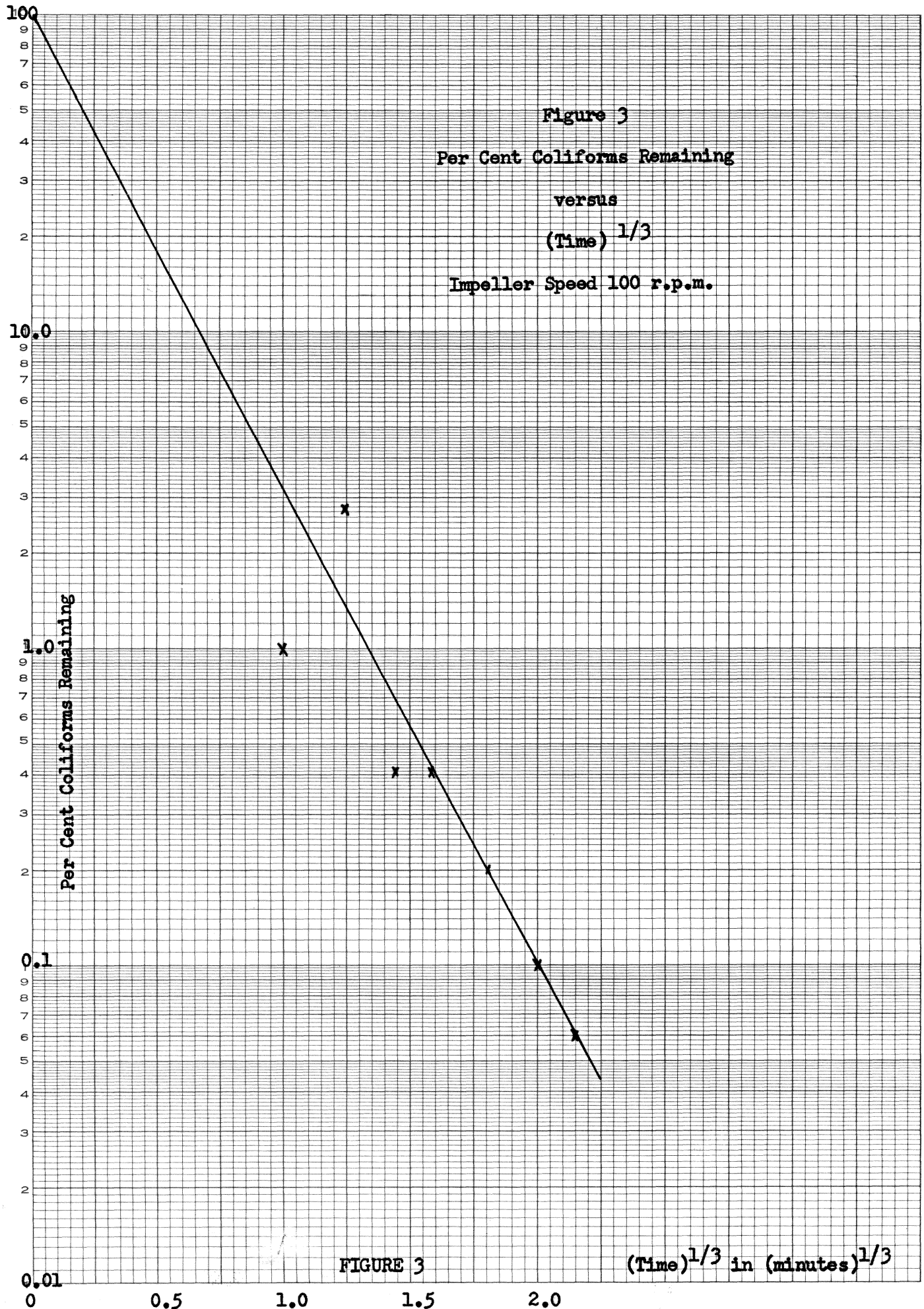


Figure 4
Per Cent Coliforms Remaining
versus
(Time)^{1/3}
Impeller Speed 255 r.p.m.

