

K VALUES FOR TRICKLING FILTERS

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

James E. Germain

1963



This is to certify that the

thesis entitled

K VALUES FOR TRICKLING FILTERS

presented by

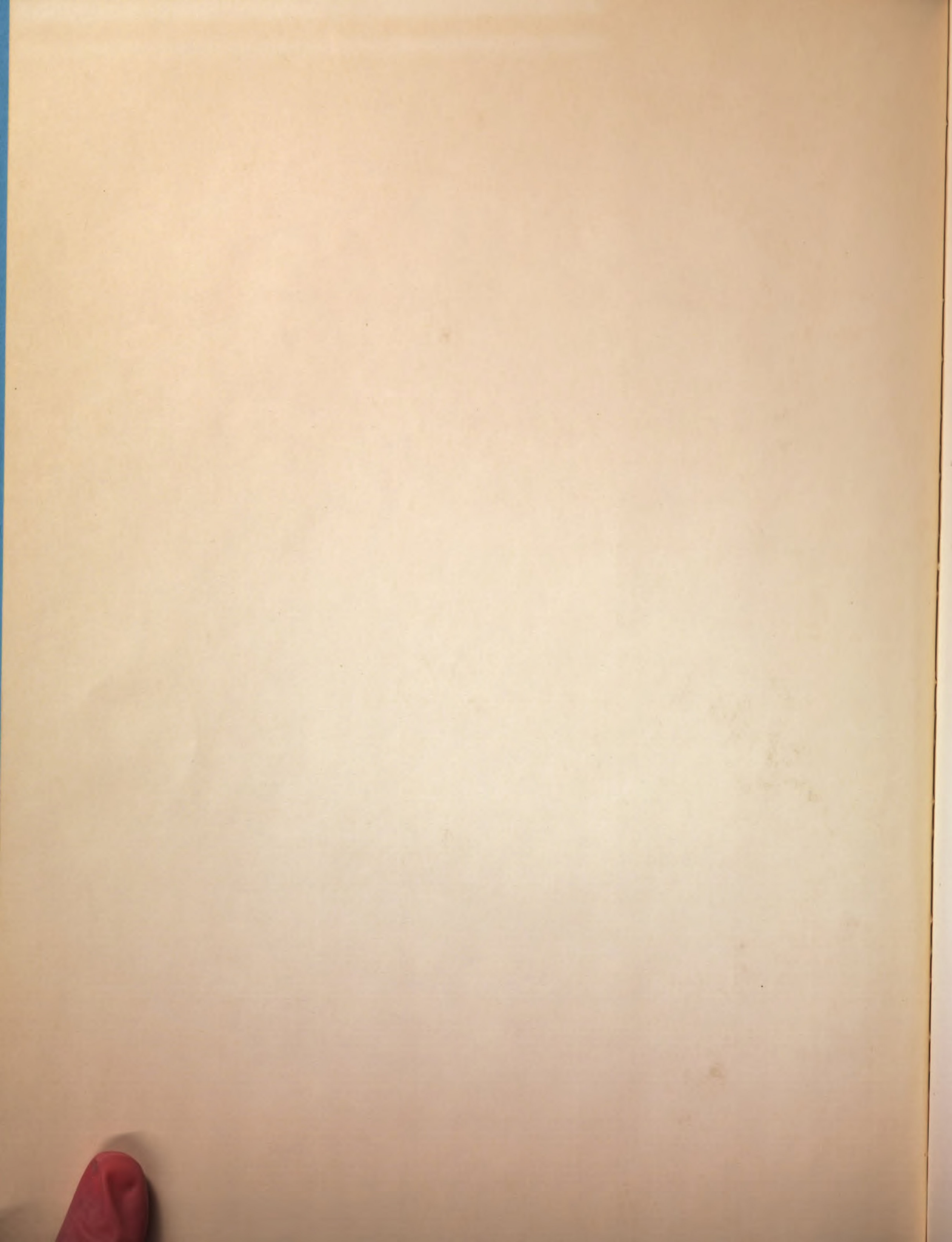
James E. Germain

has been accepted towards fulfillment
of the requirements for

M. S. degree in Sanitary Engineering

R. L. Colm
Major professor

Date May 17, 1963



ABSTRACT

K VALUES FOR TRICKLING FILTERS

James E. Germain

This thesis contains an analysis of the value "K" in the expression $p = 10^{-KD/Q^{2/3}}$ as determined from operational data on trickling filters, where

p = Fraction of BOD remaining

D = Filter depth in feet

Q = Hydraulic load in MGAD

K = Constant

Data from 19 Michigan rock trickling filter plants were analyzed and the K values determined. Several of these plants were analyzed on a daily basis to show the normal fluctuation of K at a single plant. K values were also determined for rock trickling filter plants in other regions of the country with different climatic conditions. In addition pilot plant and full scale plant data were analyzed which indicate that in a rock filter the K value decreases with increasing depth. In contrast the analysis of a considerable amount of data from trickling filter plants using open type plastic media demonstrated that in these cases K was constant and independent of depth.

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James E. Germain

Thus the validity of the expression used to determine K was proven correct for open type media. It is believed that the variations in K found for conventional filters employing crushed stone or rock as filter media are due to a lack of air supply and clogging and that this is especially true in the deeper parts of the filter. Based on the results of this analysis an attempt was made to use the K value as an indicator of the treatability of various industrial and municipal wastes.

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The author wishes to express his sincere appreciation to Dr. Karl L. Schulze of the Department of Civil and Sanitary Engineering for his valuable guidance and assistance in connection with this thesis; and also to the Michigan Department of Health, Mr. George Martin, Engineer - Manager of the Green Bay Metropolitan Sewerage District, and Dow Industrial Service for contributing a major part of the experimental data which were analyzed in this thesis.

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LIST OF SYMBOLS

Symbols are defined as they are used throughout this thesis, but for convenience common symbols are listed here also.

L_E = BOD of settled filter effluent, mg/l

L_I = BOD of incoming plant waste, mg/l

L_D = BOD of mixed flow (incoming plus recirculation), mg/l

t = A factor representing contact time on the filter

K = Filter reaction rate (to the base 10)

k = Filter reaction rate (to the base e)

C = a constant

D = Depth of Filter in feet

Q = Hydraulic load to filter in MGAD, including recycle flow

n = An exponent

p = Fraction of incoming BOD remaining = $\frac{L_E}{L_I}$

p_1 = Fraction of BOD remaining in filter effluent related to BOD of mixed flow (incoming plus recirculation)
 $= \frac{L_E}{L_D}$

r = Recycle ratio = $\frac{Q_R}{Q_I}$

Q_I = Flow to the plant in terms of MGAD

Q_R = Recirculated flow in terms of MGAD

LIST OF SYMBOLS

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C = a constant

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n = An exponent

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p_I = Fraction of BOD remaining in filter effluent related to BOD of mixed flow (incoming plus recirculation)

$$\frac{I_E}{I_D} =$$

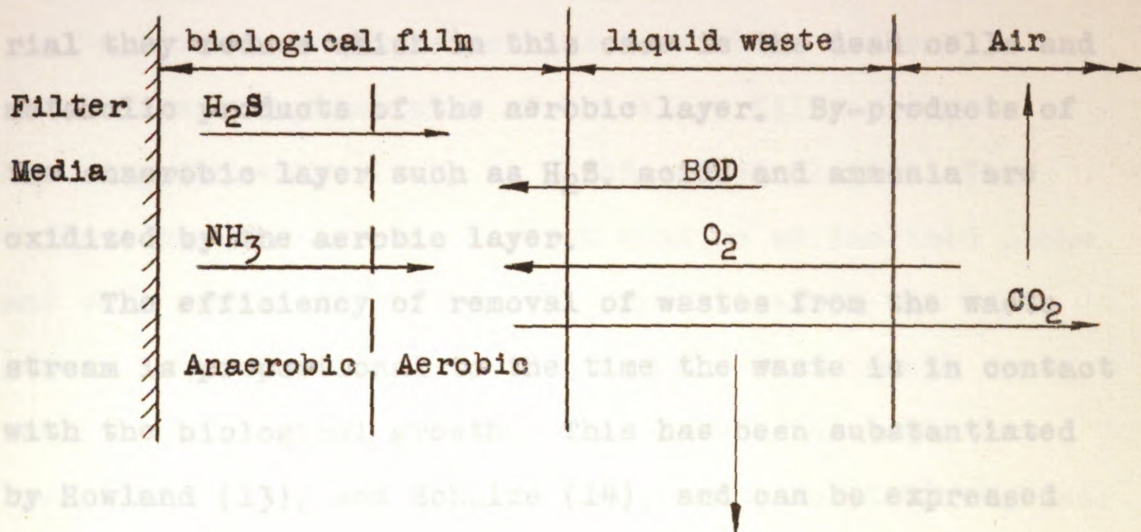
r = Recycle ratio = $\frac{Q_R}{Q_I}$

Q_I = Flow to the plant in terms of MGAD

Q_R = Recirculated flow in terms of MGAD

CHAPTER I - INTRODUCTION

A trickling filter is a fixed bed through which a biologically treatable waste is passed and is broken down by the biological growth within the filter. The basic mechanism consists of some type of media (rock, slag, or artificial material such as plastic) on which a biological film grows as the waste is trickled over it. This can be illustrated diagrammatically as below.



mathematically by the following formula:

$$\frac{L_E}{L_I} = e^{-kt} \quad (1)$$

in which

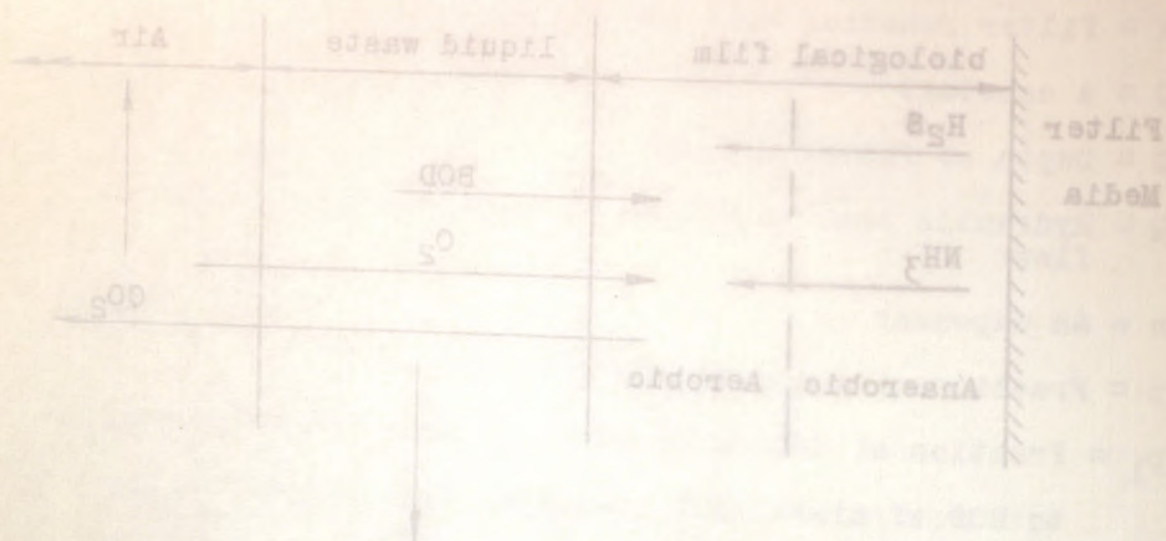
L_E = Filter effluent BOD, mg/l

L_I = Incoming BOD applied to filter, mg/l (without recirculation)

t = Contact time

k = Reaction Rate

A trickling filter is a fixed bed through which a biologically treatable waste is passed and is broken down by the biological growth within the filter. The basic mechanism consists of some type of media (rock, slag, or artificial material such as plastic) on which a biological film grows as the waste is trickled over it. This can be illustrated diagrammatically as below.



The filter medium serves to support the biological growth, shown here as the anaerobic and aerobic layers. The aerobic layer is the effective portion of the filter as it oxidizes the waste which is captured out of the liquid waste stream. The air passing through the filter performs the very important function of supplying oxygen to the aerobic bacteria. The anaerobic layer is black in color and exists in the area devoid of oxygen. The organisms comprising this layer receive their oxygen from the material they reduce which in this case is the dead cells and metabolic products of the aerobic layer. By-products of the anaerobic layer such as H_2S , acids and ammonia are oxidized by the aerobic layer.

The efficiency of removal of wastes from the waste stream is proportional to the time the waste is in contact with the biological growth. This has been substantiated by Howland (13), and Schulze (14), and can be expressed mathematically by the following formula:

$$\frac{L_E}{L_I} = e^{-kt} \quad (1)$$

in which

L_E = Filter effluent BOD, mg/l

L_I = Incoming BOD applied to filter, mg/l (without recirculation)

t = Contact time

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mathematically by the following formula:

$$\frac{L_2}{L_1} = e^{-kt} \quad (1)$$

in which

L_2 = Filter effluent BOD, mg/l

L_1 = Incoming BOD applied to filter, mg/l (without respiration)

t = Contact time

k = Reaction Rate

The mean contact time t through the filter media has been expressed by Schulze (1) and Howland (13) by the following relationship:

$$t = CD/Q^n$$

Where

C = A constant

D = Depth of filter in feet

Q = Hydraulic load, MGAD

n = an exponent, which has been shown to be $2/3$

Hydraulic principles of trickling filters were investigated extensively by Bloodgood et al (12). The authors showed that the contact time on an inclined plane and on a sphere was inversely proportional to the $2/3$ power of the liquid application rate. Experiments on an inclined plane with slime showed that the contact time increased up to 50% when the plane was flat (2.87 degrees) but at a 45 degree angle the contact time increased less than 10%. In additional experiments using $3/4$ inch to 3 inch balls the contact time increased 12% but this was proven to be due to the increase in diameter of the balls caused by the biological film.

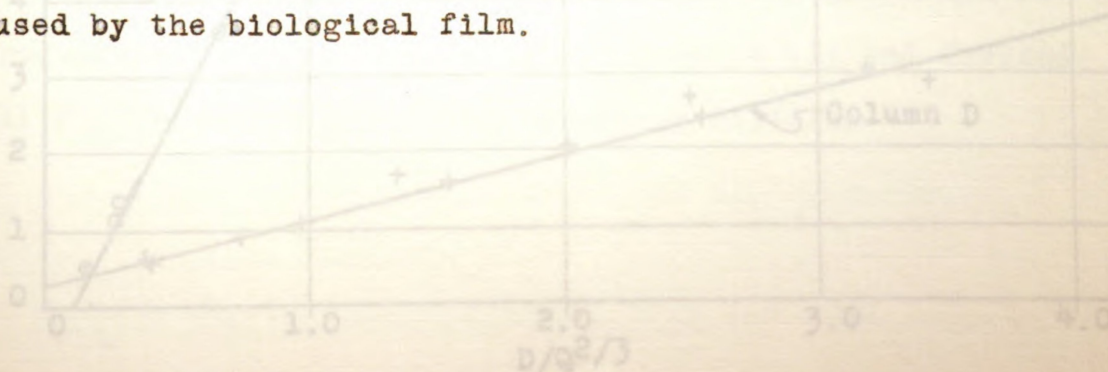


FIGURE 1 - DETENTION TIME VERSUS $D/Q^{2/3}$ AFTER SINKOFF

The mean contact time t through the filter media has been expressed by Schulze (1) and Howland (12) by the following

relationship:

$$t = C D^n \quad (2)$$

Where
 C = A constant
 D = Depth of filter in feet
 n = Hydraulic load, MGAD
 n = an exponent, which has been shown to be $2/3$
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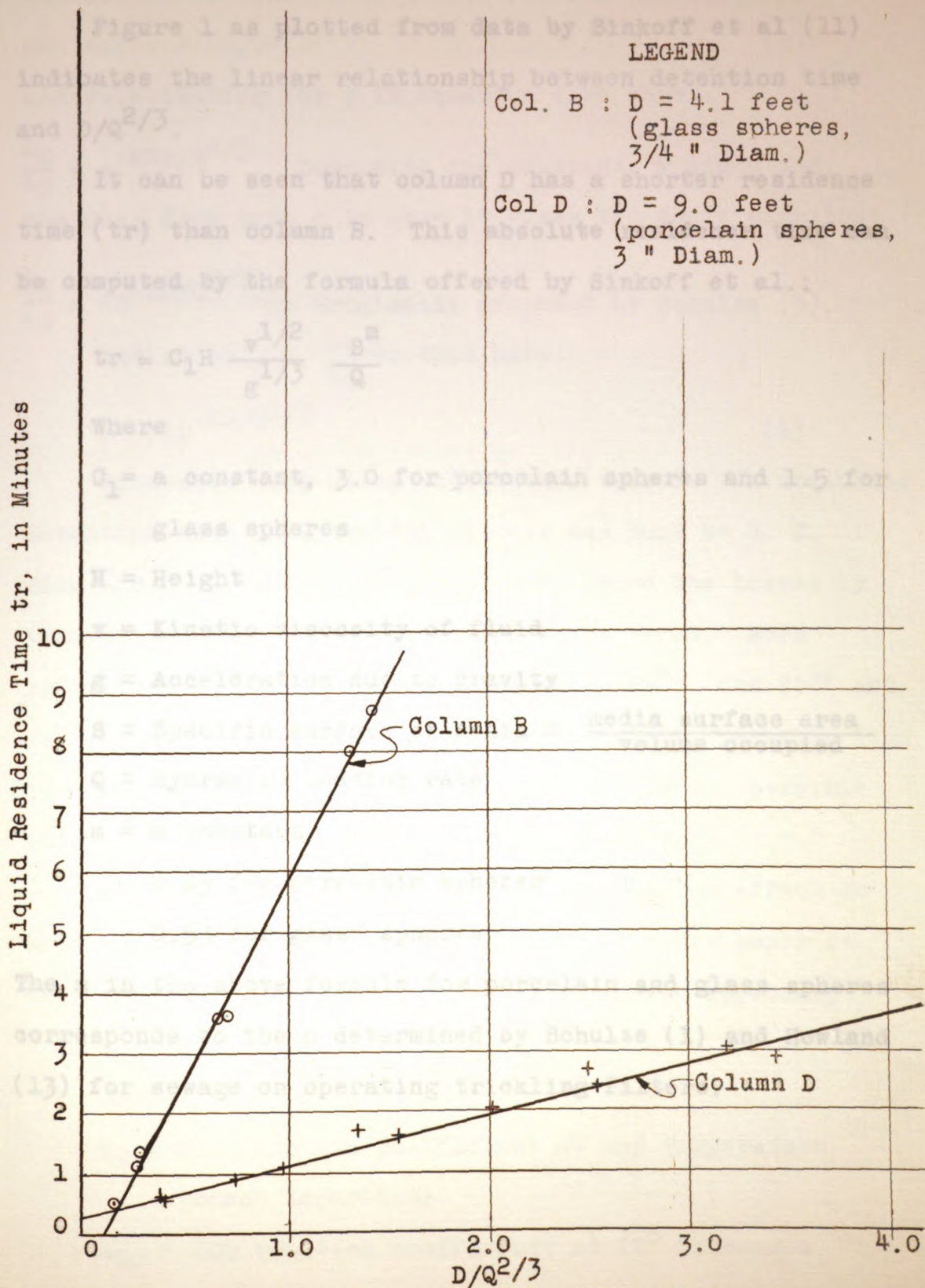


FIGURE 1 - DETENTION TIME VERSUS $D/Q^{2/3}$ AFTER SINKOFF

The mean contact time t through the filter media has been expressed by Schulze (1) and Howland (17) by the following

$$t = CD \sqrt[n]{Q} \quad (2)$$

Where
 C = A constant
 D = Depth of filter in feet
 Q = Hydraulic load, MGAD
 n = an exponent, which has been shown to be $5/3$
 Hydraulic principles of trickling filters were investigated extensively by Bloodgood et al (18). The authors showed that the contact time on an inclined plane and on a sphere was inversely proportional to the $5/3$ power of the liquid application rate. Experiments on an inclined plane with silt showed that the contact time increased up to 50° when the plane was flat (0.87 degrees) but at a 45 degree angle the contact time increased less than 10% . In additional experiments using $3/4$ inch to 3 inch balls the contact time increased 15% but this was proven to be due to the increase in diameter of the balls caused by the biological film.

