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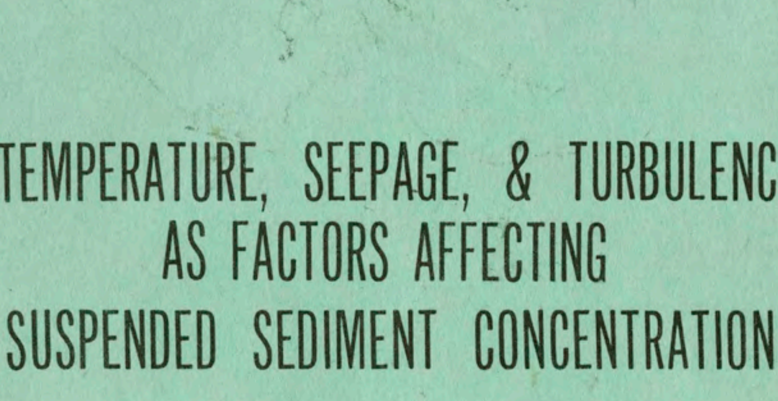
TEMPERATURE, SEEPAGE, & TURBULENCE AS FACTORS AFFECTING SUSPENDED SEDIMENT CONCENTRATION

By

James R. Barton and Maurice L. Albertson



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TEMPERATURE, SEEPAGE, AND TURBULENCE
AS FACTORS AFFECTING
SUSPENDED SEDIMENT CONCENTRATION

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FOREWORD

The studies described in this report were made during the period from October 1950 to August 1951. All testing was done at the Hydraulics Laboratory of Colorado A & M College, Fort Collins, Colorado. The turbulence tank studies were authorized by a contract between the Colorado Agricultural Research Foundation of Colorado A & M College, through the Civil Engineering Section of the Experiment Station and the office of the Chief Engineer, United States Bureau of Reclamation, Denver Federal Center, Denver, Colorado.

Construction of equipment was begun during October 1950 and preliminary testing was begun February 1951. Mr. E. W. Lane and Mr. E. J. Carlson of the Bureau of Reclamation made several inspection trips during the progress of the work so that they were in frequent contact with the project.

Some of the theoretical aspects and part of the dimensional analysis were done by Dr. C. S. Yih. Mr. A. Dad Farmanfarma took the pictures used in the report and Dr. Pin-Nam Lin was frequently consulted during the analysis of the results.

The building of the equipment and all testing were done by James R. Barton, research associate and Robert H. Wilde, research assistant. Part of the precision shop work was done by Mr. Lyle Wiggen, supervisor of the shop at the Hydraulics Laboratory.

The report was written by Mr. James R. Barton and all work was done under the supervision of Dr. Maurice L. Albertson.

ABSTRACT

One of the main objectives of the turbulence tank studies was to accumulate information which could eventually be applied to design problems. Because of the success of other experimenters in using the turbulence tank principle to study certain phases of sedimentation, a turbulence tank was constructed to study the effect of temperature and seepage on the load of suspended sediment and the effect of turbulence on fall velocity of sedimentary particles. These three subjects were investigated in the turbulence tank at Colorado A & M College. The following paragraphs briefly describe the results of the experiments.

A variation of temperature resulted in a change of the average concentration C of suspended sediment. An increase in temperature decreased the average sediment concentration, although several factors were involved in the change. The tests showed that the ratio C/c_o can be predicted according to the equation

$$C/c_o = \frac{\epsilon}{wh} \left(1 - e^{-\frac{wh}{\epsilon}}\right).$$

Analysis of the data indicated that the mixing coefficient for a given sediment size remained constant with variations in temperature. Although the depth of water h was held constant so that the ratio C/c_o was simply a function of the fall velocity w, c_o was also affected by temperature. This relationship, however, was not completely evaluated. The sediment concentration in the upper region of the tank always decreased with an increase in temperature while the concentration curve extrapolated to the bed (where $c = c_o$) increased. With a given increment of temperature increase the percentage increase in c_o was higher for the 60-micron spheres than it was for the 20-micron spheres. However, the region in the tank affected by the increase in c_o was smaller for the 60 micron spheres. Since the equation involves factors which are not ordinarily known, Fig. 18 is the most useful plot in determining the effect of temperature on the suspended sediment concentration.

The seepage studies as summarized in Figs. 21 and 22 showed that for seepages of 2 cu ft/day/sq ft or less, the effect on average sediment concentration was less than 4 percent. However, as the rates increased, the effect on sediment concentrations became more evident. Although large seepage rates out of the tank seldom affected the concentration more than 20 percent, large seepage rates into the tank caused changes of as much as 100 percent. Since the effect was much more pronounced for the 20-micron glass spheres than for the 60-micron spheres, the results imply that as the seepage velocity approaches the fall velocity of the particles, the concentration of sediment is increased or decreased markedly depending on the direction of seepage.

Analysis of the effect of turbulence on fall velocity posed many difficult problems. The comparison made in this report is believed to be logical and reasonable although the quantitative results may not be exact. The results show that the effect of turbulence on the fall velocity of flat particles was considerable. In fact the turbulence increased the effective fall velocity as much as 25 percent when the mean sized particle normally settled with a Reynolds number of less than 2.0. No tests were made for Reynolds numbers exceeding 2.0.