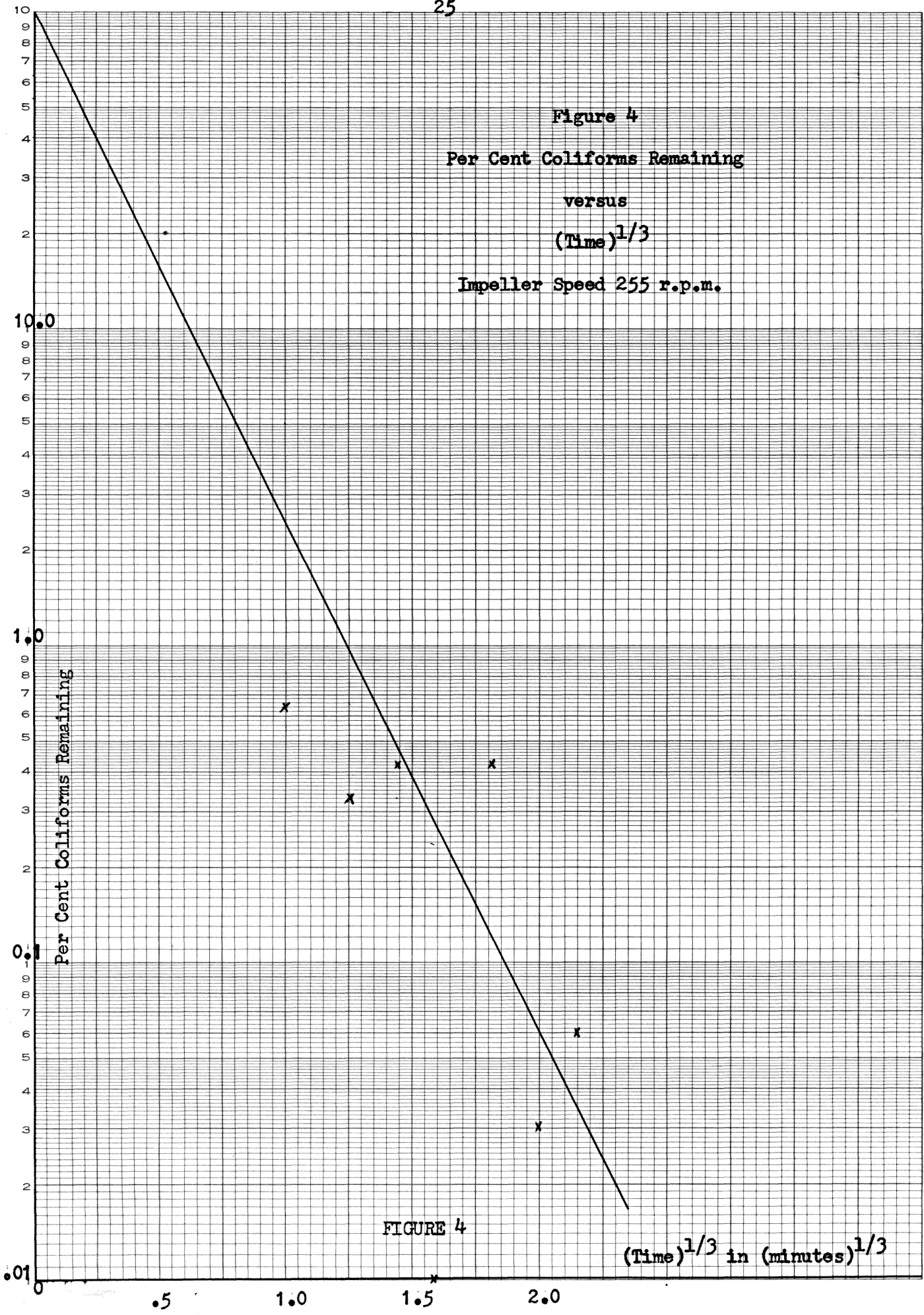


FIGURE 4

(Time)^{1/3} in (minutes)^{1/3}

Figure 5
Per Cent Coliforms Remaining
versus
(Time)^{1/3}
Impeller Speed 32 r.p.m.