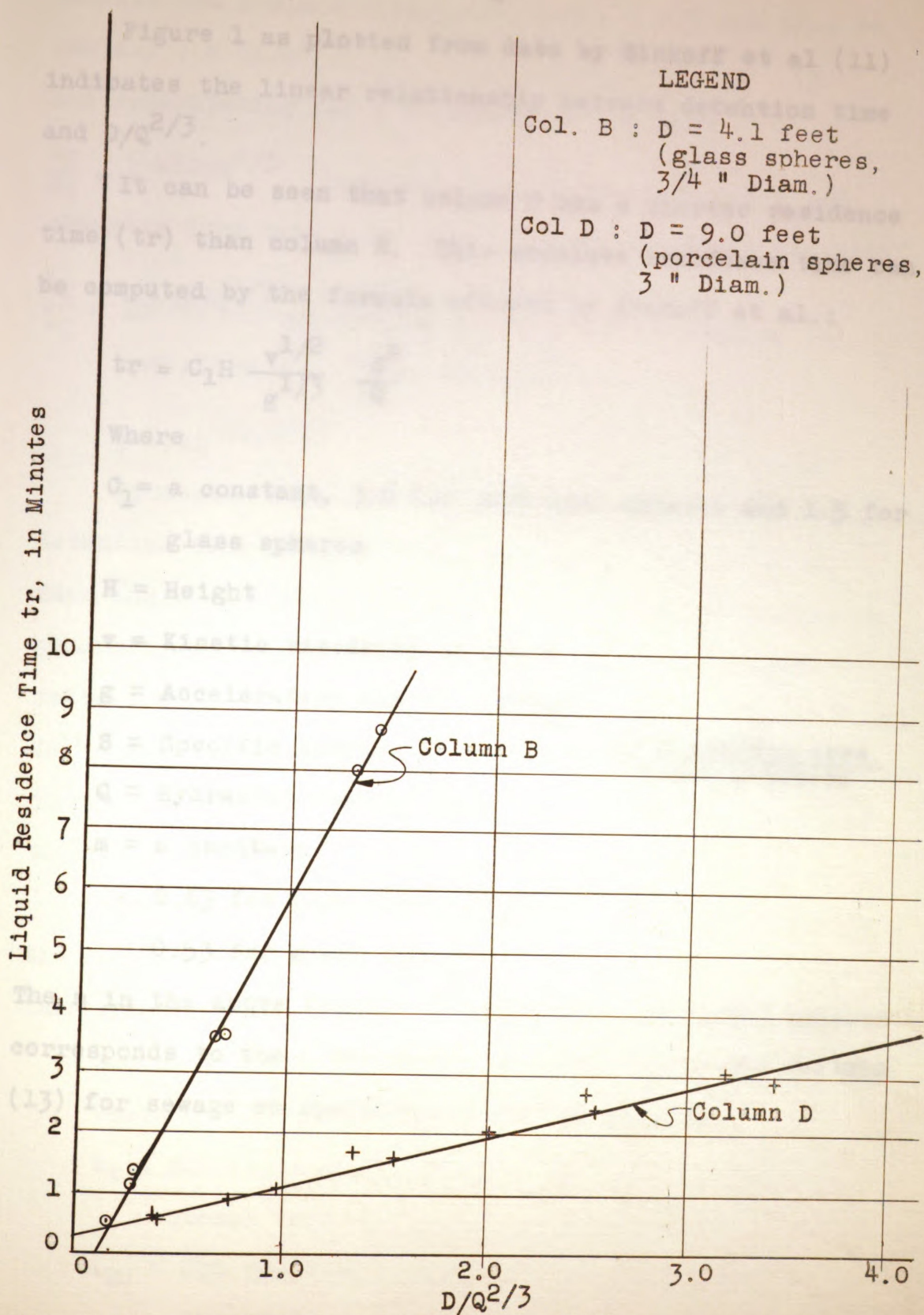


FIGURE 1 - DETENTION TIME VERSUS $D/Q^{2/3}$ AFTER SINKOFF

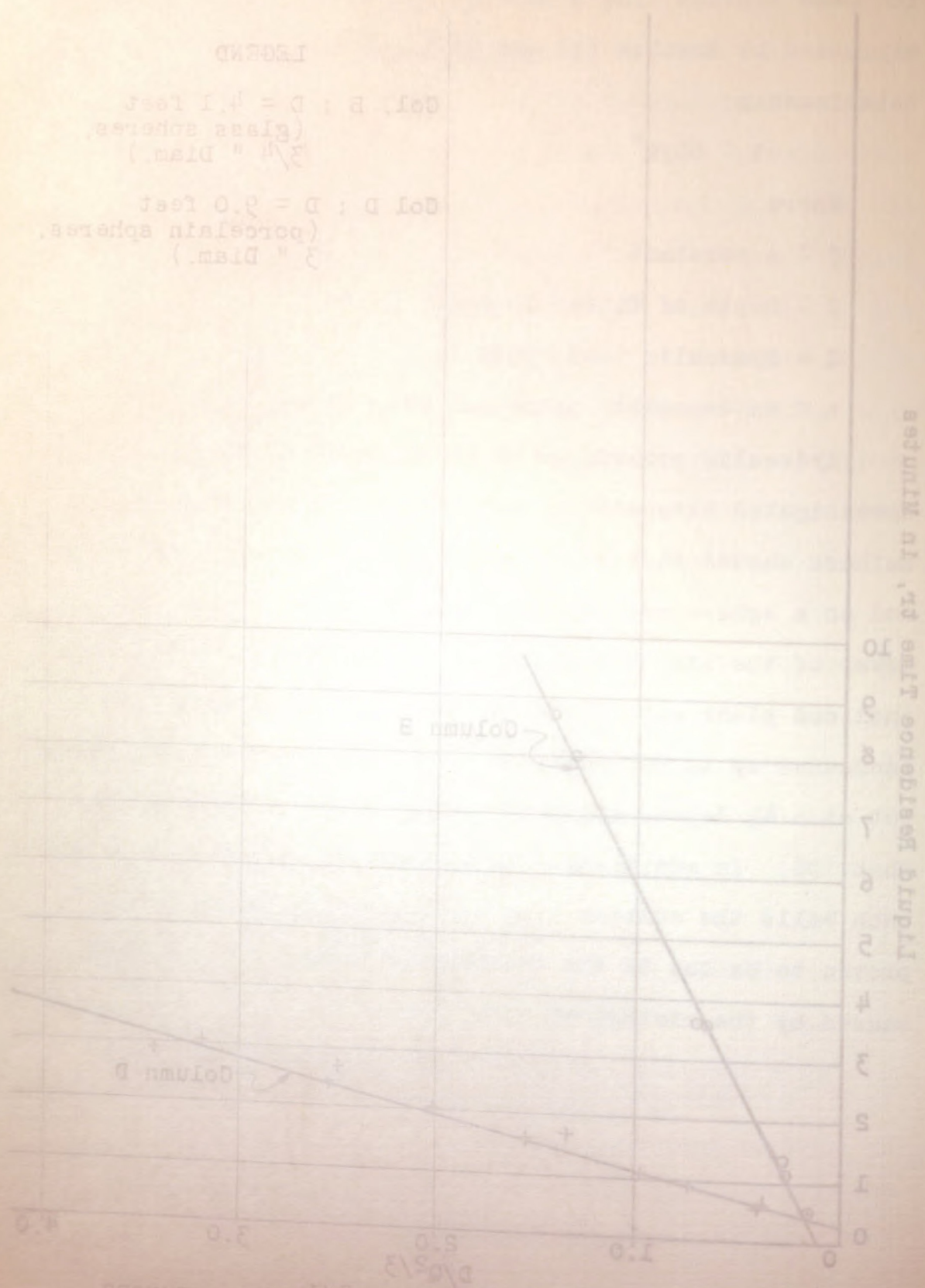


FIGURE 1 - DETENTION TIME VERSUS $D/d^{1/2}$ AFTER SINTER

Figure 1 as plotted from data by Sinkoff et al (11) indicates the linear relationship between detention time and $D/Q^{2/3}$.

It can be seen that column D has a shorter residence time (t_r) than column B. This absolute residence time can be computed by the formula offered by Sinkoff et al.:

$$t_r = C_1 H \frac{v^{1/2}}{g^{1/3}} \frac{S^m}{Q}$$

Where

C_1 = a constant, 3.0 for porcelain spheres and 1.5 for glass spheres

H = Height

v = Kinetic viscosity of fluid

g = Acceleration due to gravity

S = Specific surface of media = $\frac{\text{media surface area}}{\text{volume occupied}}$

Q = Hydraulic loading rate

m = a constant,

0.83 for porcelain spheres

0.53 for glass spheres

The m in the above formula for porcelain and glass spheres corresponds to the n determined by Schulze (1) and Howland (13) for sewage on operating trickling filters.

k_t = BOD reaction coefficient at any temperature,

common logarithms

k_{20} = BOD reaction coefficient at 20° C; common

logarithms

Figure 1 as plotted from data by Sinkoff et al (11)

indicates the linear relationship between detention time

and $D\sqrt{Q}$.

It can be seen that column B has a shorter residence time (t_r) than column A. This absolute residence time can be computed by the formula offered by Sinkoff et al.

$$t_r = G_1 H \frac{V^{1/2}}{S^{1/2}} \frac{S^m}{Q}$$

Where

G_1 = a constant, 3.0 for porcelain spheres and 1.5 for

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H = Height

v = Kinetic viscosity of liquid

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Q = Hydraulic loading rate

m = a constant,

0.83 for porcelain spheres

0.53 for glass spheres

The m in the above formula for porcelain and glass spheres corresponds to the n determined by Schuler (1) and Howland (12) for sewage on operating trickling filters.

Schulze and Howland determined that $n = 2/3$ and thus we can say $t = CD/Q^{2/3}$; (3)

and substituting for t in equation 1 we have

$\frac{L_E}{L_I} = e^{-kCD/Q^{2/3}}$. Combining the constants k and C and changing from base e to base 10 gives the basic equation:

$\frac{L_E}{L_I} = 10^{-KD/Q^{2/3}}$ as originally proposed by Schulze (5).

And since $p = \frac{L_E}{L_I}$ we then have

$$p = 10^{-KD/Q^{2/3}} \quad (4)$$

Extensive work using radioactive tracers for measuring detention time in trickling filters was done by G. E. Eden and K. V. Melbourne (24). They found the losses by adsorption of Na^{24} , Rb^{86} , and K^{42} to be great. More satisfactory results were obtained with Br^{82} , and Co^{58} and Co^{60} . However these authors did not vary the hydraulic load on their experimental filter so that it was not possible to obtain a series of K values from their data.

Temperature is another factor that has an effect on the performance of trickling filters. In his paper on this subject Howland (10) used the following approach:

$$\text{Assume } k_t = k_{20} c^{(T - 20)}$$

Where

k_t = BOD reaction coefficient at any temperature,
common logarithms

k_{20} = BOD reaction coefficient at $20^\circ C$; common
logarithms

Schulze and Howland determined that $n = 2\sqrt{3}$ and thus we

$$(3) \quad \text{can say } t = 0.002\sqrt{3};$$

and substituting for t in equation 1 we have

$$\frac{L_E}{L_I} = e^{-K_D \sqrt{3}} \quad \text{Combining the constants } k \text{ and } 0 \text{ and}$$

changing from base e to base 10 gives the basic equation

$$\frac{L_E}{L_I} = 10^{-K_D \sqrt{3}} \quad \text{as originally proposed by Schulze (2)}$$

And since $p = \frac{L_E}{L_I}$ we then have

$$(4) \quad p = 10^{-K_D \sqrt{3}}$$

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Temperature is another factor that has an effect on

the performance of trickling filters. In his paper on

this subject Howland (10) used the following equation:

$$\text{Assume } k_T = k_{20} e^{0.07(T - 20)}$$

Where

k_T = BOD reaction coefficient at any temperature,

common logarithms

k_{20} = BOD reaction coefficient at $20^\circ C$; common

logarithms

c = A number chosen to fit experimental data (1.047 is used in BOD calculations)

T = Temperature in $^{\circ}\text{C}$

with the value k_t appearing in:

$$L = L_a 10^{-k_t t} \quad (5)$$

Where

L = Ultimate first stage BOD at time t

L_a = Ultimate first stage BOD at time 0

t = Time, in days

BOD remaining can be expressed by L/L_a thus:

$$\frac{L}{L_a} = 10^{-k_t t}$$

and substituting for k_t we have

$$\frac{L}{L_a} = 10^{-tk_{20} c(T - 20)} \quad (6)$$

where c has been found by Howland to be very close to 1.035 for the trickling filter treatment process.

However since all the required temperature data were not available in the plant operating results used in this thesis, effects of temperature on K were not included.

According to a development given by Schulze (5) p is obtained as follows:



$\theta = 1$ = A number chosen to fit experimental data (1.04)

L_0 = ultimate first stage BOD at time 0

T = Temperature in $^{\circ}\text{C}$

with the value k_f appearing in

$$L = L_0 (1 - e^{-k_f t})$$

(5)

Where

L = Ultimate first stage BOD at time t

L_0 = Ultimate first stage BOD at time 0

t = Time, in days

BOD remaining can be expressed by $L - L_0$ thus:

$$\frac{L}{L_0} = 1 - e^{-k_f t}$$

and substituting for k_f we have

$$\frac{L}{L_0} = 1 - e^{-k_f \theta (T - 20)}$$

(6)

where θ has been found by Howard to be very close

to 1.035 for the trickling filter treatment process.

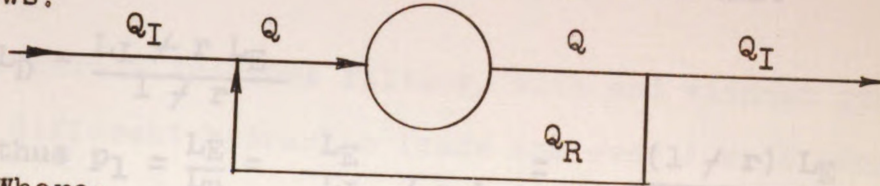
However since all the required temperature data were not

available in the plant operating results used in this

thesis, effects of temperature on K were not included.

CHAPTER II - PROCEDURE

The equation $p = 10^{-KD/Q^{2/3}}$ as presented in the previous chapter is suited for filters without recirculation. Using some additional refinements the equation can be adapted to recirculation conditions. This is shown as follows:



Where:

Q = Hydraulic load to the filter in MGAD

Q_I = Hydraulic flow to the treatment plant in MGAD

Q_R = Recirculated flow in MGAD, and

$r = (\text{recycle ratio}) = \frac{Q_R}{Q_I}$

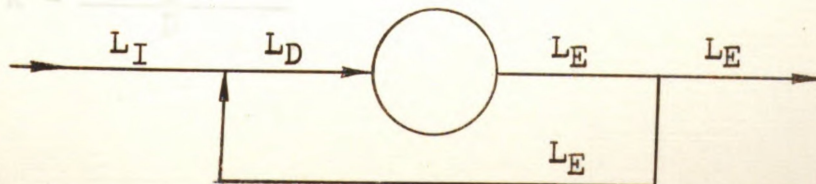
From the flow diagram above it can be seen that

$$Q = Q_I - Q_R = Q_I - rQ_I = Q_I (1 - r)$$

Thus for a filter with recycle:

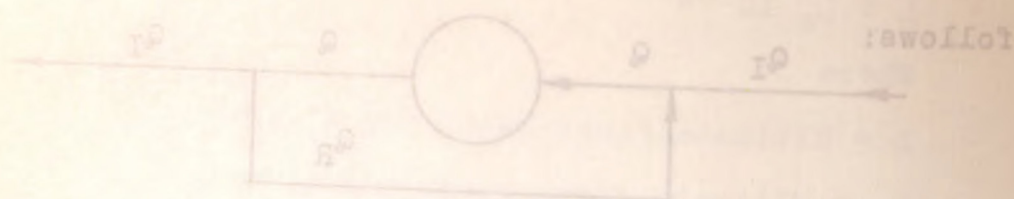
$$p_1 = 10^{-KD/[Q_I (1 - r)]^{2/3}} \quad (7)$$

It is often desirable to determine p (the overall fraction of BOD remaining) from a computed value of p_1 . According to a development given by Schulze (5) p is obtained as follows:



CHAPTER II - PROCEDURE

The equation $p = 10^{-KD\sqrt{Q_1}}$ as presented in the previous chapter is suited for filters without recirculation. Using some additional refinements the equation can be adapted to recirculation conditions. This is shown as follows:



Where:

Q = Hydraulic load to the filter in MGAD
 Q_1 = Hydraulic flow to the treatment plant in MGAD
 Q_2 = Recirculated flow in MGAD, and
 $r = \frac{Q_2}{Q_1}$ (recycle ratio)

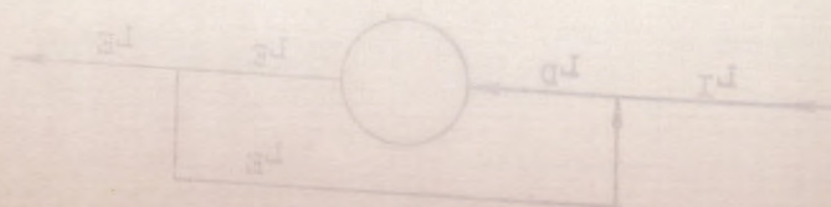
From the flow diagram above it can be seen that

$$Q = Q_1 + Q_2 = Q_1 + rQ_1 = Q_1(1 + r)$$

Thus for a filter with recycle:

$$p_1 = 10^{-KD\sqrt{Q_1(1+r)}}$$

It is often desirable to determine p (the overall fraction of BOD remaining) from a computed value of p_1 . According to a development given by Schultz (5) p is obtained as follows:



Where:

L_D = BOD applied to filter in mg/l

L_I = BOD in primary effluent in mg/l

L_E = BOD in final effluent in mg/l

From the flow diagram it can be seen that

$$L_D = \frac{L_I \cancel{+} r L_E}{1 \cancel{+} r}$$

$$\text{thus } p_1 = \frac{L_E}{L_D} = \frac{L_E}{\frac{L_I \cancel{+} r L_E}{1 \cancel{+} r}} = \frac{(1 \cancel{+} r) L_E}{L_I \cancel{+} r L_E} \quad (8)$$

and if we let $L_I = 1.000$, L_E will equal the fraction remaining expressed as a decimal which we have previously designated as p .

$$\text{thus } p_1 = \frac{(1 \cancel{+} r)p}{1 \cancel{+} r p} \quad (8)$$

By rearranging the terms to solve for p we obtain the equation for overall fraction of BOD remaining.

$$p = \frac{1}{\left(\frac{1 \cancel{+} r}{p_1}\right) - r} \quad (9)$$

By substituting p_1 for p in equation 4 and solving for K , the equation is determined that was used throughout the thesis to compute K .

$$K = \frac{\log \frac{1}{p_1} Q^{2/3}}{D} \quad (10)$$

Where:

L_D = BOD applied to filter in mg/l

L_1 = BOD in primary effluent in mg/l

L_E = BOD in final effluent in mg/l

From the flow diagram it can be seen that

$$L_D = \frac{L_1 + r L_E}{1 + r}$$

$$\text{Thus } p_1 = \frac{L_E}{L_D} = \frac{L_E}{\frac{L_1 + r L_E}{1 + r}} = \frac{L_E (1 + r)}{L_1 + r L_E}$$

and if we let $L_1 = 1,000 L_E$ will equal the fraction remaining expressed as a decimal which we have previously designated as p .

$$\text{Thus } p_1 = \frac{(1 + r)p}{1 + r p} \quad (8)$$

By rearranging the terms to solve for p we obtain the equation for overall fraction of BOD remaining.

$$p = \frac{1}{\left(\frac{1 + r}{p_1} \right) - r} \quad (9)$$

By substituting p_1 for p in equation 4 and solving for K , the equation is determined that was used throughout the thesis to compute K .

$$K = \frac{\log \frac{1}{p_1} \frac{1}{2.303}}{D} \quad (10)$$

CHAPTER III - EVALUATION OF K FOR MUNICIPAL WASTE

In order to obtain a range of values of K, the design criteria of the 10 State Standards (19) were used for sample treatment plant designs. The calculations and their results are shown in Tables 1, 2, 3, and 4 and on Figures 2 and 3.

Figure 2 includes filters, with and without recycle, for 3 different hydraulic loads and over a wide range of efficiencies. It can be seen that within the design criteria of the 10 State Standards the K values must vary from 0.00 to 0.95 to predict the expected degree of treatment. Figure 3 also indicates that in order to agree with the 10 State Standards K values would have to increase with the dosage rate.

TABLE 1 - K VALUES FROM 10 STATE STANDARDS

Flow to plant (Avg.)	1430
Influent BOD, mg/l	123
Prim. Effluent BOD, mg/l	80
Final Effluent BOD, mg/l	12.3
Recycle Ratio	
$\frac{S_2}{S_1} = \frac{34}{123} = .276$	
$R = \frac{2}{.276} = 7.25$	
Flow to Filter, MGD	2.75
Acresage @ 30 MGD	.0916
Volume @ depth = 5' - 0", CF	1000
Organic Load to Filter, #/day	246
Organic Dosage, #/1000 CF/day	42.3
$p_1 = \frac{(1 + R)p}{1 + R^2}$	.154
$\log \frac{p_1}{p_2}$	.333
$q = \frac{1}{1 + R^2}$	.477
q^2	30
n , feet	9.65
$K = \frac{1}{\log \frac{p_1}{p_2}} \left(\frac{q^2}{n} \right)$	.95

CHAPTER III - EVALUATION OF K FOR MUNICIPAL WASTE

In order to obtain a range of values of K, the design criteria of the 10 State Standards (19) were used for sample treatment plant designs. The calculations and their results are shown in Tables I, S, 3, and 4 and on Figures 2 and 3.

Figure 2 includes filters, with and without recycle, for 3 different hydraulic loads and over a wide range of efficiencies. It can be seen that within the design criteria of the 10 State Standards the K values must vary from 0.00 to 0.95 to predict the expected degree of treatment. Figure 3 also indicates that in order to agree with the 10 State Standards K values would have to increase with the dosage rate.

TABLE 1 - K VALUES FROM 10 STATE STANDARDS DESIGN CRITERIA, 90 PERCENT GROSS REMOVAL
Flow to plant (Avg.)