Although it is believed that the results of this experiment can be applied to field problems, more research is needed to adequately define the effects of temperature, of seepage, and of turbulence on the fall velocity. More tests on temperature, seepage and turbulence could be effectively run in the turbulence tank, but data on the effects of temperature should also be gathered in a flume.

INTRODUCTION

With an increase of irrigated agriculture in the west, the problem of sedimentation in rivers and canals has become a real threat to the success of many irrigation projects. As the problems of scour and deposition of sediment in canals, deposition in reservoirs, and erosion of top-soil become more pronounced, the need becomes greater and greater for the engineer to find solutions to the problems of sediment transportation and deposition. In recent years much progress has been made in the field of practical solutions, but many of these answers are specific and not generally applicable to all situations. For this reason, many difficult problems remain unanswered.

Nearly 20 years ago the Soil Conservation Service launched an extensive program of research in the field of sedimentation. Part of this program was reported by Rouse (1) who used a circular turbulence jar, similar to that of Hurst (2), to create a uniform turbulent mixing coefficient throughout the system. The results of this experiment agreed closely with the mixing length theory of suspension of sediment and the later work of Dobbins (3) contributed further to the subject.

Although Rouse and Dobbins determined the effect of particle size and turbulent mixing upon concentration of sediment, there remained to be determined the influence of temperature (viscosity), seepage, particle shape, and size gradation.

Because of the promising results of these previous experiments and the indication that much remained to be learned from similar studies, the Bureau of Reclamation has launched a sedimentation program intended to obtain information which can be used in the actual design of irrigation projects. The progress which has been made in the fields of measurement of sediment and of stable channel design is very encouraging, but there are still many conditions for which little or no fundamental data are available.

With the object of amplifying their research program, the Bureau of Reclamation contracted with Colorado A & M College to carry out fundamental studies in a turbulence tank on the following subjects:

1. The effect of temperature on the suspended sediment concentration for a given condition of turbulence.

2. The effect of seepage on the suspended sediment concentration.
    a. For seepage out of the canal
    b. For seepage into the canal
3. The effect of turbulence on the fall velocities of particles of different shapes.
4. The effect of various mixtures (size graduation) of the bed material on the suspended sediment concentrations.

Owing to difficulties which arose during the first three subjects of the experiment, no time was available to complete subject number four.

All phases of the experimentation were performed in a glass-walled turbulence tank which was designed to produce uniform turbulence in the liquid in the tank. Both Rouse and Dobbins used an agitator having a vertical motion to create turbulence, whereas the present experiments were conducted using an agitator with a horizontal motion.