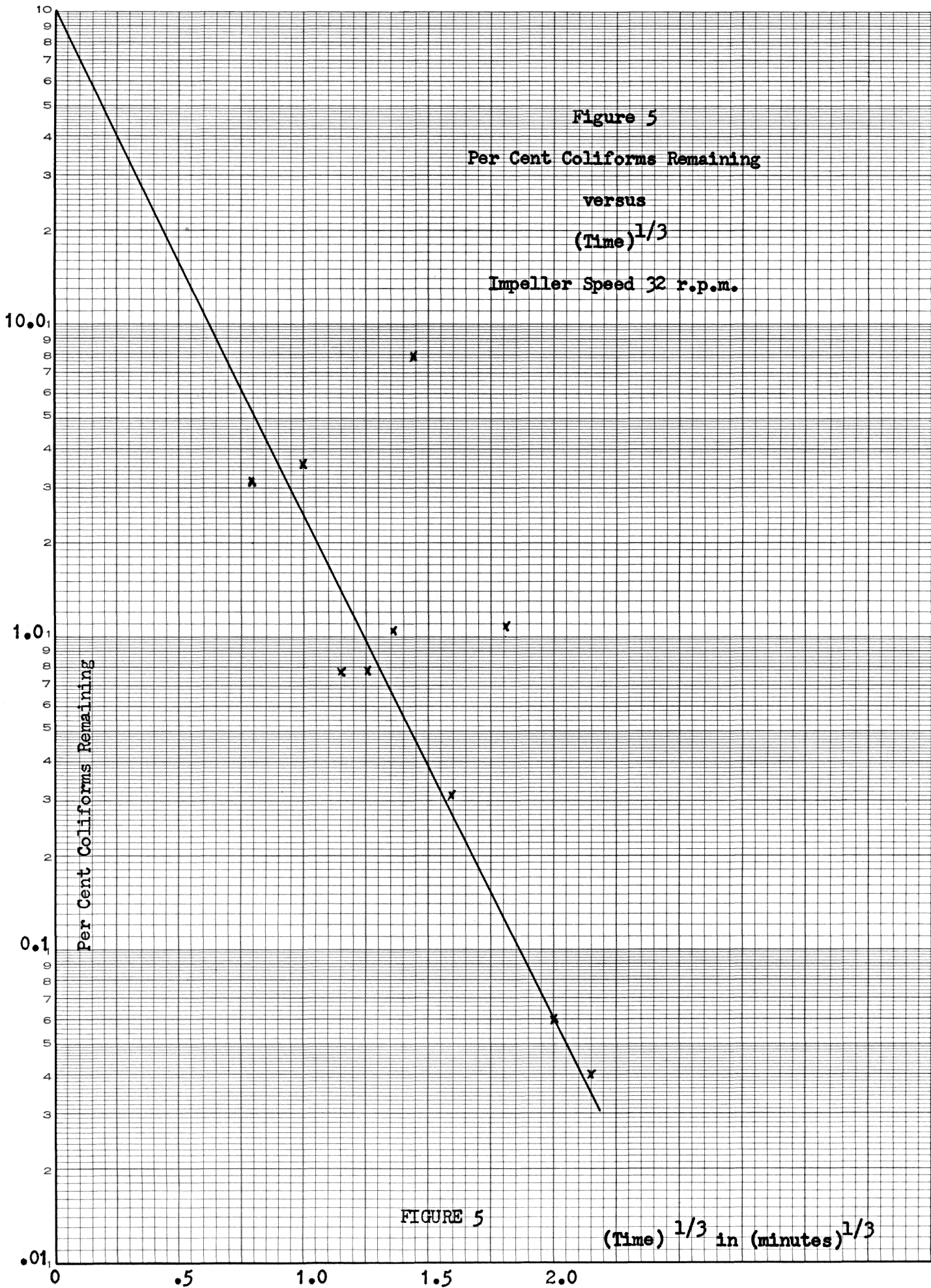