	1MGD	1MGD	1MGD	1MGD
Influent BOD,mg/l	123	185	247	308
Prim. Effluent BOD,mg/l, S ₂	80	120	160	200
Final Effluent BOD,mg/l, S ₄	12.3	18.5	24.7	30.8
Recycle Ratio				
$R = \frac{S_2}{S_4} - 3$	1.75	1.75	1.75	1.75
Flow to Filter, MGD	2.75	2.75	2.75	2.75
Acreage @ 30 MGAD	.0916	.0916	.0916	.0916
Volume @ depth = 5' - 0", CF	20,000	20,000	20,000	20,000
Organic Load to Filter, #/day	846	1,270	1,700	2,120
Organic Dosage, #/1000 CF/day	42.3	63.5	85.0	106
$p = \frac{(1+r)p}{1+r}$	.154	.154	.154	.154
$\log \frac{1}{p_1}$	.333	.333	.333	.333
Q, MGAD	.477	.477	.477	.477
$Q^{2/3}$	30	30	30	30
D, feet	9.65	9.65	9.65	9.65
$K = \frac{1}{\log \frac{1}{p_1} (Q^{2/3})}$	5	5	5	5
	.95	.95	.95	.95

ANALYSIS OF VARIANCE OF MEAN SQUARES STATE OF NORTH CAROLINA - 1954

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other elements

$$F - \frac{SS}{MS} = F$$

MS, final of work

MS, final of work

MS, final of work

MS, final of work

MS, final of work

q

$$\frac{q(1 + \frac{f}{f})}{q(1 + \frac{f}{f})} = q$$

$\frac{1}{q}$ goL

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TABLE 2 - K VALUES FROM 10 STATE STANDARDS DESIGN CRITERIA, 30 MGAD DOSAGE RATE

Flow to plant (Avg.)	LMGD	LMGD	LMGD	LMGD
Influent BOD, mg/l	185	185	185	185
Prim. Effluent BOD, mg/l, S ₂	120	120	120	120
% Treatment, overall	40%	50%	60%	70%
Final Effluent BOD, mg/l, S ₄	111	92.6	74	55.5
Recycle Ratio				
$R = \frac{S_2 - S_4}{S_4}$	0	0	0	0
Flow to Filter, MGD	1.00	1.00	1.00	1.00
Acreage @ 30 MGAD	.0333	.0333	.0333	.0333
Volume @ depth = 5'-0", CF	7,250	7,250	7,250	7,250
Organic Load to Filter, #/day	670	670	670	670
Organic Dosage, #/1000 CF/day	92.5	92.5	92.5	92.5
P	.925	.772	.617	.463
P ₁	.925	.772	.617	.463
$\log \frac{1}{P_1}$	.033	.112	.210	.333
$Q^{2/3}$	9.65	9.65	9.65	9.65
D, feet	5	5	5	5
$K = \frac{1}{D} \log \frac{1}{P_1} (Q^{2/3})$	.064	.22	.41	.64

TABLE 2 - K VALUES FROM 10 STATE STANDARDS DESIGN CRITERIA, 30 MGAD DOSAGE RATE (CONTINUED)

Flow to plant (Avg.)	1MGD	1MGD	1MGD
Influent BOD, mg/l	185	185	185
Prim. Effluent BOD, mg/l, S ₂	120	120	120
% Treatment, overall	75%	80%	95%
Final Effluent BOD, mg/l, S ₄	46.3	37	9.12
Recycle Ratio			
$R = \frac{S_2 - S_4}{S_4}$	0	.12	5.1
Flow to Filter, MGD	1.00	1.12	6.1
Acreage @ 30 MGAD	.0333	.374	.203
Volume @ depth = 5' - 0", CF	7,250	8,140	44,300
Organic Load to Filter, #/day	670	695	1,392
Organic Dosage, #/1000 CF/day	92.5	85.5	31.4
p	.386	.308	.076
p ₁	.386	.340	.333
$\log \frac{1}{p_1}$	.412	.467	.477
Q ^{2/3}	9.65	9.65	9.65
D, feet	5	5	5
$K = \frac{1}{D} (\log \frac{1}{p_1} (Q^{2/3}))$	.795	.90	.95

TABLE 3 - K VALUES FROM 10 STATE STANDARDS DESIGN CRITERIA, 15 MGAD DOSAGE RATE

Flow to plant (Avg.)	1MGD	1MGD	1MGD	1MGD
Influent BOD, mg/l	185	185	185	185
Prim. Effluent BOD, mg/l, S ₂	120	120	120	120
% Removal	40%	50%	60%	70%
Final Effluent BOD, mg/l, S ₄	111	92.5	74.0	55.5
Recycle Ratio				
$R = \frac{S_2}{S_4} - 3$	0	0	0	0
Flow to Filter, MGD	1.00	1.00	1.00	1.00
Acreage @ 15 MGAD	.0666	.0666	.0666	.0666
Volume @ depth = 5' - 0", CF	14,500	14,500	14,500	14,500
Organic Load to Filter #/day	1,000	1,000	1,000	1,000
Organic Dosage, #/1000 CF/day	69	69	69	69
p	.925	.772	.617	.462
P ₁	.925	.772	.617	.462
$\log \frac{1}{P_1}$	.033	.112	.210	.333
Q ^{2/3}	6.08	6.08	6.08	6.08
D, feet	5	5	5	5
$K = \frac{1}{D} (\frac{Q^2}{3})$	.04	.14	.26	.41

TABLE 3 - K VALUES FROM 10 STATE STANDARDS DESIGN CRITERIA, 15 MGAD DOSAGE RATE (CONTINUED)

Flow to plant (Avg.)	1MGD	1MGD	1MGD	1MGD
Influent BOD, mg/l	185	185	185	185
Prim. Effluent BOD, mg/l, S ₂	120	120	120	120
% Removal		80%	90%	95%
Final Effluent BOD, mg/l, S ₄		37.0	18.5	9.25
Recycle Ratio				
$R = \frac{S_2 - S_4}{S_4}$		0.12	1.75	5.1
Flow to Filter, MGD		1.12	2.75	6.1
Acreage @ 15 MGAD		2.0747	2.1835	2.407
Volume @ depth = 5' - 0", CF		16,300	40,000	88,500
Organic Load to Filter, #/day		1,037	1,270	1,394
Organic Dosage, #/1000 CF/day		63.5	31.7	15.8
P	.925	.308	.154	.077
P ₁	.925	.333	.333	.333
$\log \frac{1}{P_1}$	.033	.477	.477	.477
$Q^2/3$	2.62	6.08	6.08	6.08
D, feet	5	5	5	5
$K = \frac{1}{D} (Q^2/3)$	.02	.58	.58	.58

TABLE 4 - K VALUES FROM 10 STATE STANDARDS DESIGN CRITERIA, 5 MGAD DOSAGE RATE

Flow to plant (Avg.)	1MGD	1MGD	1MGD	1MGD
Influent BOD, mg/l	185	185	185	185
Prim. Effluent BOD, mg/l, S_2	120	120	120	120
% Removal	40%	50%	60%	70%
Final Effluent BOD, mg/l, S_4	111	92.5	74.0	55.0
Recycle Ratio				
$R = \frac{S_2 - S_4}{S_4}$	0	0.12	0.75	0
Flow to Filter, MGD	1.0	1.0	1.0	1.0
Acreage @ 5 MGAD	2.00	2.00	2.00	2.00
Volume @ depth = 5' - 0", CF	43,500	43,500	43,500	43,500
Organic Load to Filter, #/day	1,000	1,000	1,000	1,000
Organic Dosage, #/1000 CF/day	23	23.2	23.6	23.28
p	.925	.772	.617	.462
p_1	.925	.772	.617	.462
$\log \frac{1}{p_1}$	.033	.112	.210	.333
$Q^{2/3}$	2.82	2.82	2.82	2.82
D, feet	5	5	5	5
$K = \frac{1}{D} \left(\frac{Q^{2/3}}{p_1} \right)$	.02	.06	.12	.19

TABLE 4 - K VALUES FROM 10 STATE STANDARDS DESIGN CRITERIA, 5 MGAD DOSAGE RATE (CONTINUED)

Flow to plant (Avg.)	1MGD	1MGD	1MGD
Influent BOD, mg/l	185	185	185
Prim. Effluent BOD, mg/l, S ₂	120	120	120
% Removal	80%	90%	95%
Final Effluent BOD, mg/l, S ₄	37.0	18.5	9.25
Recycle Ratio			
$R = \frac{S_2 - S_4}{S_4}$	.12	1.75	5.1
Flow to Filter, MGD	1.12	2.75	6.1
Acreage @ 5 MGAD	2.24	5.50	12.2
Volume @ depth = 5' - 0", CF	48,800	120,000	264,000
Organic Load to Filter, #/day	1,037	1,270	1,394
Organic Dosage, #/1000 CF/day	21.2	10.6	5.28
p	.308	.154	.077
p ₁	.333	.333	.333
$\log \frac{1}{p_1}$	.477	.477	.477
Q ^{2/3}	2.82	2.82	2.82
D, feet	5	5	5
$K = \frac{\log \frac{1}{p_1} (Q^{2/3})}{D}$	.27	.27	.27

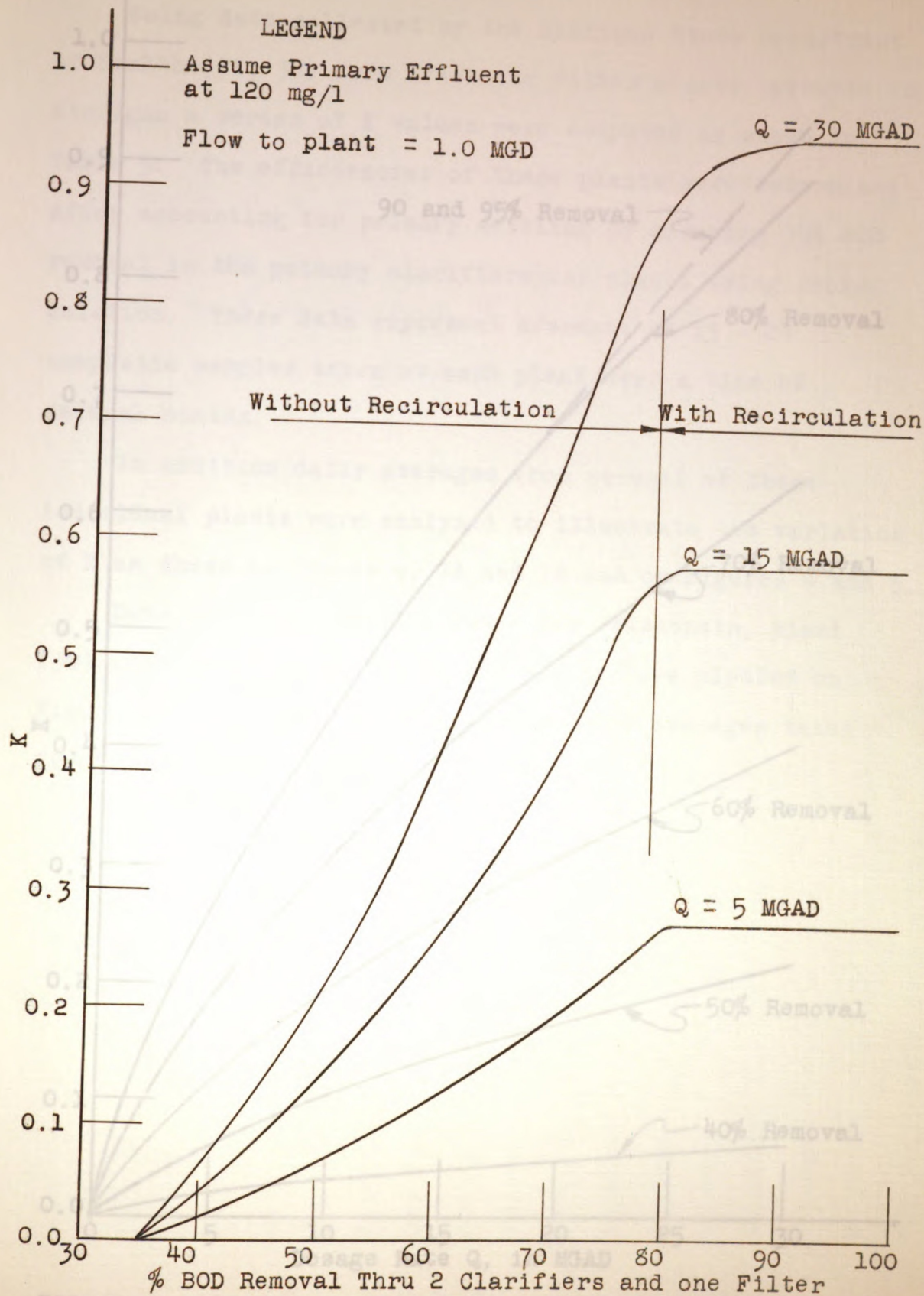
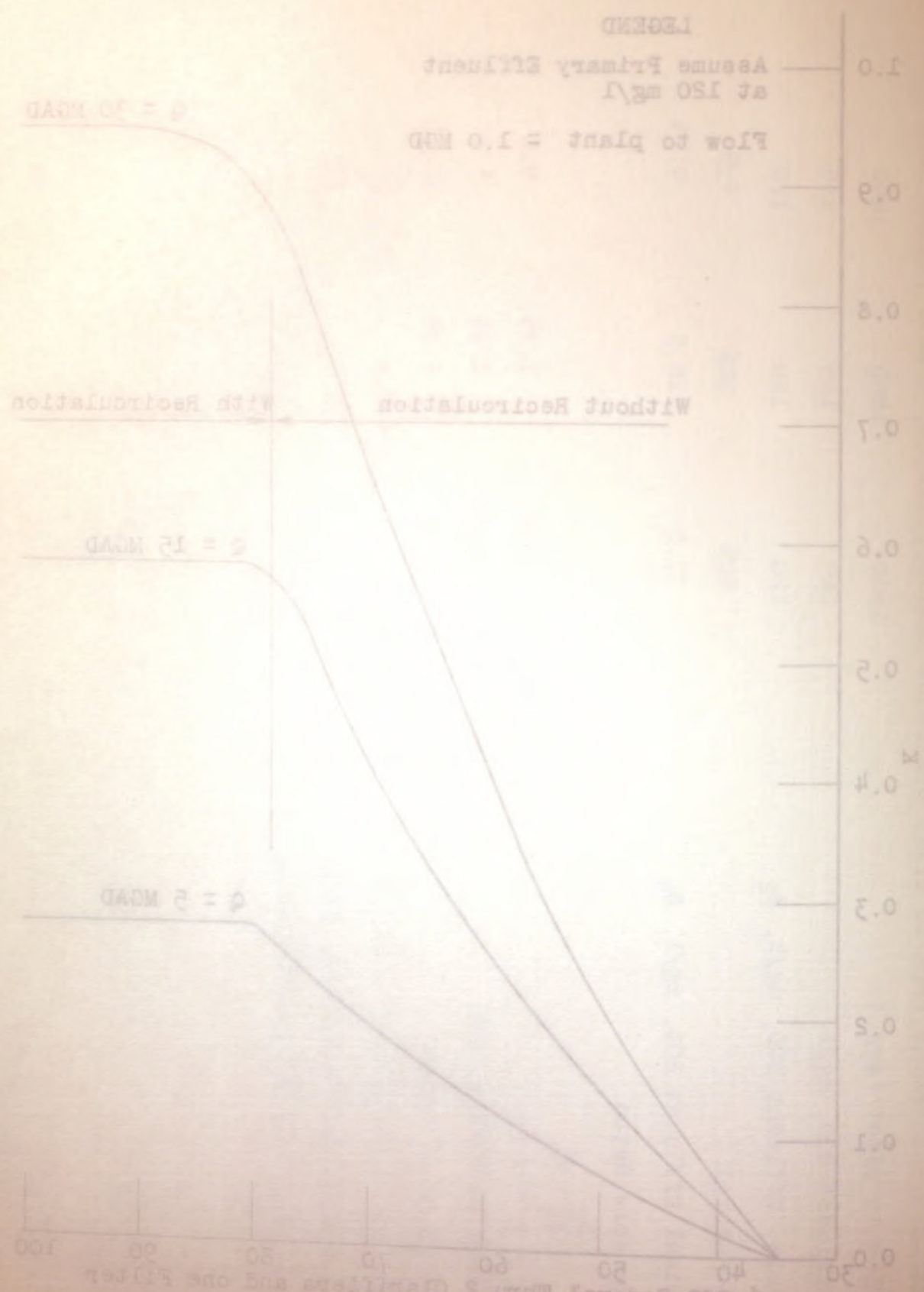


FIGURE 2 - "K" VALUES FROM 10 STATE STANDARDS DESIGN CRITERIA.