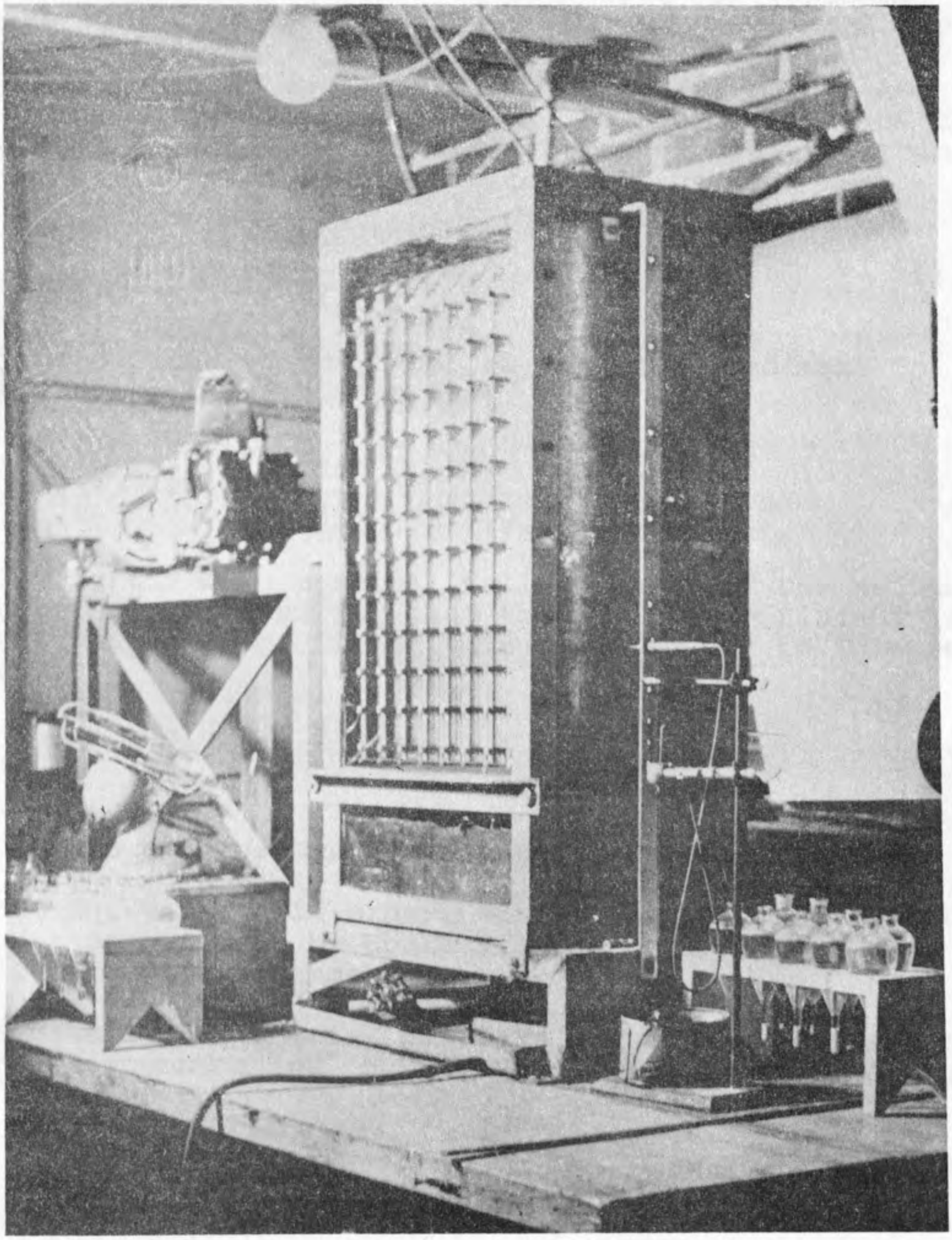


Fig. 1

General View of Turbulence Tank and Auxiliary Equipment

THEORETICAL AND DIMENSIONAL ANALYSIS

The fundamental equation of diffusion for sediment expresses the rate N of upward movement of sediment per unit area in terms of the mixing coefficient ϵ and the gradient of sediment concentration dc/dy where c is the concentration at a point and y is the distance of the point from the boundary in the direction of sediment transport. This equation is expressed as follows

$$N = -\epsilon \frac{dc}{dy} \qquad (1)$$

and may be equated to the rate cw at which sediment is falling through the fluid so that

$$cw = -\epsilon \frac{dc}{dy} \qquad (2)$$

where w is the mean terminal fall velocity of the sediment in suspension. By assuming that the mixing coefficient is uniform throughout the fluid, this equation may be integrated to give

$$\frac{c}{c_a} = e^{-\frac{w}{\epsilon}(y-a)} \qquad (3)$$

where c_a is a concentration at some depth "a" above the bed.

That Eq. 3 is valid experimentally as well as theoretically, has been proven by Rouse (1) for natural sediments having a narrow size range.

To determine the total quantity of sediment in suspension an average concentration C may be used over the depth h of the fluid so that

$$Ch = \int_0^h c\,dy \qquad (4)$$

which may be combined with Eq. 3 to give

$$C = c_a \int_0^h e^{-\frac{w}{\epsilon}(y-a)}\,dy \qquad (5)$$

By assuming that ϵ is again independent of y, and letting $a = 0$, Eq. 5 may be integrated so that

$$C = c_o \frac{\epsilon}{wh} \left(1 - e^{-\frac{wh}{\epsilon}}\right) \tag{6}$$

where c_o is the concentration at $a = 0$.

Evidently, the average concentration throughout the fluid depends only upon the concentration c_o and the dimensionless parameter ϵ/wh which is a ratio of the upward diffusion of sediment to the fall velocity of sediment over the distance h. The concentration c_o is determined by extrapolating the sediment concentration curve to the point where $y = 0$.

Although Eq. 6 is apparently quite simple and sufficient to express the average concentration C, the hypothetical concentration c_o depends upon the properties of the sediment and the fluid as well as the distance of the bottom of the agitator from the bed itself. The average concentration was very sensitive to the distance between the bed and the bottom of the agitator. Because no analytical expression exists for the effect of these variables upon the concentration c_o, which in turn influences the average concentration, dimensional analysis may be employed to systematically arrange the variables involved. The average concentration C may be equated to the following function

$$C = \phi_1 (h, e, \epsilon, w, \sigma, sf, \rho_s, \rho, \mu) \tag{7}$$

and arranged in dimensionless form as

$$C = \phi_2 \left(\frac{h}{e}, \frac{\nu}{wh}, \frac{\epsilon}{wh}, \sigma, sf, \frac{\rho_s}{\rho}\right) \tag{8}$$

where

e - distance from bed to bottom of agitator,
ν - kinematic viscosity of suspending fluid,
σ - standard deviation of fall velocity of sediment particles,
sf - shape factor of sediment particles,
ρ - density of suspending fluid,
ρ_s - density of sediment particles.

If ρ/ρ_s is held a constant throughout the studies and sf and σ are assumed to be of secondary importance, then

$$C = \phi_3 \left(\frac{h}{e}, \frac{\nu}{wh}, \frac{\epsilon}{wh}\right) \tag{9}$$

or

$$C = \phi_4 \left(\frac{h}{e}, \frac{\nu}{\epsilon}, \frac{\epsilon}{wh}\right) \tag{10}$$

Since ϵ is assumed to be constant as long as the size, arrangement, and motion of the agitator is unchanged, the different parameters may be varied by varying the size of sediment, the distance e, and the temperature of the fluid. For a given sediment size, the effect of viscosity on concentration may be studied by varying the temperature, and the effect of proximity of the agitator to the bed may be studied by varying h/e. Likewise, the effect of sediment size on concentration may be studied when h/e and temperature are held constant.