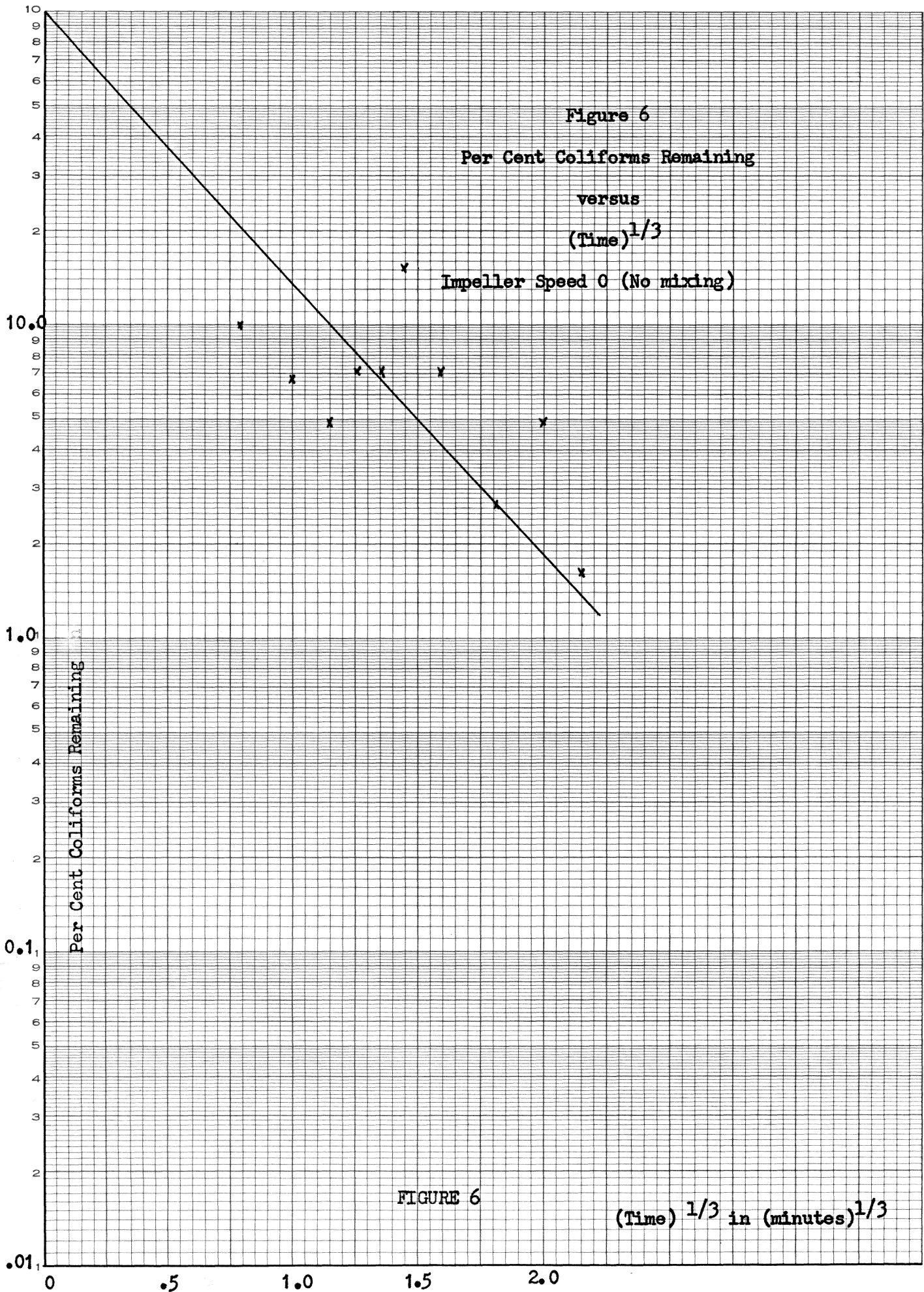