FIGURE 2 - "K" VALUES FROM 10 STATE STANDARDS DESIGN CRITERIA

* BOD Removal thru 2 Clarifiers and one Filter



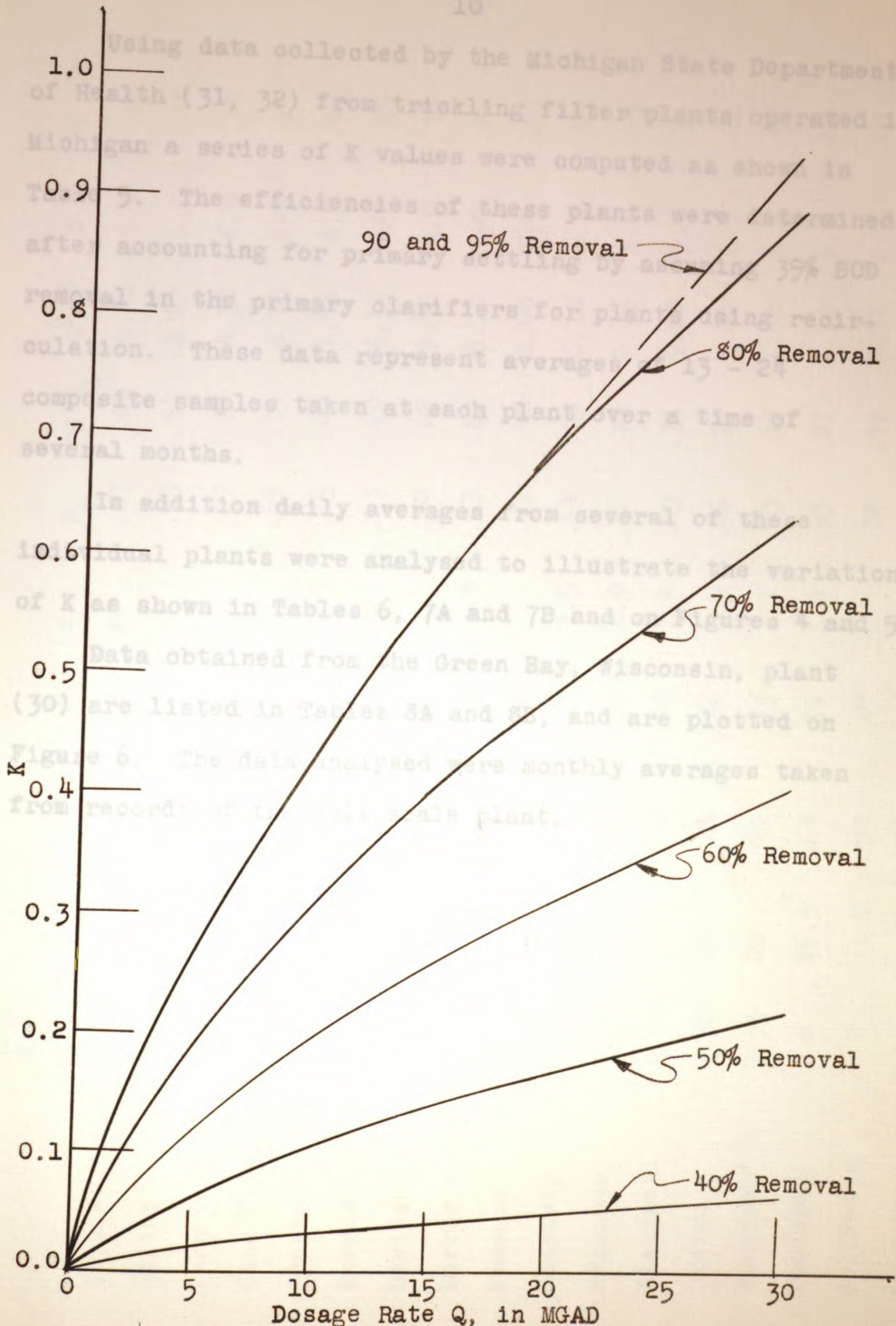


FIGURE 3 - K VERSUS DOSAGE RATE AS EXPECTED FROM 10 STATE STANDARDS FOR A 5.0 FEET DEEP ROCK TRICKLING FILTER

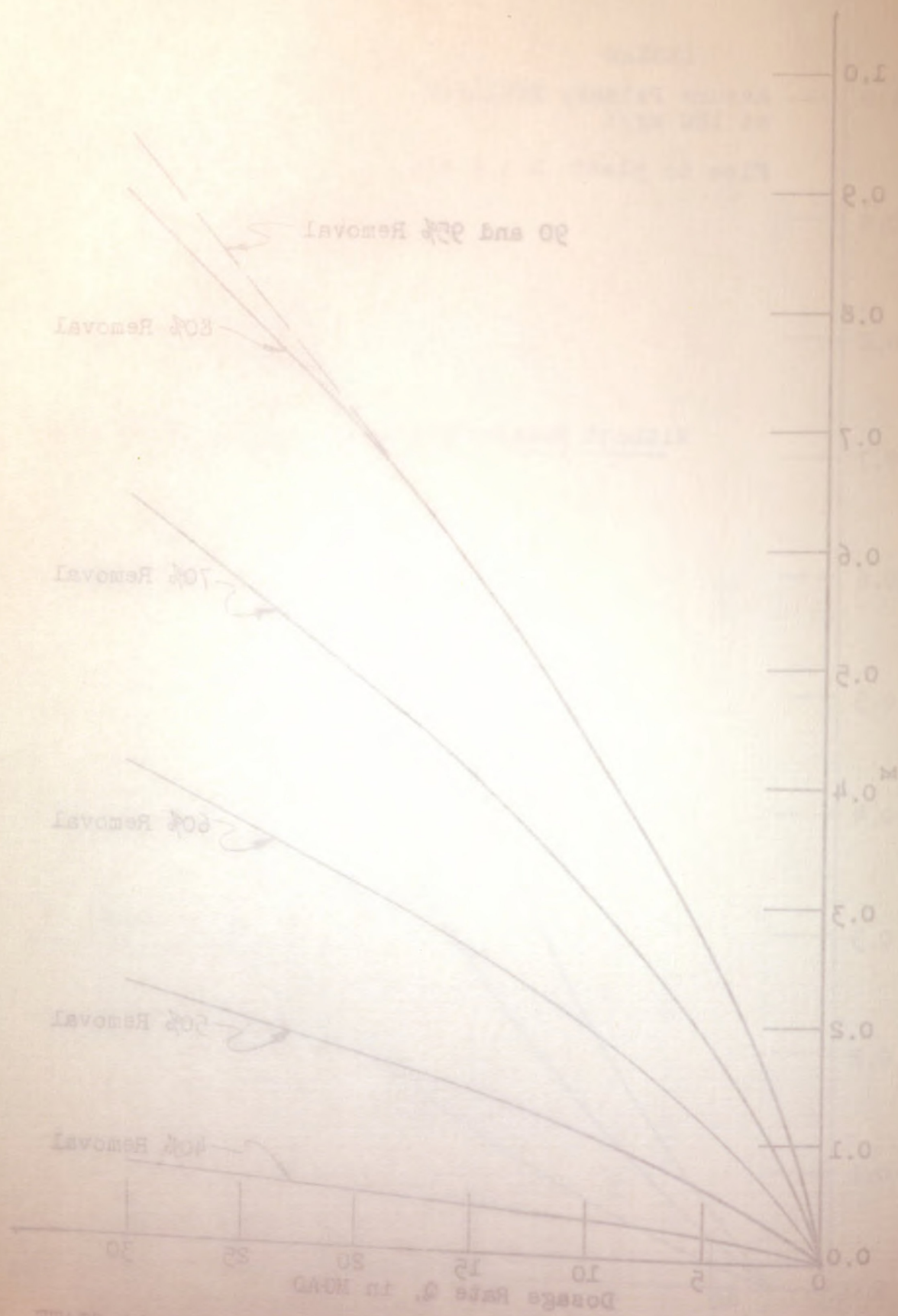


FIGURE 3 - K VERSUS DOSAGE RATE AS EXPERTED FROM 10 STATE STANDARDS FOR A 5.0 FEET DEEP ROCK TRICKLING FILTER

Using data collected by the Michigan State Department of Health (31, 32) from trickling filter plants operated in Michigan a series of K values were computed as shown in Table 5. The efficiencies of these plants were determined after accounting for primary settling by assuming 35% BOD removal in the primary clarifiers for plants using recirculation. These data represent averages of 13 - 24 composite samples taken at each plant over a time of several months.

In addition daily averages from several of these individual plants were analysed to illustrate the variation of K as shown in Tables 6, 7A and 7B and on Figures 4 and 5.

Data obtained from the Green Bay, Wisconsin, plant (30) are listed in Tables 8A and 8B, and are plotted on Figure 6. The data analysed were monthly averages taken from records of the full scale plant.

AVG.
Flow
MGD

Cryder Mopar

Saline

Lake Odessa

Cass City

Sparta

Ford-Nixon

Davidson

Harbor Beach

Fremont

Benadusky

Megaunee

Plainwell

Otsego

Standish

Tecumseh

Coldwater

* Q₀ represents average dosage rate for those filters with variable hydraulic load to the filter.

Using data collected by the Michigan State Department of Health (31, 32) from smoking filter plants operated in Michigan a series of K values were computed as shown in Table 5. The efficiencies of these plants were determined after accounting for primary settling by assuming 75% BOD removal in the primary clarifiers for plants using recirculation. These data represent averages of 15 - 24 composite samples taken at each plant over a time of several months.

In addition daily averages from several of these individual plants were analysed to illustrate the variation of K as shown in Tables 6, 7A and 7B and in Figures 4 and 5. Data obtained from the Green Bay, Wisconsin, plant (30) are listed in Tables 8A and 8B, and are plotted on Figure 6. The data analysed were monthly averages taken from records of the full scale plant.

TABLE 5 - MICHIGAN FILTERS (31, 32)

	Avg. Flow MGD	Q	% Efficiency	p	r	p ₁	log $\frac{1}{p_1}$	Q ^{2/3}	D	K
Crysler Mopar	.03	10.6	62	.38	10	.87	.06	4.80	6.0	.05
Saline	0.1	2.9	71	.29	--	.29	.54	2.04	6.0	.18
Lake Odessa	0.12	9.0	82	.18	5	.57	.24	4.32	6.0	.17
Cass City	0.15	16.0*	82	.18	3	.69	.14	6.35	6.46	.15
Sparta	0.20	3.86	83	.17	1.5	.34	.47	1.48	8.0	.09
Ford-Wixom	0.21	16.0*	92	.08	6	.63	.20	6.35	5.45	.25
Davidson	0.22	29.0*	60	.40	5	.80	.09	9.45	6.0	.14
Harbor Beach	0.27	15.0*	91	.09	5.5	.63	.20	6.10	5.45	.24
Fremont	0.35	1.0	89	.11	--	.33	.48	1.00	5.45	.10
Sandusky	0.36	15.0	66	.34	2.5	.64	.19	6.10	6.0	.19
Negaunee	0.37	10.0	70	.30	2.0	.56	.25	4.65	6.0	.19
Plainwell	0.44	13.3	72	.28	1.4	.49	.31	5.60	5.0	.35
Otsego	0.50	22	64	.36	2.5	.66	.17	7.85	6.5	.21
Standish	0.55	20	61	.39	1.7	.63	.14	1.60	6.0	.37
Tecumseh	0.6	26.5*	64	.36	1.0	.53	.27	8.90	6.0	.40
Coldwater	1.0	1.9	90	.10	--	.32	.49	1.54	8.48	.09

* Q, represents average dosage rate for those filters with variable hydraulic load to the filter.

K
.17
.45
.12

 $D = 6$

Date, June and July, 1958 using 8 hour composite samples

TABLE 5 - MICHIGAN FILTERS (CONTINUED)

Avg. Flow MGD	Q	% Efficiency	p	r	$p_1 \log \frac{1}{p_1}$	$Q^2/3$	D	K
Southern Michigan Prison	1.0	2.0	.18	--	.74	1.60	7.0	.17
Mount Clements	3.0	62	.38	--	.42	6.35	6.0	.45
Flint	22.0	63	.37	--	.43	2.92	10.0	.12

TABLE 6 - TRICKLING FILTER, SANDUSKY, MICHIGAN (31, 32)

Data obtained from the Michigan Department of Health

Q = 15 MGAD including variable recirculated flow

D = 6.0 feet

Date, June and July, 1958 using 8 hour composite samples.

Flow MGD	% Efficiency	p	r	p ₁	$\log \frac{1}{p_1}$	K
.22	59	.41	2.58	.72	.14	.14
.22	73	.27	2.58	.57	.24	.24
.22	76	.24	2.58	.53	.27	.27
.23	66	.34	2.43	.64	.19	.19
.24	75	.25	2.16	.51	.29	.29
.24	75	.25	2.29	.53	.28	.28
.24	52	.48	2.29	.76	.12	.12
.24	69	.31	2.29	.60	.22	.22
.25	66	.34	2.6	.62	.21	.21
.25	59	.41	2.16	.67	.17	.17
.26	71	.29	2.04	.55	.25	.25
.26	53	.47	2.04	.73	.14	.14
.26	60	.40	2.04	.67	.17	.17
.26	58	.42	2.16	.70	.15	.15
.28	56	.44	1.82	.68	.17	.17
.28	54	.46	1.82	.71	.15	.15

TABLE 6 - TRICKLING FILTER, SANDUSKY, MICHIGAN (21, 32)

Data obtained from the Michigan Department of Health

Q = 15 MGAD including variable recirculated flow

D = 6.0 feet

Date, June and July, 1958 using 8 hour composite samples.

Flow MGAD	Efficiency %	r	$\frac{1}{1+r}$	K
22	59	.41	2.58	.14
22	73	.27	2.58	.24
22	76	.24	2.58	.27
23	66	.34	2.43	.19
24	75	.25	2.16	.29
24	75	.25	2.29	.26
24	52	.48	2.29	.12
24	69	.31	2.29	.22
25	66	.34	2.2	.21
25	59	.41	2.16	.17
26	71	.29	2.04	.22
26	53	.47	2.04	.14
26	60	.40	2.04	.17
26	58	.42	2.16	.15
28	56	.44	1.82	.17
28	54	.46	1.82	.12

TABLE 6 - TRICKLING FILTER, SANDUSKY, MICHIGAN (31, 32)

(CONTINUED)

Flow MGD	% Efficiency	p	r	p ₁	$\log \frac{1}{p_1}$	K
.29	71	.29	1.72	.53	.27	.27
.29	65	.35	1.73	.60	.22	.22
.30	58	.42	1.63	.66	.18	.18
.31	63	.37	1.55	.60	.22	.22
.32	73	.27	1.47	.48	.32	.32
.49	78	.22	0.61	.31	.51	.52

TABLE 2 - TRICKLING FILTER, SANDUSKY, MICHIGAN (31, 32)
(CONTINUED)

Flow m ³ /d	Efficiency %	T	p _f	$\log \frac{1}{p_f}$	K
29	71	1.75	.23	.64	57
29	62	1.73	.60	.22	55
30	58	1.63	.66	.18	48
31	63	1.55	.60	.22	55
32	73	1.47	.48	.32	55
33	78	0.61	.31	.51	55

TABLE 7A - TRICKLING FILTER, SPARTA, MICHIGAN

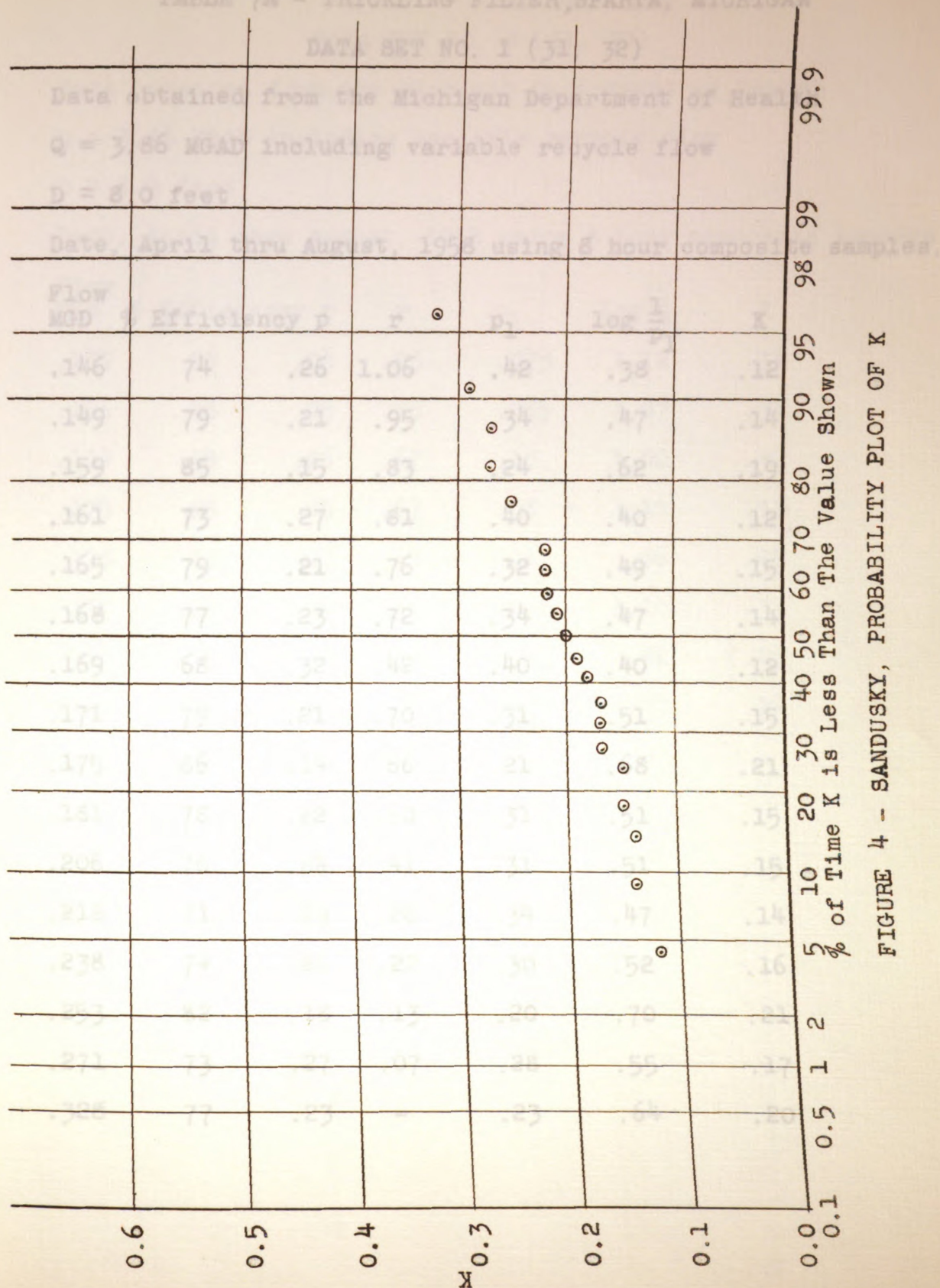


FIGURE 4 - SANDUSKY, PROBABILITY PLOT OF K

УЧЕТ РАБОТЫ НА ПОДЪЕМНО-ПОДВИЖНОМ РАБОЧЕМ МЕСТЕ

Время, затраченное на выполнение работ, в мин.

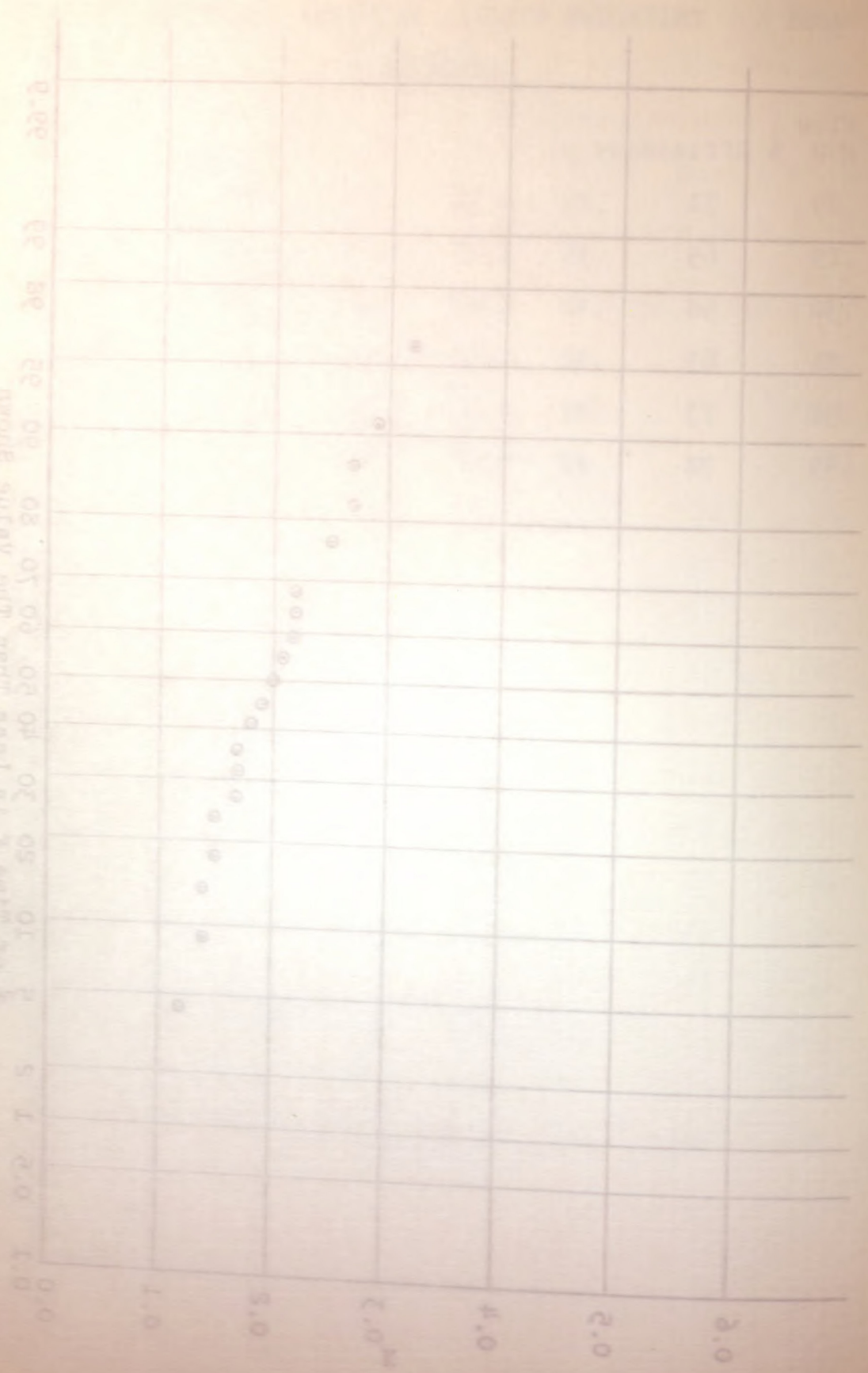


TABLE 7A - TRICKLING FILTER, SPARTA, MICHIGAN

DATA SET NO. 1 (31, 32)

Data obtained from the Michigan Department of Health

Q = 3.86 MGAD including variable recycle flow

D = 8.0 feet

Date, April thru August, 1958 using 8 hour composite samples.

Flow MGD	% Efficiency	p	r	p_1	$\log \frac{1}{p_1}$	K
.146	74	.26	1.06	.42	.38	.12
.149	79	.21	.95	.34	.47	.14
.159	85	.15	.83	.24	.62	.19
.161	73	.27	.81	.40	.40	.12
.165	79	.21	.76	.32	.49	.15
.168	77	.23	.72	.34	.47	.14
.169	68	.32	.42	.40	.40	.12
.171	79	.21	.70	.31	.51	.15
.175	86	.14	.66	.21	.68	.21
.181	78	.22	.60	.31	.51	.15
.206	76	.24	.41	.31	.51	.15
.218	71	.29	.28	.34	.47	.14
.238	74	.26	.22	.30	.52	.16
.253	82	.18	.13	.20	.70	.21
.271	73	.27	.07	.28	.55	.17
.328	77	.23	-	.23	.64	.20

TABLE 7A - TRICKLING FILTER, BIASTA, MICHIGAN

DATA SET NO. 1 (31, 32)

Data obtained from the Michigan Department of Health

Q = 3.86 MGAD including variable recycle flow

D = 8.0 feet

Date, April thru August, 1958 using 8 hour composite samples

Flow MGD	Efficiency	p	r	p ₁	$\log \frac{1}{p_1}$	K
.146	74	.26	1.06	.42	.38	.12
.149	79	.21	.92	.34	.47	.14
.159	82	.12	.83	.24	.62	.19
.161	73	.27	.81	.40	.40	.12
.162	79	.21	.78	.32	.49	.12
.168	77	.23	.72	.34	.47	.14
.169	68	.32	.42	.40	.40	.12
.171	79	.21	.70	.31	.51	.12
.172	86	.14	.66	.21	.68	.21
.181	78	.22	.60	.31	.51	.12
.206	76	.24	.41	.31	.51	.12
.218	71	.29	.28	.34	.47	.14
.238	74	.26	.22	.30	.52	.16
.253	82	.18	.13	.20	.70	.21
.271	73	.27	.07	.22	.65	.17
.328	77	.23	-	.23	.64	.20

TABLE 7B - TRICKLING FILTER, SPARTA, MICHIGAN

DATA SET NO. 2 (31, 32)

Data obtained from the Michigan Department of Health

Q = 3.86 MGAD including variable recycle flow

D = 8.0 feet

Date, April thru August, 1958 using 8 hour composite samples.

Flow MGD	% Efficiency	p	r	p ₁	$\log \frac{1}{\bar{p}_1}$	K
.149	96	.04	.95	.075	1.12	.34
.166	95	.05	.75	.085	1.07	.32
.174	94	.06	.67	.10	1.00	.30
.175	95	.05	.67	.08	1.10	.33
.178	93	.07	.63	.11	.96	.29
.182	95	.05	.59	.08	1.10	.33
.182	90	.10	.60	.15	.82	.25
.188	88	.12	.54	.17	.77	.24

TABLE 7B - TRICKLING FILTER, SPARTA, MICHIGAN

DATA SET NO. 2 (31, 32)

Data obtained from the Michigan Department of Health

Q = 3.86 MGD including variable recycle flow

D = 8.0 feet

Date, April thru August, 1958 using 8 hour composite samples.