When the effects of seepage are to be studied, Eq. 9 becomes

$$C = \phi_5 \left(\frac{h}{e} \quad \frac{\nu}{wh} \quad \frac{\epsilon}{wh} \quad \frac{P}{w} \right) \qquad (11)$$

where P is the seepage rate in terms of velocity. If the effect of seepage upon concentration is to be studied, then it is necessary to hold all other parameters in Eq. 11 constant and vary only P/w.

EQUIPMENT AND PROCEDURE FOR TESTING

After considerable discussion of the relative merits of horizontal motion versus vertical motion of the agitators, the horizontal motion was selected as most desirable because it permitted the lattice to move at a constant distance from the bed. Such a design required a rectangular shape for the tank and therefore the area of the bed was increased over the area used in previous investigations.

Once the equipment was constructed, the testing consisted of two phases, (a) the preliminary testing using natural sand and (b) the final testing using spherical glass beads and vermiculite.

Construction of equipment

The tank in which the testing was performed consisted of a 1 1/2-in. angle framework with 1/4-in. plate brass on the ends and the bottom while the two sides were covered with 3/8-in. plate glass to facilitate observation. The tank had the following inside dimensions: 12 in. wide by 18 1/2 in. long by 36 in. high. The principal details and essential operating features of the tank are all shown in Fig. 1.

The agitator was composed of a series of eight grids which were connected to a horizontal shaft on 2-in. centers and each grid was made of 5/16 in. aluminum square bars on 2-in. centers each way.

The agitator was driven by a 1/3-hp, 60-cycle, 110-volt A.C. motor coupled directly to a torque converter. By means of the hydraulic torque converter, the speed of the shaft could be regulated so that the frequency of agitation within the tank could be controlled accurately between 0 cycles per second and 5 cycles per second. Although the frequency of agitation could be readily changed to vary the velocity of the eddies, the size of the eddies was a function of the 2-in. grid and lattice spacing and the 5/16-in. aluminum square bars making up the grid. Since the construction of the eight grids was a major undertaking, only one grid size was used. By adjusting the connecting rod in a slot on a cam fastened to the drive shaft, the stroke of the reciprocating shaft could be adjusted to any length between zero and 1 15/16 in. By this means the degree of turbulence in the tank could be controlled to some extent.

A 6-in. space was left in the tank below the bottom of the agitator to disperse seepage water which was involved

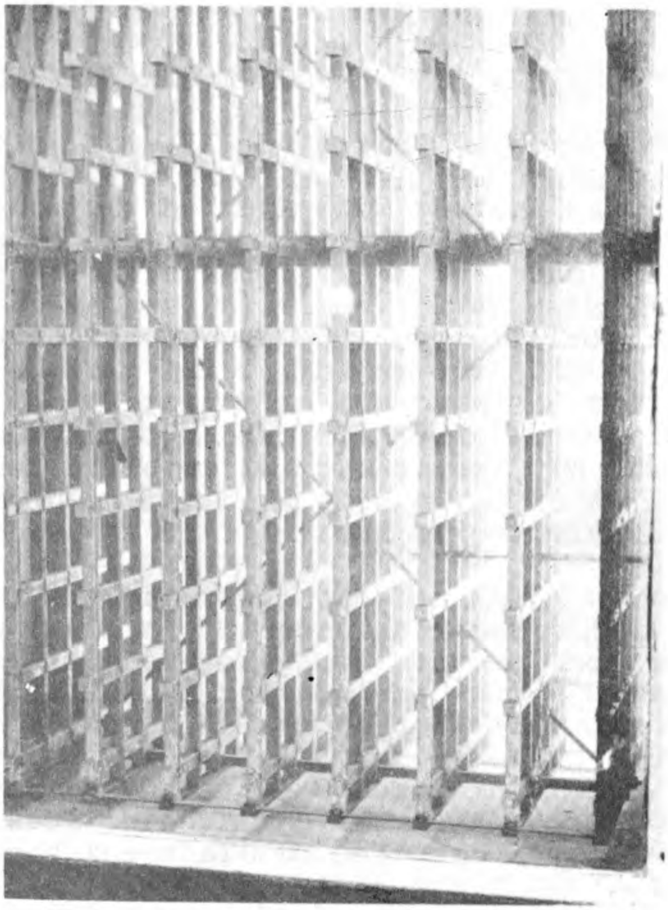
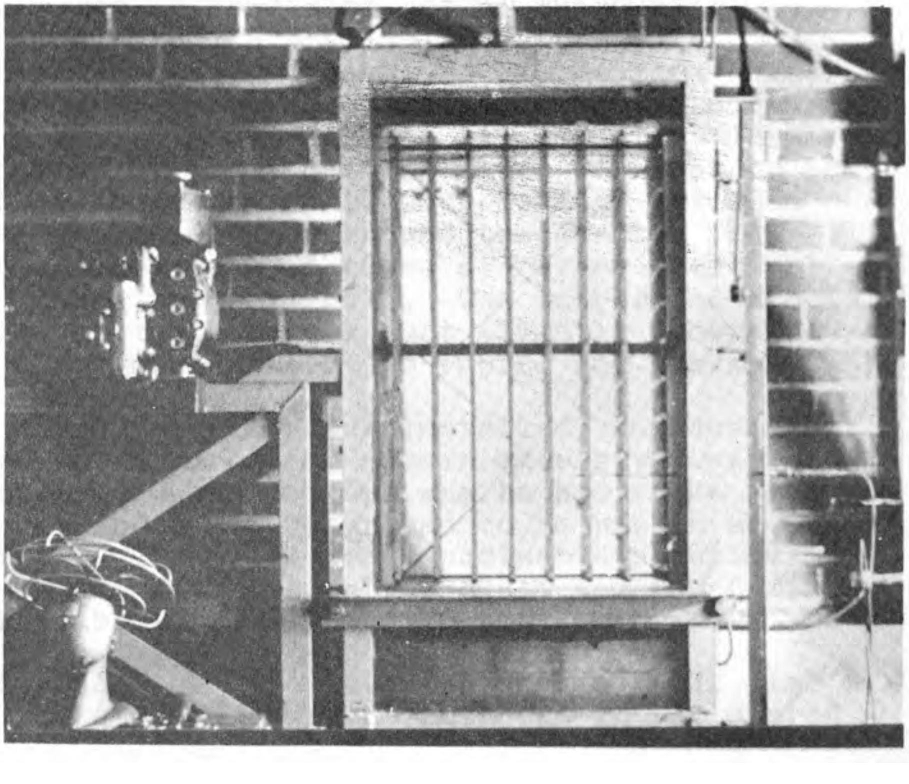