FIGURE 5

(Time)^{1/3} in (minutes)^{1/3}



V GENERAL DISCUSSION

In the calculation for the power to volume ratio and the mean temporal velocity gradient, the plot of Power Number versus Reynolds' Number reported by Bates (1) was used to determine the impeller power. Bates specifies geometric similiarity and a non-swirling system to use the suggested plot. A comparison of the geometric characteristics of the system used by Bates and the system used in this research is given below.

<u>Characteristic</u>	<u>Bates</u>	<u>This Research</u>
D/T	0.33	0.312
C/T	0.33	0.094
Z/T	1.0	0.625
n_b	4	4
n	6	6
w/D	0.125	0.12
w_b / T	0.0833	0.10

The values are similar with the exception of the C/T ratio. The power applied to the systems used in these experiments will have a slightly higher value than those derived from the plot due to the decreased clearance. Thus the values of the power parameters determined from the plot are slightly less than the actual values delivered to the system as designed.

With no mixing other than the turbulence generated from the introduction of iodine solution, the slope of the disinfection curve

was less than in the previous experiments. The data points were also more dispersed presumably due to the presence of pockets of different iodine concentration within the system. A difference in iodine concentration would result in great differences between various samples in respect to concentration of coliform organisms remaining. Conceivably, a reduction in the indicated rate of kill could also be attributed to the failure to disrupt the floccules within the sewage. In this case organisms contained within sewage floccules would be protected from the bactericidal action of the disinfectant and therefore survive for longer periods.

The data points in Experiments 1, 2 and 3 showed good fit to the expression $N/N_0 = k t^{1/3}$. The curves in all three experiments could be approximated by this exponential relation. The points exhibited little dispersion from the above equation when plotted on semi-logarithmic paper.

The analysis of the combined results indicated that the disinfection rate in the systems subjected to mixing at 32 revolutions per minute corresponding to $G = 11$ per second and $P/V = 0.29$ foot pounds per second per 1,000 gallons was similar to the disinfection in the systems mixed at 100 revolutions per minute corresponding to $G = 61$ per second and $P/V = 8.9$ foot pounds per second per 1,000 gallons, and 255 revolutions per minutes corresponding to $G = 251$ per seconds and $P/V = 148$ foot pounds per second per 1,000 gallons. The similarity implied that a mixing intensity greater than $G = 11$ per

second and $P/V = 0.29$ foot pounds per second per 1000 gallons, did not increase the efficiency of disinfection as a result of increased disruption of the floccules and dispersion of the disinfectant.

Eliassen reported the effects of initial mixing on disinfection systems. The systems were mixed by paddle stirring of 10 stirs @100 revolutions per minute or mechanical mixing for 15 seconds with an electric propeller. The results showed that approximately the same degree of disinfection was obtained for both types of mixing. The turbulence induced by both the paddle mixer and the mechanical stirrer used in Eliassen's research was probably sufficient to induce disruption of the floccules and dispersion of the disinfectant. The initial mixing employed by Eliassen was presumably sufficient to achieve a comparable region of mixing as attained in the continuously mixed systems used in this research. Eliassen also obtained approximately the same degree of disinfection with the paddle mixer and the mechanical stirrer indicating that the degree of mixing was not a limiting factor.