Flow MOD & Efficiency	p	r	p ₁	100 p ₁	K
.149	.95	.04	.95	1.12	.34
.166	.95	.05	.95	1.07	.35
.174	.94	.06	.94	1.00	.30
.175	.95	.05	.95	1.10	.33
.178	.93	.07	.93	.96	.29
.182	.95	.05	.95	1.10	.33
.182	.90	.10	.90	.82	.25
.188	.88	.12	.88	.77	.24

TABLE 3A - TRICKLING FILTER, GREEN BAY, WISCONSIN

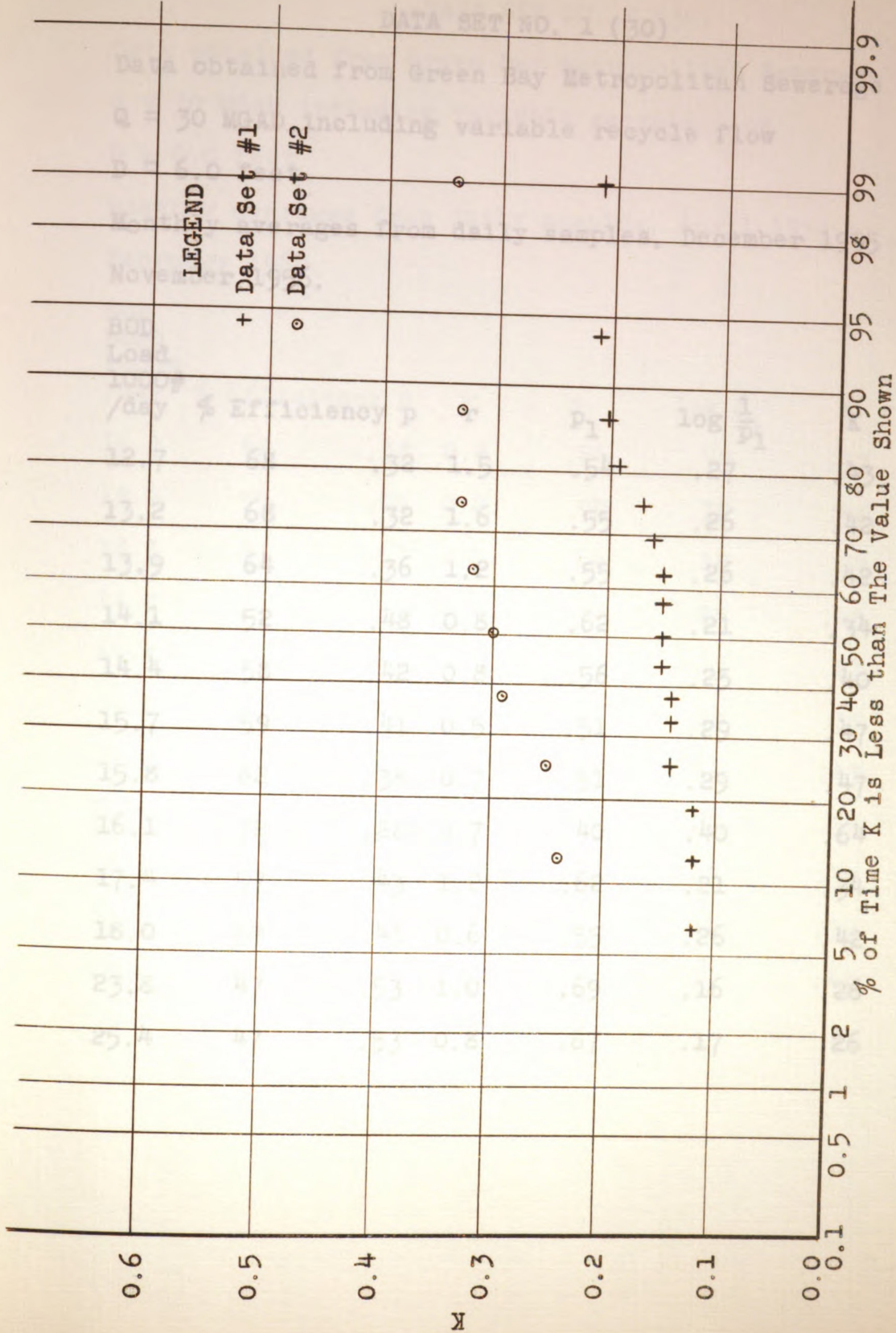


FIGURE 5 - SPARTA, PROBABILITY PLOT OF K

FIGURE 2 - EFFECT OF TEMPERATURE ON THE RATE OF
 DECOMPOSITION OF ACRYLONITRILE

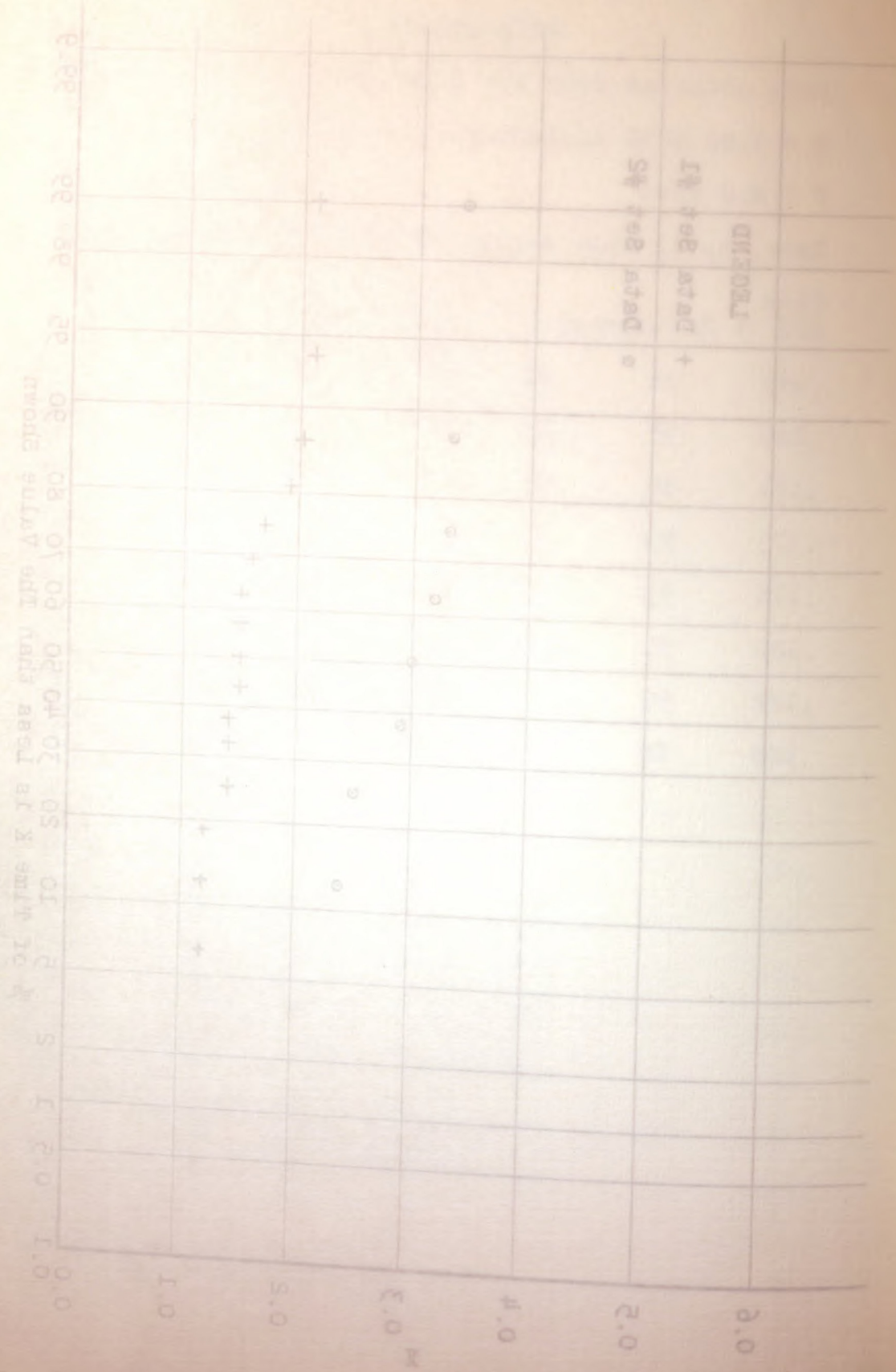


TABLE 8A - TRICKLING FILTER, GREEN BAY, WISCONSIN

DATA SET NO. 1 (30)

Data obtained from Green Bay Metropolitan Sewerage District

Q = 30 MGAD including variable recycle flow

D = 6.0 feet

Monthly averages from daily samples, December 1955 -
November 1956.

BOD Load 1000# /day	% Efficiency	p	r	p_1	$\log \frac{1}{p_1}$	K
12.7	68	.32	1.5	.54	.27	.43
13.2	68	.32	1.6	.55	.26	.42
13.9	64	.36	1.2	.55	.26	.42
14.1	52	.48	0.8	.62	.21	.34
14.4	58	.42	0.8	.56	.25	.40
15.7	59	.41	0.5	.51	.29	.47
15.8	62	.38	0.7	.51	.29	.47
16.1	72	.28	0.7	.40	.40	.64
17.4	57	.43	1.2	.62	.21	.34
18.0	57	.43	0.6	.55	.26	.42
23.8	47	.53	1.0	.69	.16	.26
25.4	47	.53	0.8	.67	.17	.26

TABLE 2A - TRICKLING FILTER, GREEN BAY, WISCONSIN

DATA SET NO. 1 (30)

Data obtained from Green Bay Metropolitan Sewerage District

$Q = 30$ MGAD including variable recycle flow

$D = 6.0$ feet

Monthly averages from daily samples, December 1955 -

November 1956.

Load 1000 lb/day	Efficiency η	r	P_1	$\log \frac{1}{P_1}$	X
12.7	.68	.38	1.5	.21	.43
13.5	.68	.38	1.6	.20	.42
13.9	.64	.36	1.5	.22	.42
14.1	.52	.48	0.8	.09	.34
14.4	.58	.42	0.8	.09	.40
15.7	.59	.41	0.9	.08	.47
15.8	.62	.38	0.7	.15	.47
16.1	.75	.58	0.7	.04	.64
17.4	.57	.43	1.2	.09	.34
18.0	.57	.43	0.6	.22	.45
23.8	.47	.53	1.0	.09	.56
25.4	.47	.53	0.8	.17	.56

TABLE 8B - TRICKLING FILTER, GREEN BAY, WISCONSIN

DATA SET NO. 2 (30)

Data obtained from Green Bay Metropolitan Sewerage District

Q = 30 MGAD including variable recycle flow

D = 6.0 feet

Monthly averages from daily samples, April 1959 - February 1960.

BOD Load 1000# /day	% Efficiency	p	r	p ₁	$\log \frac{1}{p_1}$	K
16.3	62	.38	0.4	.46	.33	.53
18.1	55	.45	0.2	.50	.30	.48
18.3	43	.57	0.5	.66	.18	.29
18.8	52	.48	0.2	.52	.28	.45
19.8	32	.68	0.3	.74	.13	.21
19.8	53	.47	0.5	.57	.24	.38
20.2	58	.42	0.6	.54	.27	.43
20.9	52	.48	0.6	.60	.22	.35
22.0	53	.47	0.5	.57	.24	.39
23.4	50	.50	0.6	.64	.19	.30
25.4	56	.44	0.5	.54	.27	.43

FIGURE 6 - GREEN BAY, PROBABILITY PLOT OF K

TABLE 88 - TRICKLING FILTER, GREEN BAY, WISCONSIN

DATA SET NO. 2 (30)

Data obtained from Green Bay Metropolitan Sewerage District

Q = 30 MGAD including variable recycle flow

D = 6.0 feet

Monthly averages from daily samples, April 1959 -

February 1960.

BOD Load 1000# /day	Efficiency %	r	p ₁	$\log \frac{r}{p_1}$	K
16.3	65	.38	.46	.33	.53
18.1	55	.45	.50	.30	.48
18.3	43	.57	.66	.16	.59
18.8	55	.48	.55	.35	.45
19.8	35	.68	.74	.13	.51
19.8	53	.47	.57	.34	.38
20.2	58	.45	.54	.27	.43
20.9	55	.48	.60	.25	.35
22.0	53	.47	.57	.34	.39
23.4	50	.50	.64	.21	.30
25.4	56	.44	.54	.27	.43

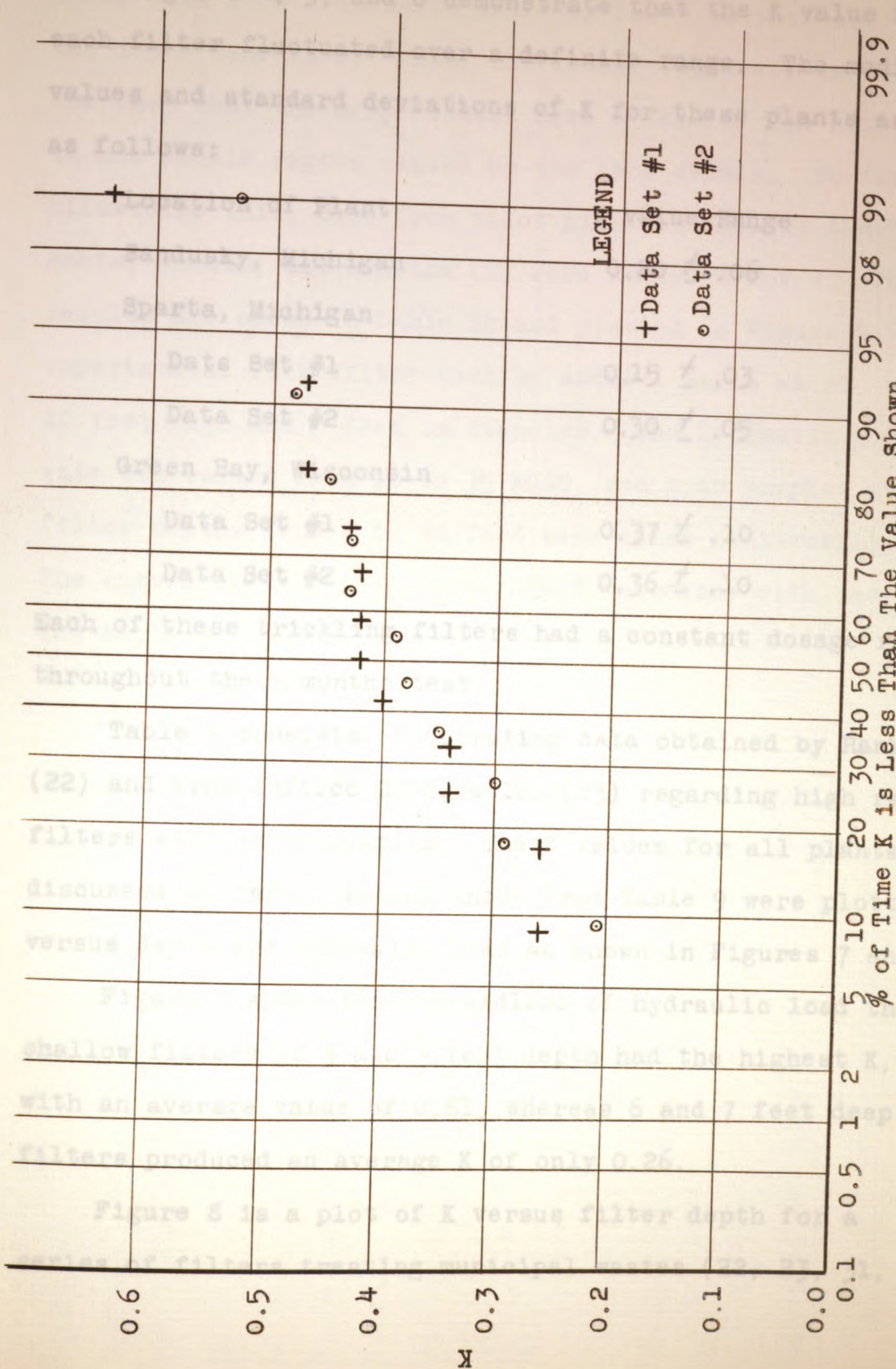


FIGURE 6 - GREEN BAY, PROBABILITY PLOT OF K

Figures 4, 5, and 6 demonstrate that the K value for each filter fluctuated over a definite range. The median values and standard deviations of K for these plants are as follows:

Location of Plant	K value Range
Sandusky, Michigan	0.20 $\pm$.06
Sparta, Michigan	
Dats Set #1	0.15 $\pm$.03
Data Set #2	0.30 $\pm$.05
Green Bay, Wisconsin	
Data Set #1	0.37 $\pm$.10
Data Set #2	0.36 $\pm$.10

Each of these trickling filters had a constant dosage rate throughout the 5 months test.

Table 9 consists of operating data obtained by Rankin (22) and from Infilco Corporation (23) regarding high rate filters with recirculation. The K values for all plants discussed so far including those from Table 9 were plotted versus depth and hydraulic load as shown in Figures 7 and 8.

Figure 7 shows that regardless of hydraulic load the shallow filters of 3 and 4 feet depth had the highest K, with an average value of 0.81, whereas 6 and 7 feet deep filters produced an average K of only 0.26.

Figure 8 is a plot of K versus filter depth for a series of filters treating municipal wastes (22, 23, 31, 32).

These data show a definite tendency for K to increase as the depth decreases. This, the author believes, is due to the fact that the deep filters have a zone of low activity in the middle region caused by the lack of air. To further illustrate this, data from pilot plant studies by Abdul - Rahim, Hindin, and Dunstan (9) were analysed for K. The results are shown in Table 10 and plotted in Figure 9. The experimental rock filter used by Abdul - Rahim et al. was 10 feet high and 5 feet in diameter. The hydraulic dosage rate was varied from 10 to 35 MGAD, and grab samples at filter depths from 1 to 10 feet were taken semi-weekly. The curves clearly illustrate how K decreases with increasing depth on a rock filter.

TABLE 9 -- HIGH RATE FILTERS WITH RECIRCULATION (22, 23)

Location	Flow MGD	Q	% Efficiency	p	r	p ₁	log $\frac{1}{p_1}$	D	K	Remarks
Centralia, Mo.	0.10	8.65	89.4	.106	0.95	.19	.720	3.0	1.05	
Grt. Neck, N. Y.	0.52	7.68	83.1	.169	1.15	.31	.507	4.0	.50	(Single
Dothan, Alabama	0.55	15.0	87.4	.126	2.31	.33	.480	3.0	.97	Stage)
Alisal, California	0.59	20.8	86.6	.134	3.06	.39	.408	3.2	.96	
Storm Lake, Iowa	1.39	21.5	84.0	.160	2.14	.375	.424	8.0	.41	
Fremont, Ohio	1.75	19.0	77.5	.225	1.5	.43	.377	3.3	.81	
Richland, Washington	2.17	19.6	82.7	.173	2.76	.44	.355	4.5	.58	
Oklahoma City, Okla.	16.17	16.3	78.0	.220	1.0	.36	.443	6.0	.47	
Siloam Springs, Ark. 1st Stage	0.255	8.1	70.5	.295	1.41	.500	.301	5.0	.24	
2nd Stage	0.255	11.8	70.5	.295	1.54	.515	.288	5.0	.30	(Two
Bentonville, Ark. 1st Stage	0.34	11.6	65.0	.350	1.67	.585	.233	5.0	.23	Stage)
2nd Stage	0.34	24.1	65.0	.350	2.78	.680	.168	5.0	.28	
Liberty, New York 1st Stage	1.13	27.2	67.0	.33	1.78	.577	.240	3.0	.73	
2nd Stage	1.13	26.0	67.0	.33	1.65	.567	.247	3.0	.73	

TABLE 9 - HIGH RATE FILTERS WITH RECIRCULATION (CONTINUED)

Location	Flow MGD	Q	% Efficiency	p	r	p ₁	log $\frac{1}{p_1}$	D	K	Remarks
Winchester Va. 1st Stage	1.93	17.3	65.0	.350	1.52	.576	.240	3.0	.53	(2 - Stage
2nd Stage	1.93	24.8	65.0	.350	2.63	.660	.180	3.0	.52	Series
Petalum, Calif. 1st Stage	0.505	12.0	81.5	.185	1.43	.355	.455	3.0	.80	Parallel)
2nd Stage	0.505	17.2	81.5	.185	2.43	.440	.357	3.0	.79	
Orlando, Florida 1st Stage	3.90	19.3	71.5	.285	1.60	.510	.292	5.0	.42	
2nd Stage	3.90	23.0	69.5	.305	2.06	.574	.241	5.0	.39	
Medford, Oregon 1st Stage	4.63	57.0	64.0	.36	1.17	.575	.241	3.0	1.19	
2nd Stage	4.63	57.0	64.0	.36	1.17	.575	.241	3.0	1.19	
Mineola, Texas	0.12	19.8	91.7	0.083	10.0	.50	.301	8.0	.27	
Alisal San. Dist. California, June	0.59	17.7	87.0	0.13	2.45	.34	.468	3.2	.92	(Accelo
Alisal, San. Dist. Calif. Sept. & Oct.	0.59	16.8	86.0	.14	2.45	.36	.444	3.2	.91	Filter)
Xenia, Ohio 5/11/49	1.60	18.8	70.0	.30	0.65	.415	.382	6.0	.44	
Xenia, Ohio 5/5/49	1.62	17.5	76.0	.24	0.65	.340	.468	6.0	.53	
Ames, Iowa	2.00	4.0	92.7	.073	2.00	.190	.722	8.0	.23	