Fig. 2

Agitator Construction
and Bracing.
Sampling Tube at
Lower Right.

Fig. 3

Front View Showing
Lattice Bracing
and Position of
Sampling Tube.



during some of the tests. A porous false bottom, consisting of porous porcelain, 1/4 in. thick, was sealed in the bottom of the tank with roofing tar. The porous porcelain was not entirely satisfactory because it cracked quite easily, owing to vibration, when the tank was in operation and required patching several times. Even with this disadvantage, however, the porcelain proved more satisfactory than a reverse filter or chamois skin. The reverse filter completely failed because of the vibration in the tank and the chamois skin was unstable and, although carefully reinforced, it deflected too much under differential pressures. In future seepage experiments consideration should be given to carborundum plate or other porous material instead of porcelain.

The principal problem which arose regarding construction was making the apparatus water tight. A double strip of raw black rubber was glued between the steel framework and the 3/8 in. glass plate. When water pressure was applied, the rubber acted as a good seal although a few minor leaks were covered with a fillet of aquarium putty around the inside edges of the glass sides. Initially, there was considerable leakage through the endwalls around the agitator shaft. Sand caused the shaft to wear and leak even more. Sealing of the 1/2 in. stainless-steel shaft was solved by the use of 1/2 in. rubber O-rings which were set in machined grooves in a block of half inch brass plates surrounging the shaft. The rings worked most efficiently when the groove width was one quarter of an O-ring diameter oversize and the diameter of the groove was about 0.005 in. smaller than the outside diameter of the O-ring. To keep sediment particles out of the O-rings it became necessary to install a small plastic pressure compartment which was sealed to each end of the tank where the shaft entered the O-ring. The dimensions of the compartment were 4 in. by 3 in. by 1/4 in. deep in the direction parallel to the shaft. A head of about 4 ft of water was kept on the compartment so that there was continuous leakage into the tank through the small clearance around the shaft. The seepage was also controlled by a piece of rubber sheet on the inside wall of the pressure cell. The rubber had a hole cut for the shaft but the hole was just slightly undersize so there was no clearance between the rubber and the shaft.

Before the pressure cells were installed, the sediment particles entered the O-rings and caused excessive wear on both the shaft and the O-rings. New shafts had to be machined about every 50 runs and new O-rings had to be put in about every 10 or 15 runs. The pressure compartments practically eliminated wear on the stainless steel shaft and new O-rings were required only about every 30 or 40 runs.

Concentration samples were taken through a horizontal brass withdrawal tube which could be inserted in any one of

10 openings arranged vertically at various elevations in the end of the tank. Each hole was fitted with a copper tubing connector which had a 5/32-in. hole for the withdrawal tube.

The withdrawal tube was 5/32-in. outside diameter and 3/32-in. inside diameter and extended inward approximately to the center of the tank. A rubber flap, glued to the wall above each hole, extended over the hole to prevent leakage when the hole was not in use. Although small flap valves were quite effective in preventing leakage, whenever the holes did leak a small brass cap was screwed on the connector to stop any remaining leakage.

The outlet end of the withdrawal tube was placed about two feet below the surface of the water in the tank. At this point, measuring tubes filled in approximately 15 seconds so that the size of the sample was essentially the same as it was for other elevation settings. Sampling heads larger than 24 in. gave erratic results because of the short sampling time. Although smaller sampling heads resulted in consistently uniform size samples, the time of sampling was excessive and would have considerably increased the time required for a test.