The results of this research showed that the continuously mixed systems with mixing intensity greater than that induced by 32 revolutions per minute, the disinfection obtained was similar. The disinfection curves for the mechanically agitated solutions had approximately the same slope. This similarity suggested that after some time period the disinfectant was sufficiently dispersed and the floccules were disrupted sufficiently to effect optimum disinfection. Realizing that Eliassen obtained the same degree of disinfection in

the initially mixed systems under different mixing conditions, it was considered conceivable that continuous mixing was not required. If the initial mixing was sufficient, the point where the data points first showed little dispersion around the line of theoretical points would probably be a rough estimate of the required initial mixing. Experiment 3 with the mixing induced by a turbine speed of 32 revolutions per minute was the experiment with the least mixing. After a time lapse of one minute the data points showed little dispersion and it was inferred from Figure 5 that mixing at this time was sufficient to place the system in the region of complete mixing and no further mixing was probably required.

From the above estimate of the initial mixing time the quantity of mixing was approximated. The values as approximated were:

$$Gt = 660$$

$$P/V = 21.6 \text{ foot pounds per 1000 gallons} \\ \text{(for 1 minute)}$$

$$\text{Tank Turnovers} = 1.3$$

This quantity of mixing would probably be sufficient to place the system in the region of complete mixing.

The investigation did realize its objectives in that the effect of continuous mixing was quantitatively evaluated for the disinfection system studied. Eliassen did not quantitatively evaluate the mixing in his research. The lower limit of the required mixing intensity

was not determined because of limitation in the available equipment. the minimum speed of the mixing equipment was too great to permit study at speeds of less than 32 revolutions per minute.

Further studies in the range below $G = 11.1$ per second and $P/V = 0.294$ foot pounds per second per 1000 gallons are indicated to determine the minimum requirements for mixing to maintain the relations obtained by this research.

VI CONCLUSION

Continuously mixed systems disinfected by iodine showed similar disinfection rates for mixing more intense than $G = 11$ per second and $P/V = 0.29$ foot pounds per second per 1000 gallons. The mixing intensity corresponds to 1.3 tank turnovers per minute. Considering these results together with Eliassen's results it was estimated that an initial mixing time of one minute was required.

The quantity of mixing for the one minute time period was estimated as $Gt = 660$, $P/V = 21.6$ foot pounds per 1000 gallons or 1.3 tank turnovers.

The investigation pursued for this thesis suggests a more detailed study to evaluate the optimum initial mixing time and the minimum mixing intensity required for adequate disinfection. It would be advisable to verify the estimates of these values that were calculated as a result of this investigation.

VII SUMMARY

When domestic sewage is disinfected it is necessary to destroy the pathogenic organisms before discharge to the environment of mankind. Some of the more resistant pathogens may survive the disinfection process and escape to the environment. To minimize the possibility it is advisable to study the unit process known as disinfection and to determine if the disinfectant is adequately mixed to minimize the number of pathogenic surviving.

The method devised to study the mixing was the determination of the disinfection rate in continuously mixed systems disinfected with iodine. The mixing intensity was evaluated and the rate of disinfection determined by plotting the per cent of microorganisms remaining against time^m on semi-logarithmic paper (5). The slope of the data plotted was approximately -2.0 when the per cent remaining was plotted against time^{1/3} for all experiments where the mean temporal velocity gradient (2) was greater than 11 per second and the power to volume ratio (9) was greater than 0.29 foot pounds per second per 1000 gallons.

From these results and interpretation of Eliassen's studies (4), the initial mixing time required was estimated as one minute and the approximate quantity of mixing required was estimated as 1.3 tank turnovers corresponding to a product of mean temporal velocity gradient and time of 660 and a power to volume ratio for one minute of 21.6 foot pounds per 1000 gallons.

The design and operation of plant scale disinfection processed

could be evaluated considering the minimum mixing defined by this thesis. Such evaluation might indicate the need for additional mixing other than the turbulence induced by the baffling presently used in the disinfection processes.