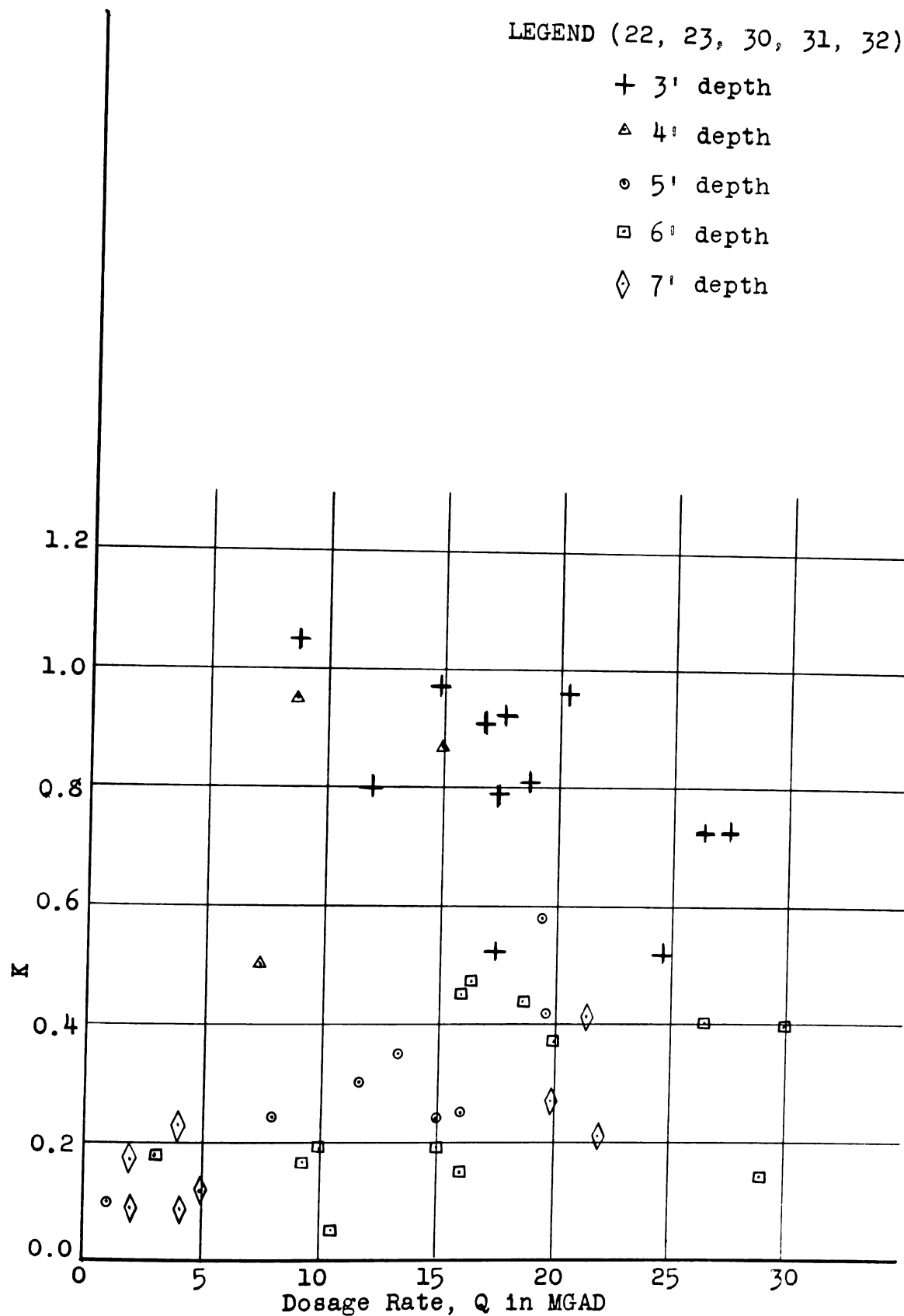


FIGURE 7 - K VERSUS DOSAGE RATE FOR OPERATING ROCK FILTER PLANTS TREATING MUNICIPAL WASTE, SHOWING INFLUENCE OF DEPTH

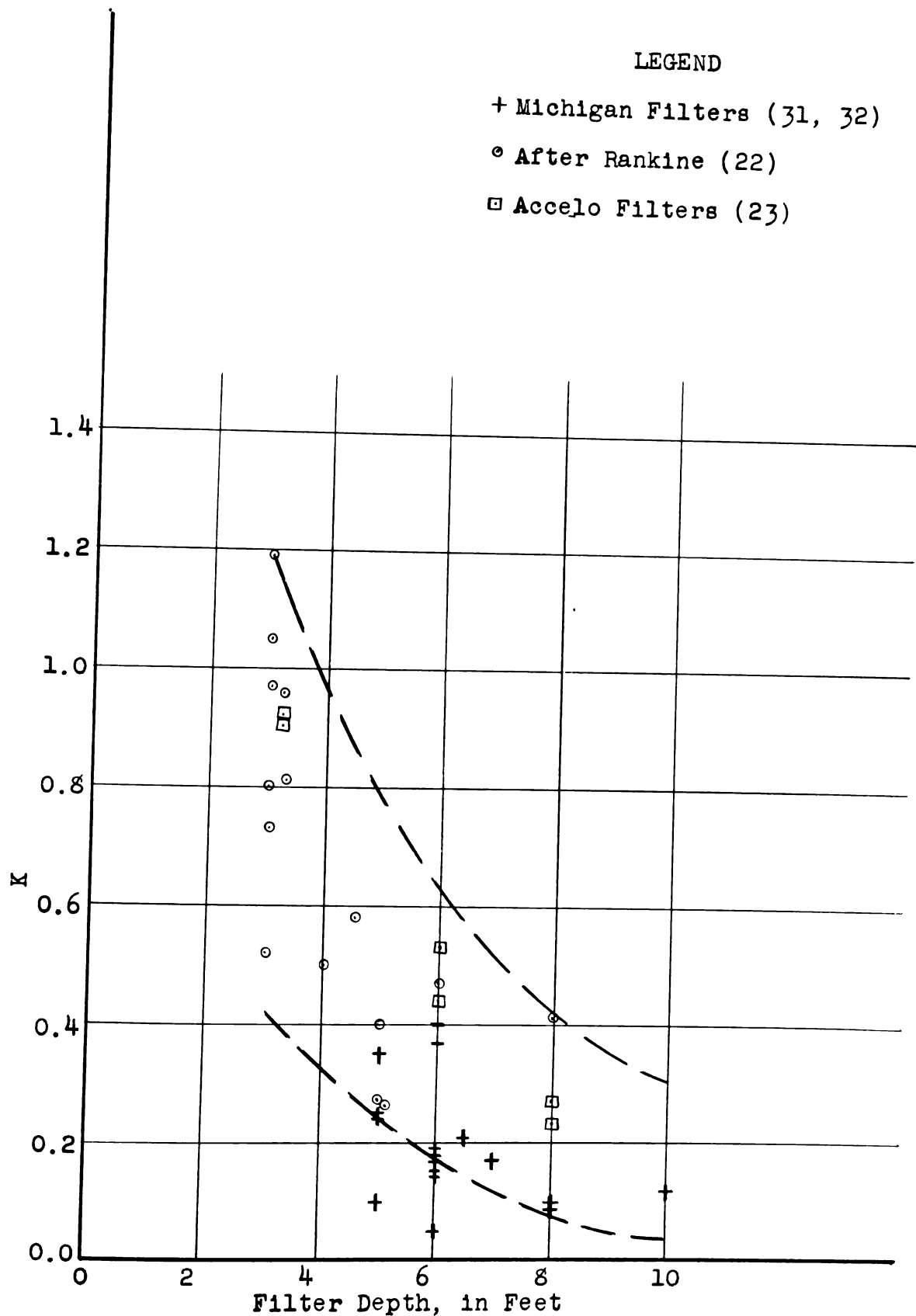


FIGURE 8 - K VERSUS DEPTH FOR OPERATING ROCK FILTER PLANTS
TREATING MUNICIPAL WASTE

TABLE 10 - PILOT PLANT DATA (9)

Q	% Efficiency	p_1	$\log \frac{1}{\bar{p}_1}$	D	K
10	43	.57	.243	1	1.13
10	55	.45	.346	2	0.80
10	62	.38	.418	3	.65
10	66	.34	.468	4	.55
10	67	.33	.481	5	.45
10	68	.32	.494	6	.38
10	71	.29	.537	7	.35
10	73	.27	.568	8	.33
10	76	.24	.619	9	.32
10	78	.22	.657	10	.30
20	23	.77	.113	1	.83
20	47	.53	.274	2	1.02
20	52	.48	.313	3	.77
20	55	.45	.346	4	.64
20	58	.42	.376	5	.57
20	60	.40	.397	6	.49
20	63	.37	.426	7	.45
20	65	.35	.454	8	.41
20	67	.33	.481	9	.40
20	70	.30	.522	10	.39

TABLE 10 - PILOT PLANT DATA (9)

Q	% Efficiency	p_1	$\log \frac{1}{\bar{p}_1}$	D	K
10	43	.57	.243	1	1.13
10	55	.45	.346	2	0.80
10	62	.38	.418	3	.65
10	66	.34	.468	4	.55
10	67	.33	.481	5	.45
10	68	.32	.494	6	.38
10	71	.29	.537	7	.35
10	73	.27	.568	8	.33
10	76	.24	.619	9	.32
10	78	.22	.657	10	.30
20	23	.77	.113	1	.83
20	47	.53	.274	2	1.02
20	52	.48	.313	3	.77
20	55	.45	.346	4	.64
20	58	.42	.376	5	.57
20	60	.40	.397	6	.49
20	63	.37	.426	7	.45
20	65	.35	.454	8	.41
20	67	.33	.481	9	.40
20	70	.30	.522	10	.39

TABLE 10 - PILOT PLANT DATA (CONTINUED)

Q	% Efficiency	p_1	$\log \frac{1}{p_1}$	D	K
20	51	.49	.308	1	2.28
20	56	.44	.362	2	1.34
20	64	.36	.441	3	1.09
20	69	.31	.505	4	.93
20	71	.29	.530	5	.81
20	72	.28	.554	6	.64
20	72	.28	.554	7	.59
20	74	.26	.582	8	.54
20	75	.25	.606	9	.50
20	77	.23	.637	10	.47
35	25	.75	.121	1	1.30
35	35	.65	.188	2	1.01
35	47	.53	.270	3	.96
35	52	.48	.322	4	.86
35	57	.43	.365	5	.78
35	59	.41	.390	6	.69
35	62	.38	.416	7	.63
35	64	.36	.442	8	.59
35	66	.34	.472	9	.56
35	70	.30	.525	10	.56

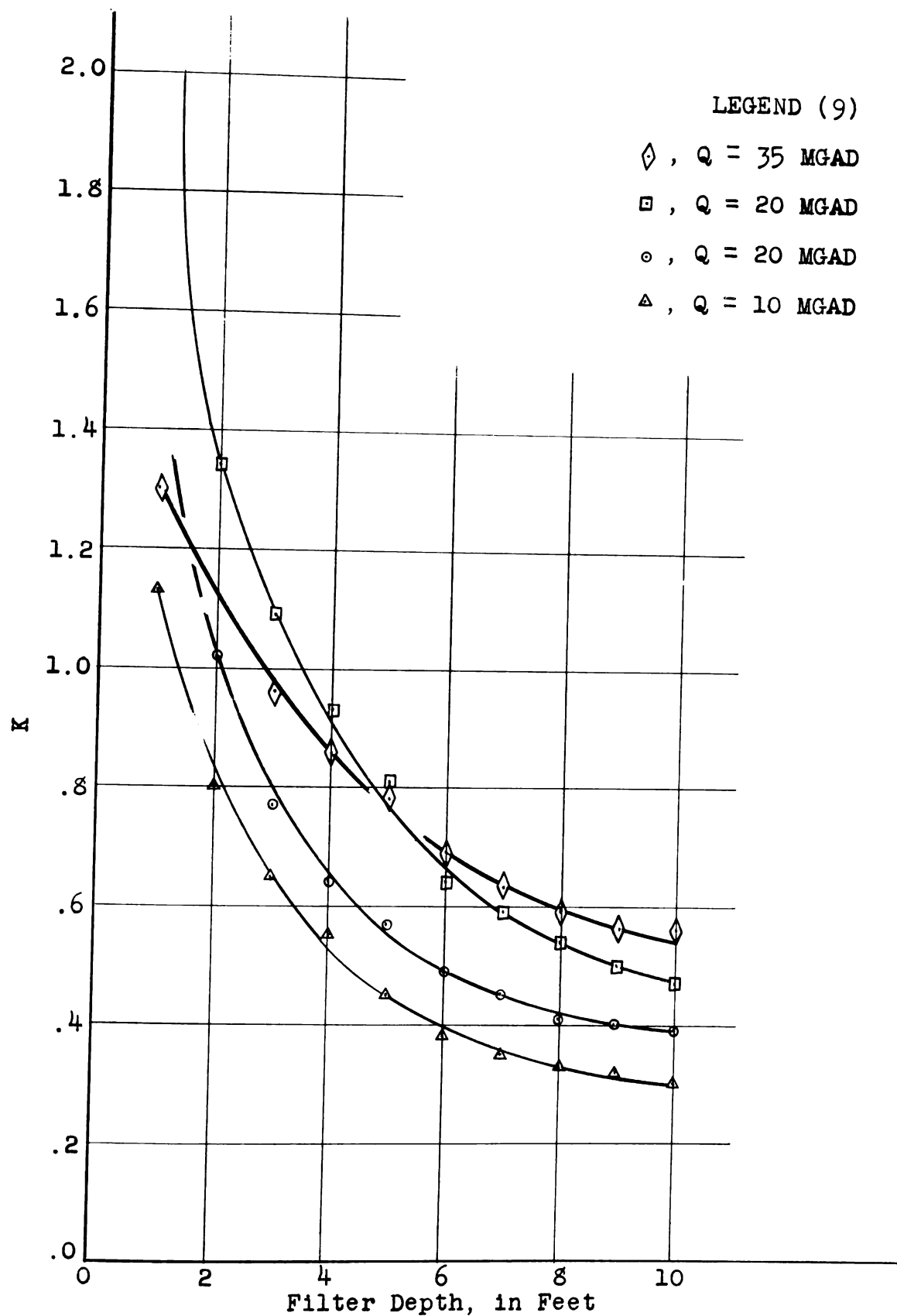


FIGURE 9 - K VERSUS DEPTH FOR A 10 FEET DEEP ROCK TRICKLING FILTER PILOT PLANT

CHAPTER IV - K AS A PARAMETER FOR TREATABILITY OF WASTES

It can be assumed that municipal wastes are more or less similar over the country, whereas industrial wastes certainly have very different characteristics. These differences could be measured by K as the degree of treatability; the higher the K value, the greater the treatability of the particular waste as long as the apparatus is the same. A comparison of K values obtained from pilot plants using an identical type of plastic media and distributor should therefore provide an index of treatability. It should be noted that the K factor is much more applicable to the open type of filter media since in this case K does not vary appreciably with depth.

Table 11 shows a series of K values computed for filters using stone as a medium and treating various industrial wastes.

The first set of data shown in table 11 relates to a full scale plant using rock media and treating a Fine Chemical Waste (25). The plant was operated at a recycle ratio of 9 with a depth of 4 feet. The average BOD removal was 53 percent. The low K with an average value of .06 is an indication that this waste was difficult to treat.

The second set of data in table 11 relates to a .004 MGD pilot plant treating Phenolic Waste (26). The K values for this pilot plant ranged from .11 to .23.

This fluctuation in K values is to be expected from a waste of this type since it is non-uniform in makeup and subject to shock loads. The third group of data was obtained from a plant (27) treating the same phenolic waste which was handled by the pilot plant. The K value of 0.14 for this case is in agreement with the K values listed for the pilot plant.

Data from a trickling filter pilot plant which was operated at the municipal treatment plant in Battle Creek, Michigan (20) are shown in table 12, and plotted on Figure 10. This filter used "Surfpac" which is the trademark of The Dow Chemical Company for their plastic biological oxidation media. This is one of several open type filter media which is commercially available. The lines drawn through the K values for each depth in Figure 10 indicate the consistency of these values in regard to depth. Thus it may be concluded that the K values in an open media type filter such as Surfpac do not vary with depth.

TABLE 11 - ROCK FILTERS TREATING INDUSTRIAL WASTE (25, 26, 27)

Flow MGD	Q	% Efficiency	p	r	p ₁	log $\frac{1}{p_1}$	D	K	Remarks
1.16	14.0	53	.47	9.0	.91	.04	4.0	.06	Fine Chemical Waste
.004	10.7	68.0	.320	-	.320	.495	10.5	.23	
.004	10.7	66.8	.332	-	.332	.479	10.5	.22	Phenolic Waste (pilot plant)
.004	10.7	42.8	.572	-	.572	.243	10.5	.11	
12.0	8.0	55	.45	-	.45	.347	10.0	.14	Phenolic Waste (full scale plant)

TABLE 12 - SURFPAC TOWER, BATTLE CREEK, MICHIGAN (20)*

Flow MGD	Q	% Efficiency	p	r	p ₁	$\log \frac{1}{p_1}$	D	K
.04	20	33	.67	-	.67	.174	10.5	.12
.04	20	59	.41	-	.41	.390	21.0	.14
.04	20	79	.21	-	.21	.676	31.5	.16
.04	20	88	.12	-	.12	.925	42.0	.16
.12	51	57	.43	-	.43	.366	21	.24
.12	51	79	.21	-	.21	.68	42	.22
.23	102	22	.78	-	.78	.108	10.5	.22
.23	102	40	.60	-	.60	.222	21.0	.23
.23	102	39	.61	-	.61	.215	31.5	.15
.23	102	57	.43	-	.43	.367	42.0	.19
.47	206	40	.60	1.0	.75	.125	21.0	.21
.47	206	51	.49	1.0	.65	.19	42.0	.16
.49	213	10	.90	-	.90	.046	10.5	.15
.49	213	12	.88	-	.88	.058	21.0	.10
.49	213	14	.86	-	.86	.068	31.5	.08
.49	213	23.5	.765	-	.765	.116	42.0	.10

* This is a combination of municipal and industrial waste

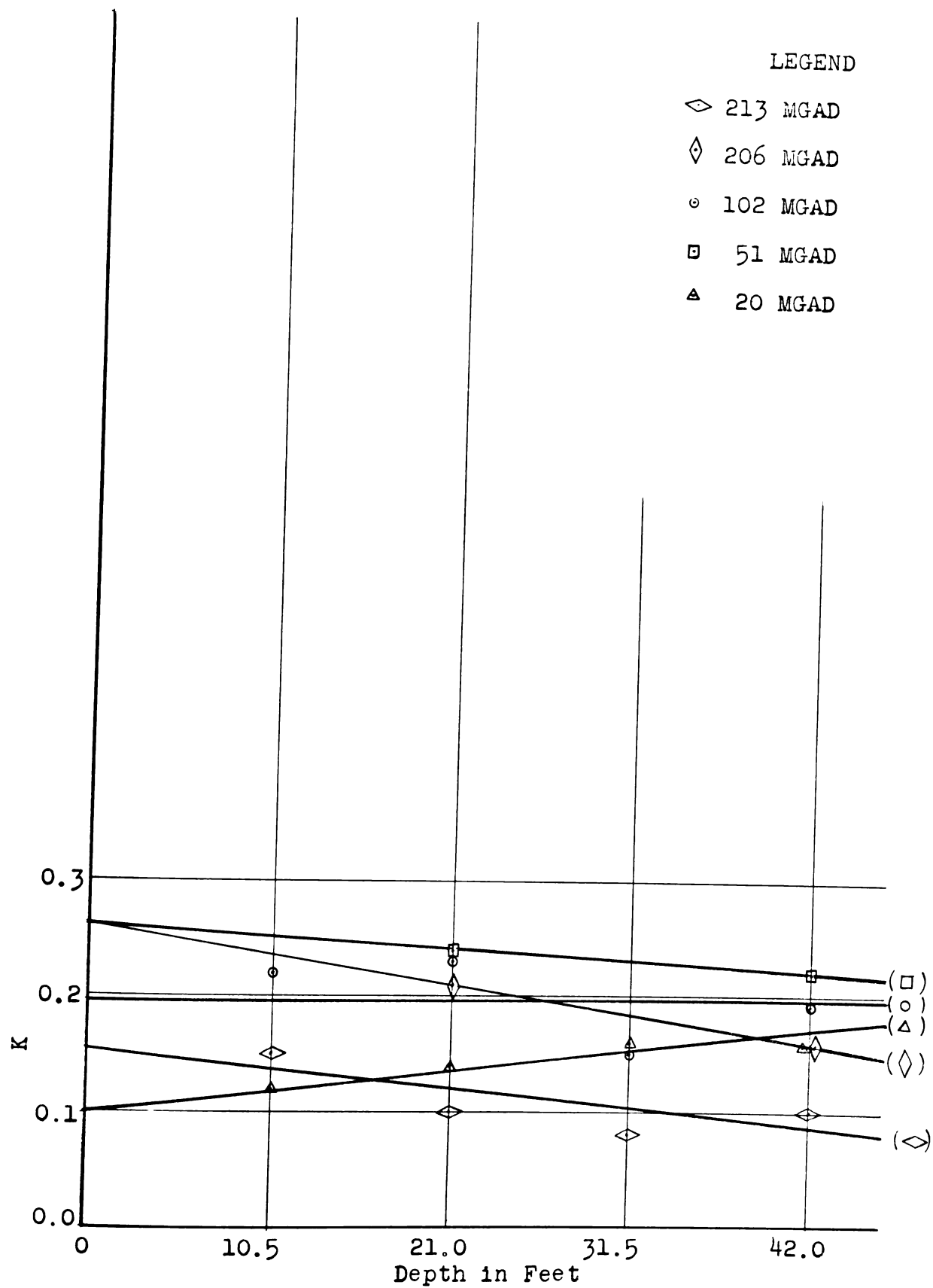


FIGURE 10 - K VERSUS DEPTH FOR SURFPAC PILOT PLANT AT
BATTLE CREEK, MICHIGAN

The same data were replotted in Figure 11 to relate the K values to the hydraulic dosage rate. The K values range from 0.08 to 0.23 while the hydraulic dosage rate varies from 20 to 213 MGAD. These data indicate that K is independent of hydraulic dosage rate.