The sediments used in the experiments were of three general types, ordinary river sand, ground vermiculite, and manufactured glass spheres. The sands were separated by fall velocity methods into fairly narrow size ranges and were used in the preliminary phases of the temperature studies. The size analysis was made with a forty power microscope by measuring at random 500 particles from each sample. Experience indicated that 250 measurements gave answers within one percent of the 500 measurements so during the size determination of the glass spheres only 250 individual measurements were made for each sample. In plotting the size distribution curves, the microscope measurements were converted to percents by weight. Vermiculite was used in the study of the effect of turbulence on the fall velocity and the size distribution of the vermiculite was made by a sieve analysis. Size distribution curves for the sediments are given in the Appendix in Fig. 24.

Sediment samples were gathered in measuring tubes of 100 ml capacity as shown in Fig. 4. The sediment collected in the tubes and settled to the bottom which was specially formed to give the volume of sediment in the 100 ml sample. There were four types of tubes, calibrated for sediment concentrations of 0.2 ml, 1.0 ml, 1.5 ml, and larger than 1.5 ml. This method proved to be quite satisfactory although not all tubes were accurately calibrated so that some had to be discarded. Tubes of different shaped bottoms did not always give identical sediment samples, and although all

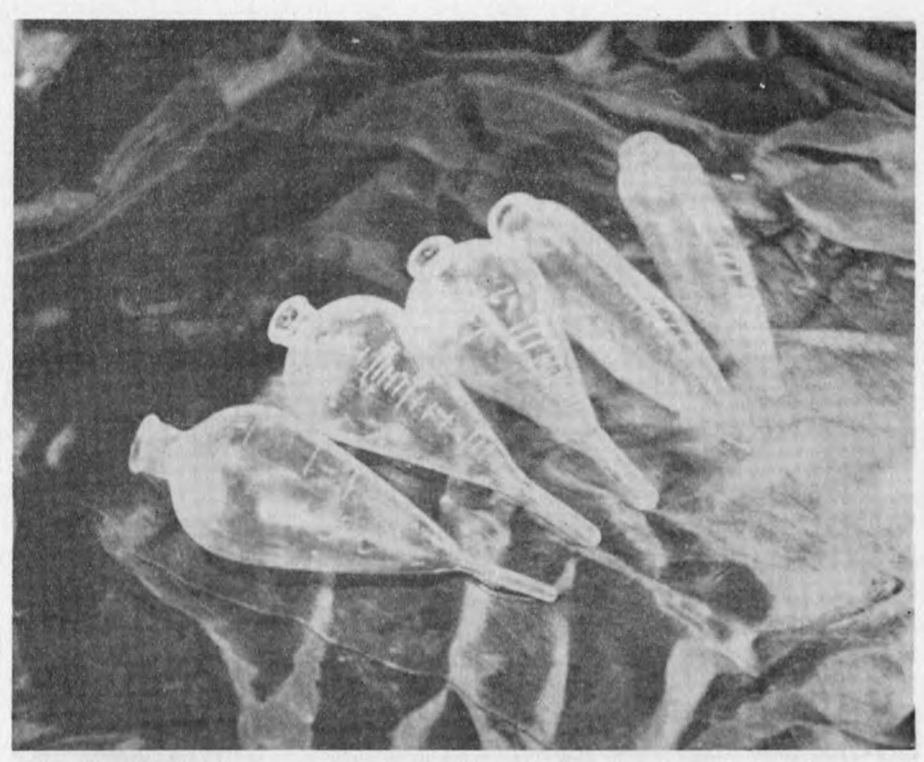


Fig. 4

Various Types of Measuring Tubes Used in Turbulence Tank Experiments

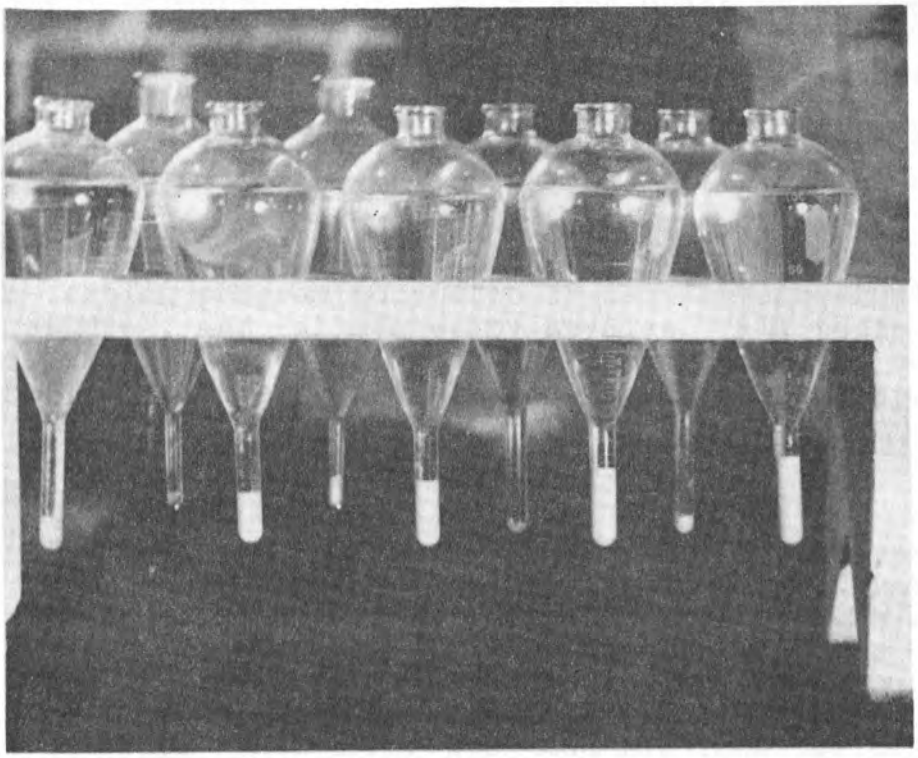


Fig. 5

Set of Samples from One Run Showing Decreasing Sediment Percentages at Increasing Elevations from the Bed. Front Right Tube, Lowest Elevation; Rear Left Tube, Highest Elevation.

tubes were calibrated with water from carefully graduated pipettes, no allowance was made for possible difference in the readings for actual sediment concentrations.

Preliminary tests indicated that longitudinal diagonal bracing was necessary to eliminate the bending in the agitator. Because the bracing had a definite effect on the results, the data recorded before the installation of the bracing were not used. The bracing stiffened the lattice so that the mixing process was increased, thereby increasing the sediment concentration. Early runs which were repeated after the bracing was installed showed larger sediment concentrations. Also during preliminary testing it was found that the torque converter had to be cooled in order to hold it at constant speed. This was accomplished by a small fan set below the converter.

Testing procedure

The testing program consisted of temperature studies, seepage studies, and fall velocity studies. All tests were performed using the following standard procedure and certain additional procedures were employed for the seepage studies and the fall velocity studies.

Temperature studies