VIII ACKNOWLEDGEMENTS

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XI. APPENDIX

A. Nomenclature

C	impeller clearance, inches
D	impeller diameter, inches
d	density, slugs per cubic foot
G	mean temporal velocity gradient, per second
g	gravitational constant, 32.2 feet per second per second
k	rate constant
K	constant
L	blade length, inches
m	time exponent
N	number of organisms remaining
No	number of organisms initially
Np	Power Number
N _{Re}	Reynolds Number
n	number of impellers
n _b	number of baffles
P	power, foot pounds per second
Q	pumping rate, cubic inches per minute
S	impeller speed, revolutions per minute
T	tank diameter, inches
V	tank volume, cubic feet
v	viscosity, pound seconds per square foot
W	impeller width, inches
w	specific weight, pounds per cubic foot
w _b	baffle width, inches
y	number of organisms destroyed
Z	liquid depth, inches

B. Sample Calculations

For 255 Revolutions per minute.

Temperature = 78°F.

w = 62.3 pounds per cubic foot

v = 1.85 pound seconds per square foot

d = 1.93 slugs per cubic foot

D = 2.5 inches

g = 32.2 feet per second squared

V = 4 liters = 1.056 gallons = 0.134 cubic feet

$$N_{Re} = \frac{d S D^2}{v 60 \cdot 144}$$

$$N_{Re} = \frac{255}{60} \frac{(2.5)^2}{144} \frac{1}{0.930 \times 10^{-5}} = 1.98 \times 10^4$$

$$N_p = 2.7$$

$$P = \frac{w N_p S^3 D^5}{g (60)^3 (12)^5} = \frac{62.3 (2.7) (255)^3 (2.5)^5}{32.2 \cdot 2.16 \times 10^5 (12)^5}$$

$$= \frac{(62.3) (2.7) (76.2) (0.00039)}{62.2} = \frac{0.156 \text{ ft. lb.}}{\text{sec.}}$$

$$P/V = 0.148 \frac{\text{ft. lb.}}{\text{sec. gal.}}$$

$$G = \sqrt{\frac{P}{v V}} = \sqrt{\frac{.1562}{(1.85 \times 10^5) (0.734)}} = 251/\text{sec.}$$

$$Q = 0.62 S D^3 = \frac{0.62 (255) 15.5}{(60) 1728} = .0238$$

ABSTRACT

When domestic sewage is disinfected it is necessary to destroy the pathogenic organisms before discharge to the environment of mankind. Some of the more resistant pathogens may survive the disinfection process and escape to the environment. To minimize this possibility it is advisable to study the unit process known as disinfection and to determine if the disinfectant is adequately mixed to minimize the number of pathogens surviving.

Eliassen et al (2) studied disinfection of sewage subjected to initial mixing. He reported the disinfection in systems subjected to slow initial mixing and systems subjected to rapid initial mixing were approximately equal.

The method devised to study the mixing was the determination of the disinfection rate in continuously mixed systems disinfected with iodine. The mixing intensity was evaluated and the rate of disinfection determined by plotting the per cent of microorganisms remaining against time ^m on semi-logarithmic paper (3). The slope of the data plotted was approximately -2.0 when the per cent remaining was plotted against time ^{1/3} for all experiments where the mean temporal velocity gradient (1) was greater than 11 per second and the power to volume ratio (4) was greater than 0.29 foot pounds per second per 1000 gallons.

From these results and interpretation of Eliassen's studies (2), the initial mixing time required was estimated as one minute and the

approximate quantity of mixing required was estimated as 1.3 tank turnovers corresponding to a product of mean temporal velocity gradient and time of 660 and a power to volume ratio for one minute of 21.6 foot pounds per 1000 gallons.

The design and operation of plant scale disinfection processes could be evaluated considering the minimum mixing defined by this thesis, such evaluation might indicate the need for additional mixing other than the turbulence induced by the baffling presently used in the disinfection processes.

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