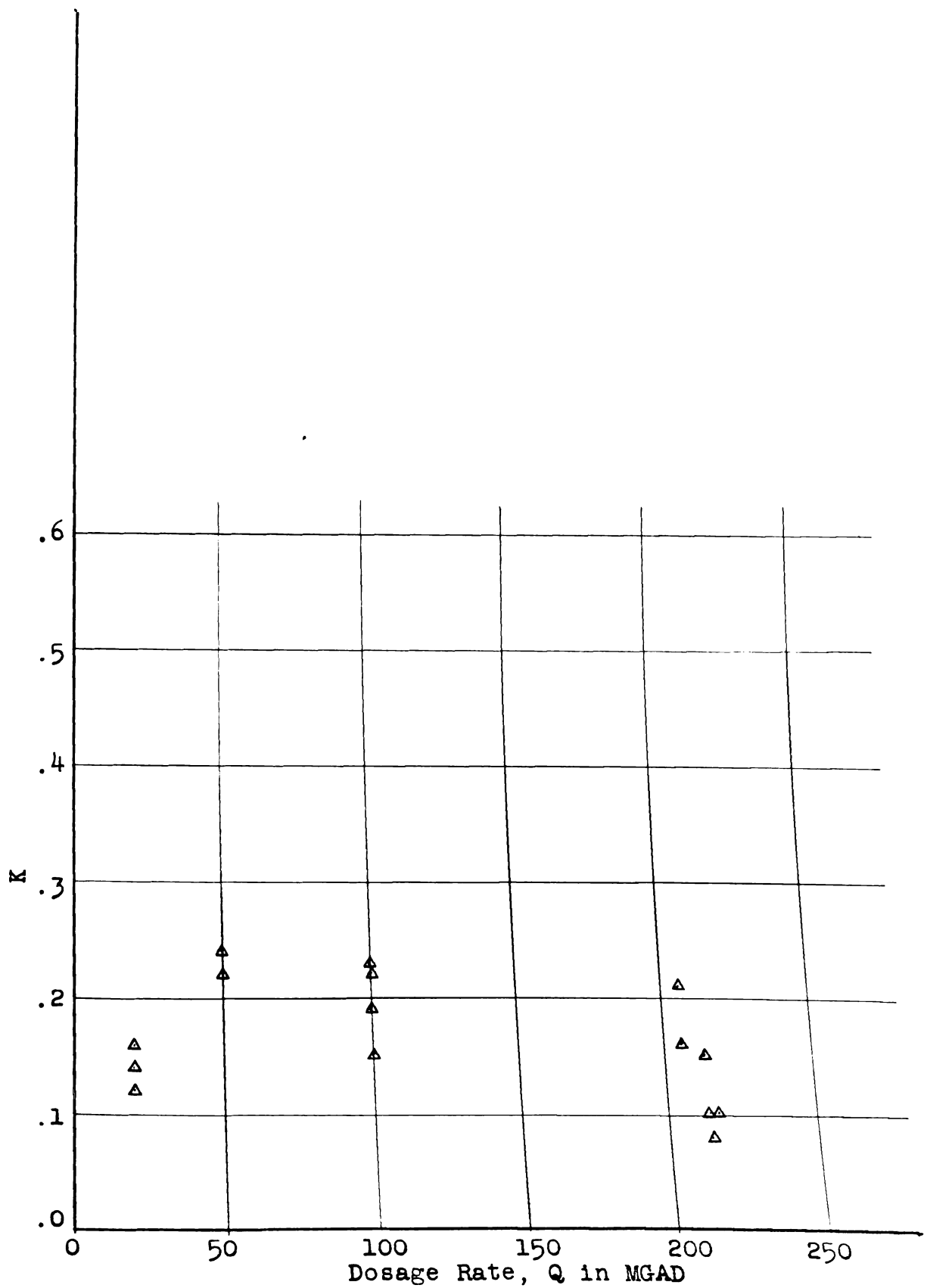


FIGURE 11 - K VERSUS DOSAGE RATE FOR BATTLE CREEK, MICHIGAN SURFPAC PILOT PLANT

Data from the Surfpac Technical Bulletin of Plastic Biological Oxidation Media (21) and other sources (28, 29) are analyzed in Tables 13, 14 and 15, and shown graphically in Figures 12 through 18. These data include the results of at least several months of testing at each location and are taken from full scale plants or from pilot plant operations set up at the respective industrial waste treatment plants. All results are from composite samples. The individual K values computed for each type of waste were then plotted versus hydraulic load as shown in Figures 12 through 18. A summary of these data is contained in Table 16 where the different types of wastes are listed according to their decreasing degree of treatability as measured by K as a parameter. From the table it can be seen that the waste with the greatest treatability was Domestic Sewage (29) with a K value of 0.75. This K value was obtained for a 10.5 feet deep roughing filter which removed 50% of the primary effluent BOD at a hydraulic load of 188 MGAD. This is certainly an outstanding performance for a filter and this is demonstrated by the high K value. The waste that gave the next highest value of treatability was the Hydrocarbon Waste (21) with a K value of 0.56. This plant employed a recycle ratio of 4.5 and obtained 91 percent BOD removal.

A K value of 0.30 was measured for a municipal sewage when the pilot plant was not operated as a roughing filter but for 82% BOD removal. One filter pilot plant treated pulp and paper wastes at the same locality with varied operating conditions and produced different K values (21). A K value of 0.27 resulted when the waste was treated at a temperature of 48 - 54° C and a K value of 0.17 was obtained at a temperature of 39 - 41° C. At a Coke Plant the Ammonia Still waste produced a K of 0.30, but when the same plant was treating Final Cooler Mixture a K of 0.19 was produced. The most difficult to treat waste was a Paper Mill Waste (21) which was from a source other than the Pulp and Paper waste above, and produced K values of 0.15 and 0.09 when operated on separate filters with depths of 31.5 feet and 42 feet respectively.

TABLE 13 - SURFPAC TOWER TREATING COKE PLANT WASTE (21)

Flow MGD	Q	% Efficiency	p	r	p ₁	$\log \frac{1}{p_1}$	D	K	Remarks
.018	82.0	70.8	.292	0.25	.34	.468	29.75	.30	(Coke Plant Ammonia Still)
.029	132.0	60.8	.392	0.33	.46	.337	29.75	.29	
.029	132.0	49.9	.501	-	.50	.301	29.75	.30	
.058	264.0	55.5	.445	1.00	.615	.211	29.75	.29	
.019	87.6	58.9	.411	0.33	.471	.327	29.75	.22	(Coke Plant Ammonia Still
.038	172.0	34.5	.655	0.31	.712	.147	29.75	.15	Final Cooler Mixture)
.039	177.0	53.5	.465	0.33	.535	.272	29.75	.29	
.047	213.0	36.1	.639	0.29	.795	.100	29.75	.12	
.053	238.0	30.8	.692	0.20	.730	.136	29.75	.18	

TABLE 14 - SURFPAC TOWERS TREATING INDUSTRIAL WASTES (21)

Q	% Efficiency	p	r	p ₁	log $\frac{1}{p_1}$	D	K	Remarks
20.7	68.7	.313	0.5	.406	.392	23	.13	(Effluent from sour water stripper)
119	91	.090	4.5	.350	.456	19.8	.56	(Hydrocarbon Waste)
77.7	50.2	.498	1.00	.666	.176	31.5	.10	
77.7	69.1	.309	1.00	.475	.323	31.5	.19	(Paper Mill Waste)
136.0	50.6	.494	.75	.632	.200	31.5	.17	
58.2	48.5	.515	.50	.670	.174	42	.06	
58.2	58.6	.414	.50	.577	.239	42	.085	(Paper Mill Waste)
58.2	66.3	.337	.50	.495	.306	42	.11	
77.7	59.3	.407	.30	.605	.218	42	.095	
58.2	61.6	.384	2.00	.650	.183	21	.13	
77.0	57.4	.426	1.00	.595	.226	21	.19	(Pulp and Paper Waste Roughing Filter Temp. 39° C to 41° C)
87.0	51.2	.488	.50	.590	.229	21	.21	
96.0	43.3	.566	.67	.684	.166	21	.16	
116.0	33.5	.665	.50	.748	.126	21	.14	
145.0	31.8	.682	.50	.760	.120	21	.16	

TABLE 14 - SURFPAC TOWERS TREATING INDUSTRIAL WASTES (CONTINUED)

Q	% Efficiency	p	r	P ₁	$\log \frac{1}{P_1}$	D	K	Remarks
174.0	41.3	.587	.50	.680	.167	21	.25	(Pulp and Paper Waste Roughing Filter Temp. 48° C to 54° C)
174.0	45.0	.550	.50	.647	.189	21	.28	
202.0	43.1	.569	.50	.662	.179	21	.29	
115	62.8	.372	1.00	.544	.264	21	.30	
123	79.4	.206	3.33	.506	.296	21	.35	
145	80.6	.194	2.50	.458	.339	21	.44	
151	75.6	.244	4.00	.616	.210	21	.28	(Ragmill Waste)
189	88.6	.114	5.75	.465	.333	21	.52	
272	72.1	.279	3.72	.647	.190	21	.38	
383	64.4	.356	3.15	.698	.156	21	.39	
38.8	63	.37	2.16	.65	.188	31	.07	
62.3	71	.29	.56	.31	.508	31	.26	(Meat Packing Waste Roughing Filter)
75.0	69	.31	1.53	.44	.357	31	.20	
81.2	64	.36	2.10	.53	.276	31	.17	

TABLE 14 - SURFPAC TOWERS TREATING INDUSTRIAL WASTES (CONTINUED)

Q	% Efficiency	p	r	p_1	$\log \frac{1}{p_1}$	D	K	Remarks
109.0	69	.31	.70	.43	.366	31	.26	(Meat Packing Waste Roughing Filter)
134.0	49	.51	.60	.63	.200	31	.17	
156.0	67	.33	1.50	.55	.259	31	.24	
37.7	51.5	.455	-	.485	.314	21	.17	(Frozen Food Processing Waste Roughing Filter)
40.7	50.2	.498	-	.498	.302	21	.17	
20	89	.11	-	.11	.958	42	.17	(Domestic Sewage and Food Process- ing Wastes)
52	79	.21	-	.21	.678	42	.22	
102	55	.45	-	.45	.347	42	.19	
203	62	.38	1.00	.55	.259	42	.21	
213	34	.76	-	.76	.119	42	.10	
36.5	88	.12	-	.12	.920	42	.24	(Domestic Sewage Midland)
72.2	81	.19	-	.19	.722	42	.28	
125	78	.22	-	.22	.658	42	.39	

TABLE 15 - FILTERS USING PLASTIC MEDIA TREATING FROZEN FOOD WASTES AND DOMESTIC SEWAGE (28, 29)

Q	% Efficiency	p	r	p ₁	log $\frac{1}{P_1}$	D	K	Remarks
36	53	.47	-	.47	.327	20.0	.18	
110	62.3	.377	1.0	.55	.260	20.0	.30	(Frozen Food Wastes)
116	49.9	.501	1.0	.67	.175	20.0	.26	
277	46.3	.537	1.0	.70	.153	20.0	.32	
345	29.6	.704	1.0	.83	.080	20.0	.20	
188	49	.51	-	.51	.29	10.6	.90	
188	57	.43	-	.43	.36	10.6	1.12	(Domestic Sewage)
188	11	.89	-	.89	.05	10.6	.15	
188	41	.59	-	.59	.23	10.6	.71	
188	37	.63	-	.63	.20	10.6	.62	
188	52	.48	-	.48	.32	10.6	1.00	
188	47	.53	-	.53	.27	10.6	.84	
188	39	.61	-	.61	.21	10.6	.65	
188	43	.57	-	.57	.24	10.6	.75	
188	42	.58	-	.58	.24	10.6	.75	