1. The sediment bed was smoothed and the distance from the bottom of the agitator to the bed was measured at 15 points while the agitator was at rest. The average of these measurements was used as the value of e. The results of the measurement of e were reproducible within 2 to 5 percent. When a run was made for long periods of time, the bed near the ends of the tank scoured considerably and piled up near the center. This was probably the result of secondary currents and so by scraping the bed after each run this unfavorable bed condition was prevented from developing.

2. The motor was started and allowed to run about 15 minutes until the temperature of the hydraulic torque converter had reached equilibrium. A fan was then placed under the converter for cooling purposes and the desired speed was set on the converter. If the speed was set when the motor was started, the heating of the oil in the torque converter would cause it to lose speed and the agitator frequency would decrease so a fairly constant converter temperature had to be established before the speed was set. All speeds were

determined by a revolutions counter with a time interval of one minute and although adequate, this system was a bit awkward and time consuming.

3. Sediment samples were collected after the agitator had been running at least 20 minutes. Early tests indicated that 20 minutes was adequate time to establish equilibrium of the suspended sediment in the tank. The temperature of the water in the tank and the speed of the agitator were carefully taken just before the sediment concentration profiles were measured.

4. Sampling started at the bottom sampling hole and proceeded upward. Generally two samples were taken at every other station and since the two samples usually checked, a large number of measurements at each depth was unnecessary. S Samples were allowed to settle in the centrifuge tubes about 20 minutes before the sediment concentrations were read.

5. After smoothing the bottom with the scraper and again measuring e in 15 different places, the desired conditions were established for the next run. Generally this consisted of changing either the temperature or the distance from the agitator to the bed. All sediment in the overflow pan and that which had been washed from the sampling tubes on the previous run was dumped back into the tank to insure against excessive losses of sediment during any one run.

6. Each sediment sample was allowed to settle in the sampling tube for at least 15 minutes. The percent of sediment by volume was then read from a calibrated scale on the side of the tube. To help insure uniform compaction during the testing, each tube was tapped seven to ten times on the table before each reading. Additional data recorded were temperature of the water, speed of the agitator in revolutions per minute, type and size of the glass beads and distance from the top of the bed to the bottom of the agitator. The temperature of the water and the speed of the agitator were determined before and after each set of sediment samples was collected.

Seepage studies:- The procedure used in the seepage studies was the same as for the temperature studies. In this series of experiments, however, the temperature was kept constant at 70°F and the speed of the converter shaft