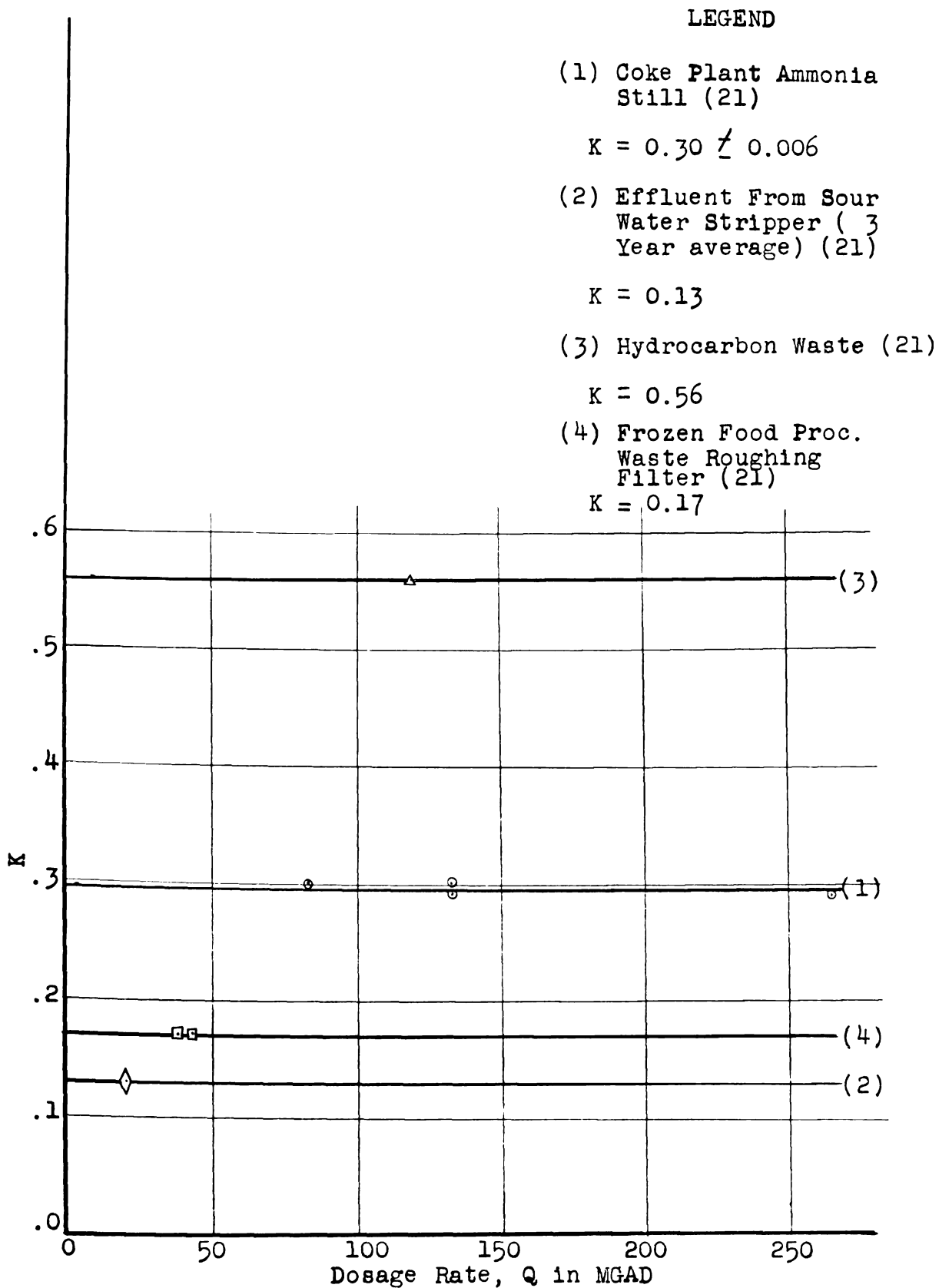


FIGURE 12 - K VERSUS DOSAGE RATE FOR INDUSTRIAL WASTES

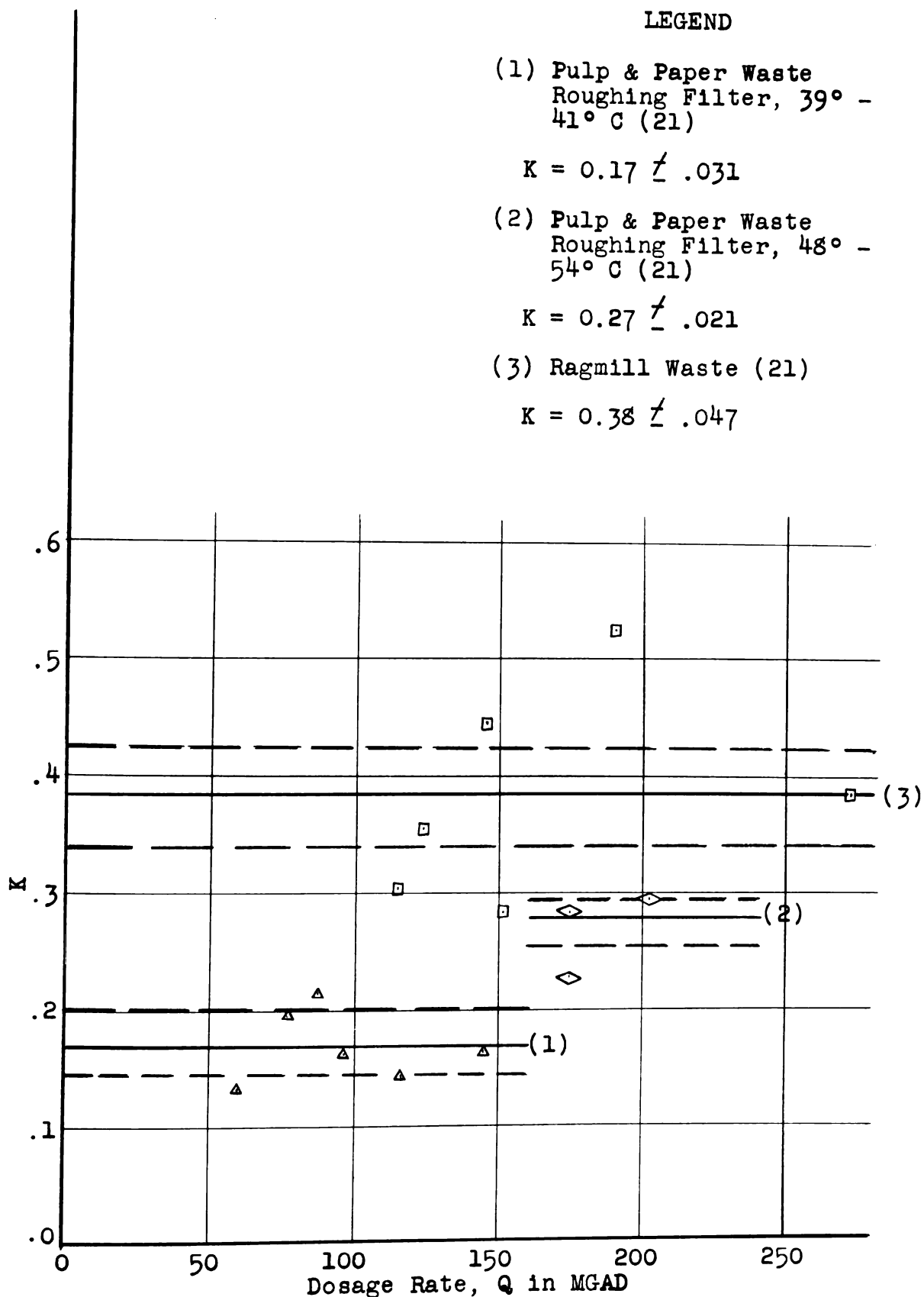


FIGURE 13 - K VERSUS DOSAGE RATE FOR INDUSTRIAL WASTES

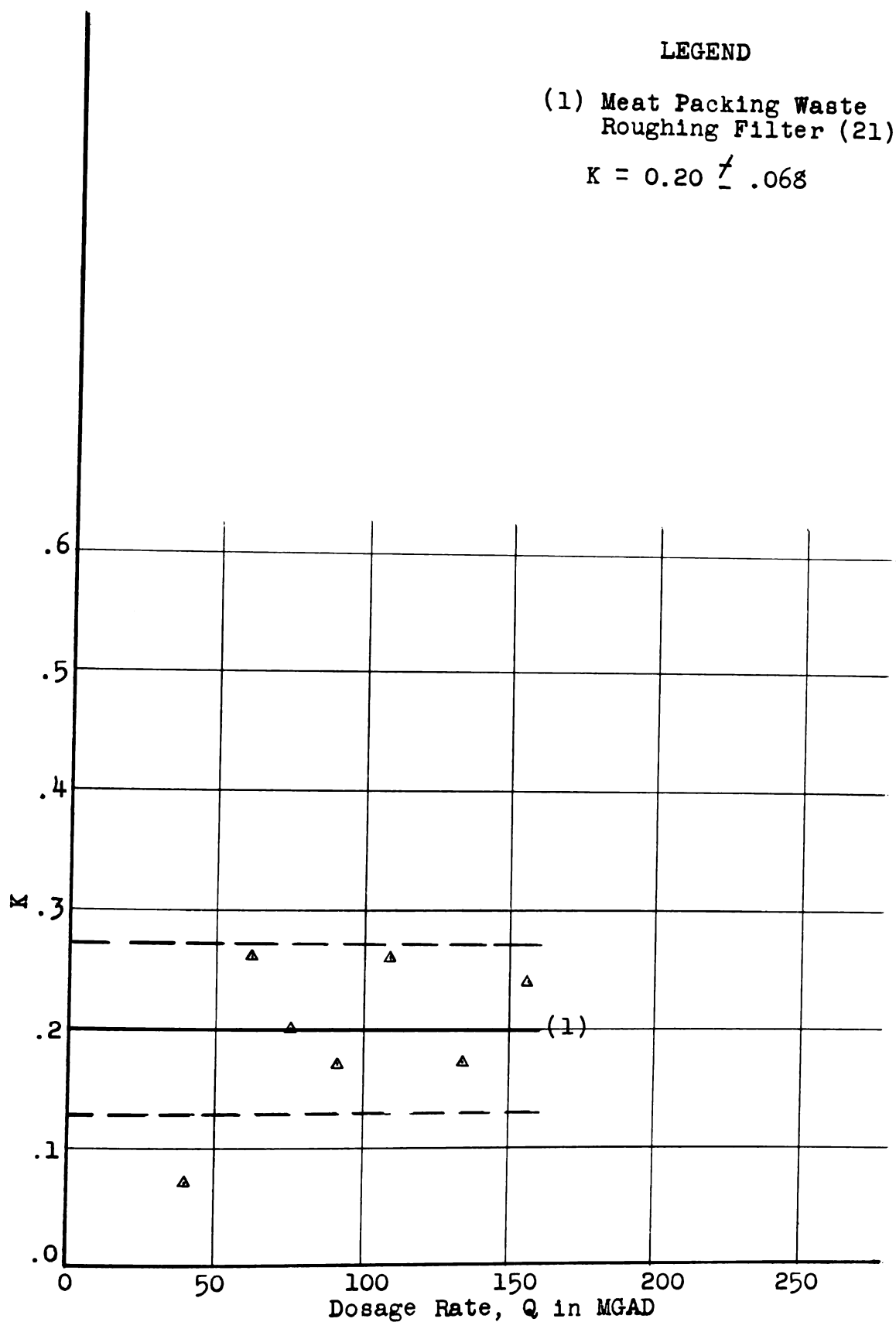


FIGURE 14 - K VERSUS DOSAGE RATE FOR INDUSTRIAL WASTES

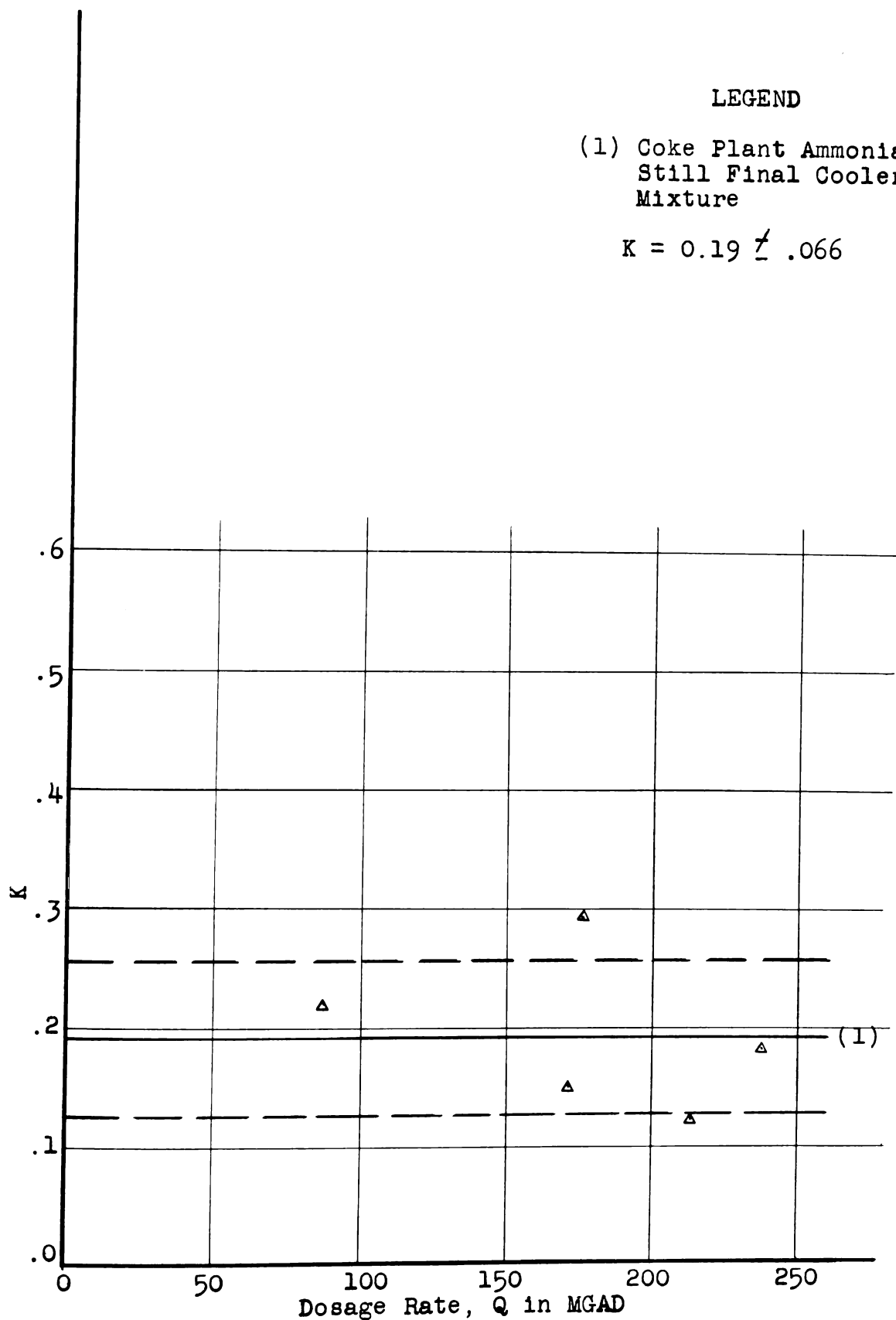


FIGURE 15 - K VERSUS DOSAGE RATE FOR INDUSTRIAL WASTES

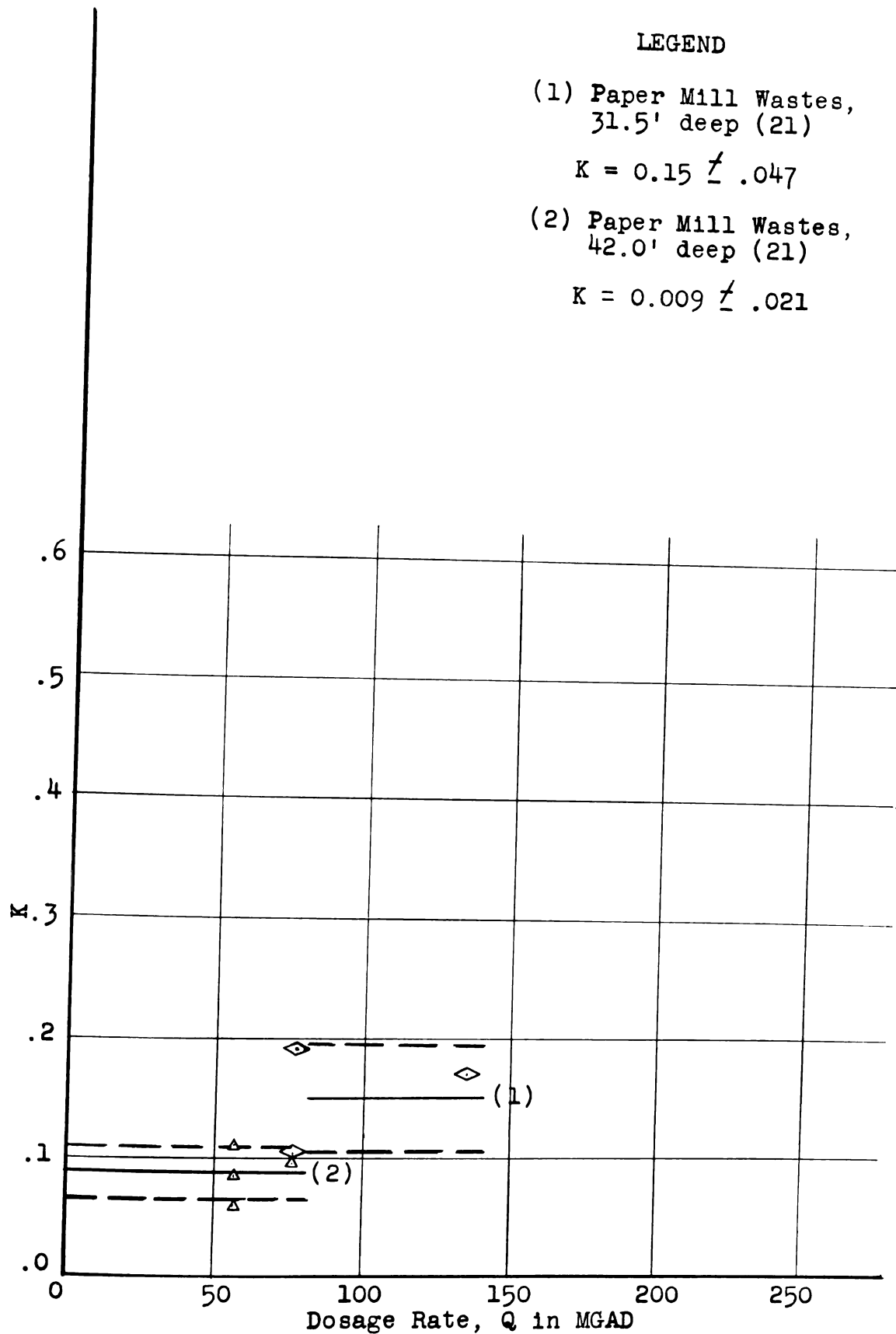


FIGURE 16 - K VERSUS DOSAGE RATE FOR INDUSTRIAL WASTES

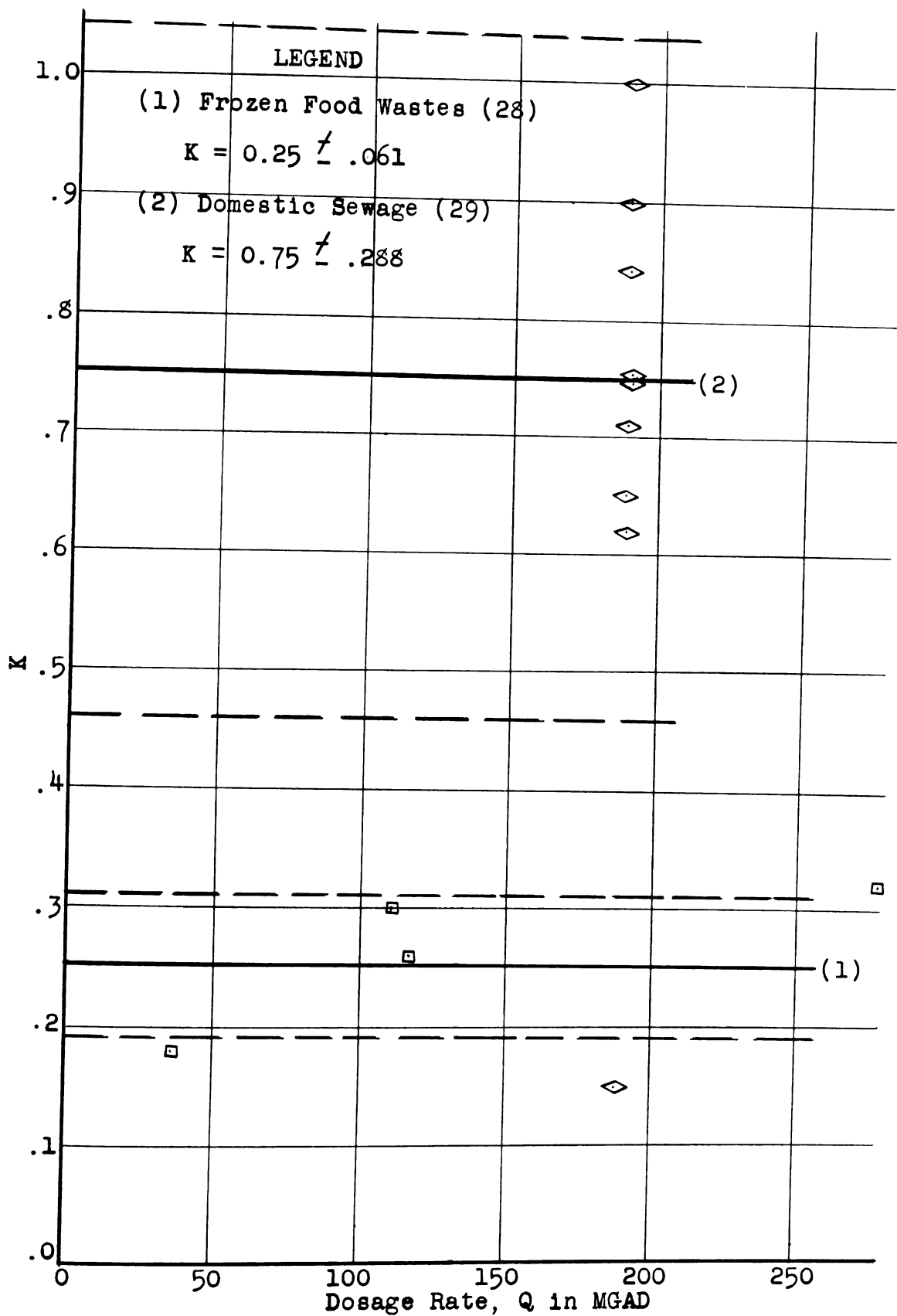


FIGURE 17 - K VERSUS DOSAGE RATE FOR INDUSTRIAL WASTES AND DOMESTIC SEWAGE

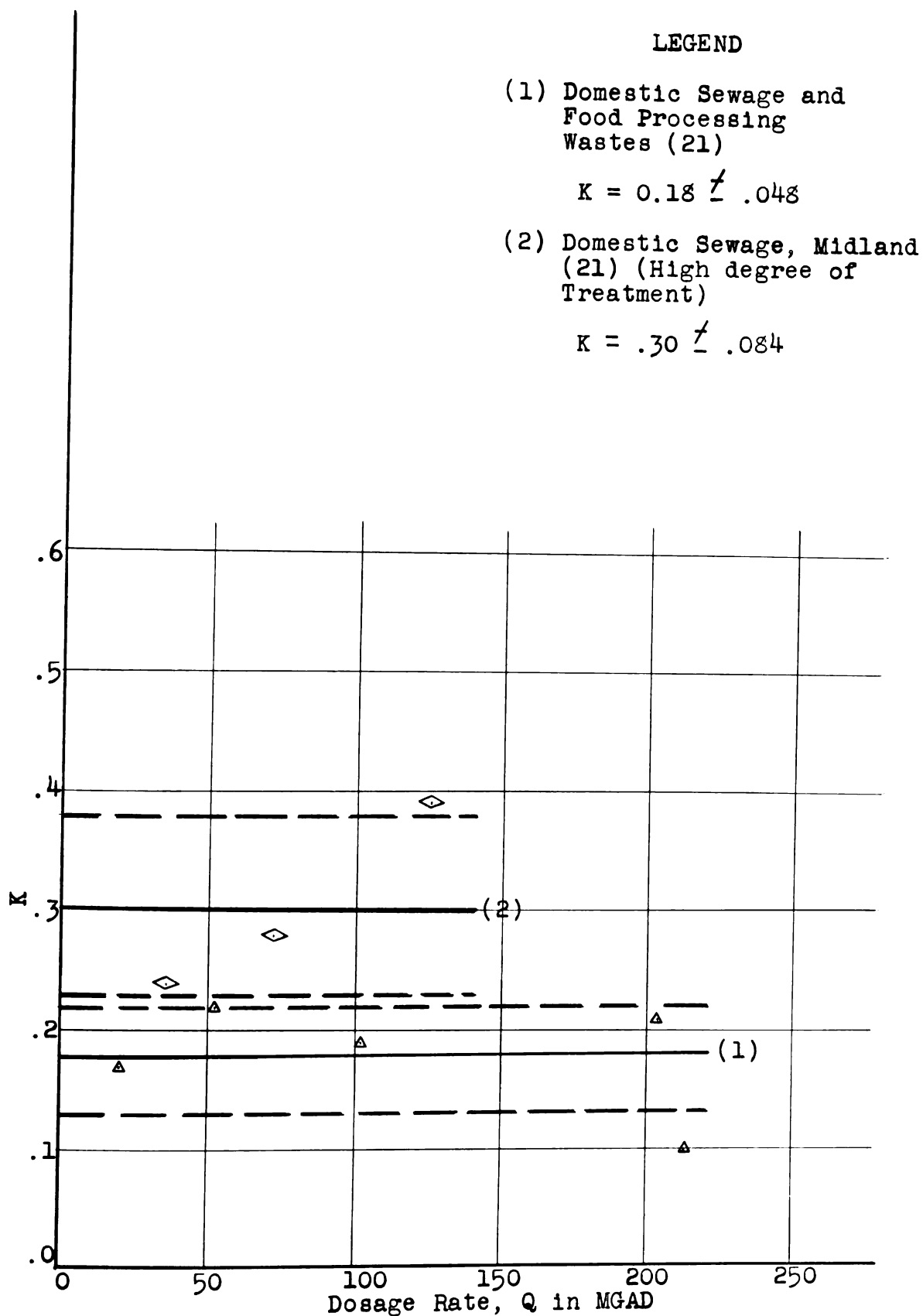


FIGURE 18 - K VERSUS DOSAGE RATE FOR INDUSTRIAL WASTES AND DOMESTIC SEWAGE

TABLE 16 - K VALUES FOR VARIOUS INDUSTRIAL WASTES

Waste	K
Domestic Sewage; (Roughing Filter)	0.75 $\frac{1}{2}$.288
Hydrocarbon Waste	0.56
Ragmill Waste	0.38 $\frac{1}{2}$.047
Domestic Sewage; (high degree of treatment)	0.30 $\frac{1}{2}$.084
Coke Plant Ammonia Still	0.30 $\frac{1}{2}$.006
Pulp and Paper; (Roughing Filter) 48 - 54° C	0.27 $\frac{1}{2}$.021
Frozen Food Waste	0.25 $\frac{1}{2}$.061
Meat Packing Waste; (Roughing Filter)	0.20 $\frac{1}{2}$.068
Coke Plant Ammonia Still, Final Cooler Mixture	0.19 $\frac{1}{2}$.066
Domestic Sewage and Food Processing Waste	0.18 $\frac{1}{2}$.048
Pulp and Paper; (Roughing Filter) 39 - 41° C	0.17 $\frac{1}{2}$.031
Frozen Food Processing Wastes	0.17
Paper Mill Waste, 78 MGAD and above	0.15 $\frac{1}{2}$.047
Effluent from Sour Water Stripper	0.13
Paper Mill Waste, 78 MGAD and below	0.09 $\frac{1}{2}$.021

CHAPTER V - DISCUSSION

The data for this thesis were obtained from the operating results of many different trickling filter plants, treating many different types of wastes from municipal to purely industrial waste. The filters used for comparison not only varied in height from three to forty feet but also in the type of media and distributors used.

Prior to the development of the new filter equations by Howland (13) and Schulze (14) there was no way of comparing trickling filter plants having such different physical structure and treating wastes of such different chemical nature. Up to date the design of conventional filters was based exclusively on empirical criteria geared toward the treatment of municipal waste. Experience has shown that these empirical formulations could not be used successfully as a design basis for the treatment of industrial wastes.

It is believed that the new equations as they are applied here not only make possible the comparison of different types of filter plants but also of different types of wastes. This means that the value of the trickling filter constant K can be used as a parameter to indicate the degree of treatability of the particular waste, if the same physical type of plant is used to treat the different wastes.

Once a series of K values has been established for a number of specific wastes these would provide a basis for a more rational design of trickling filter plants than has been available so far.

In addition to the dosage rate, depth of media, and type and size of media there are other factors which affect the performance of a trickling filter.

Prominent among these are temperature, and type of distributor. However with the data presently available it is not possible to properly evaluate these factors.

CHAPTER VI CONCLUSIONS

The data presented in this thesis demonstrate the value of the equation $p = 10^{-KD/Q^{2/3}}$ for predicting the treatment that domestic or industrial wastes will receive on a trickling filter. The depth and the hydraulic load are physical factors which can be clearly established. For the conditions analyzed K varied from 0.09 for the most difficult to treat industrial waste to 0.75 for municipal waste, and within a much narrower range for each filter or each specific waste.

The newly established equation gives a better correlation between filters using open type plastic media than it does between filters using rock media. The author believes that this is due to the oxygen deficiency that occurs within the rock filter. This conclusion is supported by the results showing the effect of depth on the performance of filters using conventional media.

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