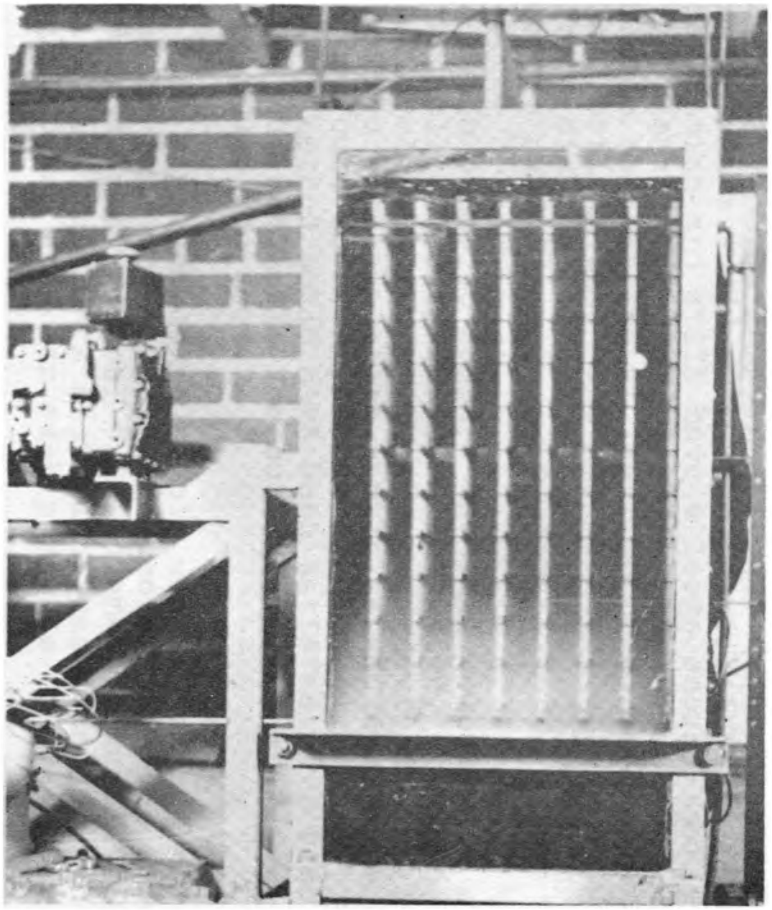


Fig. 6

Sediment Pick-up from
the Bed Shortly After
Starting the Agitator.

Fig. 7

Method of Sampling and
Sediment Distribution
Several Minutes After
Starting the Agitator.

was held at 250 rpm which was 4.17 cycles per second for the agitator in the tank. A series of tests was made on the 60-micron and the 20-micron diameter glass spheres by varying only the amount of seepage. Seepage into and out of the tank was measured in a 1000 cc graduate and all measurements were made at the pipe below the false floor in the tank. Seepage water was fed into the tank thru half inch rubber tubing which was connected to the bottom intake pipe for seepage into the tank and discharged into the top of the open tank for seepage out of the tank. Measurements were made of the hydraulic gradient thru the sand bed but these were considered qualitative only. The piezometer opening at the bottom of the bed became clogged so easily that the time required to establish equilibrium was usually very long and there was no assurance that equilibrium existed at the time the manometer was read.

Fall velocity studies:- The fall velocity studies were designed to determine the effect of turbulence on the fall velocity of particles of irregular shapes. Vermiculite, which is similar in structure to mica, was used because the flat nature of the particles presented a maximum opportunity for the turbulence to affect the fall velocity.

The sample of vermiculite used in the experiments was first put through a grinder. Because a sieve analysis indicated the size was not uniform, it was run through a U.S. No. 40 sieve which eliminated about 50 percent of the vermiculite originally obtained from the Bureau of Reclamation. Although a more uniform size was desirable, the quantity of vermiculite would have been insufficient to permit further separation and still have a large enough sample to use in the turbulence tank. The testing sample was full of fines and had to be decanted at least 30 times before it could be used. The settling time used for decantation was about 10 minutes for a distance of 8 in. The sieve analysis for the actual sample used is shown in Fig. 24.

In order to compare the fall velocity in still water with the fall velocity in turbulent water, a method of determining fall velocity in still water was devised. To pick out several hundred representative particles and drop them one by one was soon found to be impractical. Although some type of elutriation method would have been satisfactory, time and equipment were not available for such tests. Therefore, the following procedure was used.

A representative sample was taken from the vermiculite in the tank with a pair of tweezers and the sample was then dropped in a vertical 6 in. diameter plastic tube filled with distilled water. A stop watch was started when the sample was dropped and then each particle was timed as it passed a line marked on the tube about 28 1/2 in. below the water surface. If the sample was larger than 200 particles, a greater distance was required so that the particles would be spread farther apart to allow time for recording. The recorder held the watch, read the time, and recorded the data; while the observer signalled when each particle arrived at the line on the wall of the tank. Seven samples were dropped and the number of particles in each sample ranged from 29 to 294.

If the time of sampling was longer than 11 minutes, the particles passing the line were so small the observer experienced extreme difficulty in seeing the particles. For this reason, together with the fact that the larger particles should probably be given more weight, the time of sampling was limited to 11 minutes and only those particles traveling the 28 1/2 in. distance during that time were counted. Since most of the particles attained their terminal velocity in a small portion of the first inch, the time of starting the watch as the sample was placed in the water at the surface introduced only a minor error in the results. The results from all of the seven samples were reasonably consistant and, except for a sample with 29 particles, the results were within 25 percent of each other. Since the temperature was not easily controlled in the fall-velocity tank, all fall-velocities were corrected from the observed temperature to a standard temperature of 70°F. The adjustment was made according to the Stoke's equation

$$w_o = \frac{1}{18} \frac{(\rho_s - \rho_w)\, g\, d^2}{\mu} \qquad (12)$$

where

$(\rho_s - \rho_w)$ is the effective density of the particles in water,
d - mean diameter of the sediment particles,
w_o - average fall velocity of the sediment particles.

For comparison purposes, the fall velocities of the vermiculite particles in the turbulence tank were adjusted to 70°F according to Fig. 23 by assuming that the fall velocity varied inversely with the viscosity.

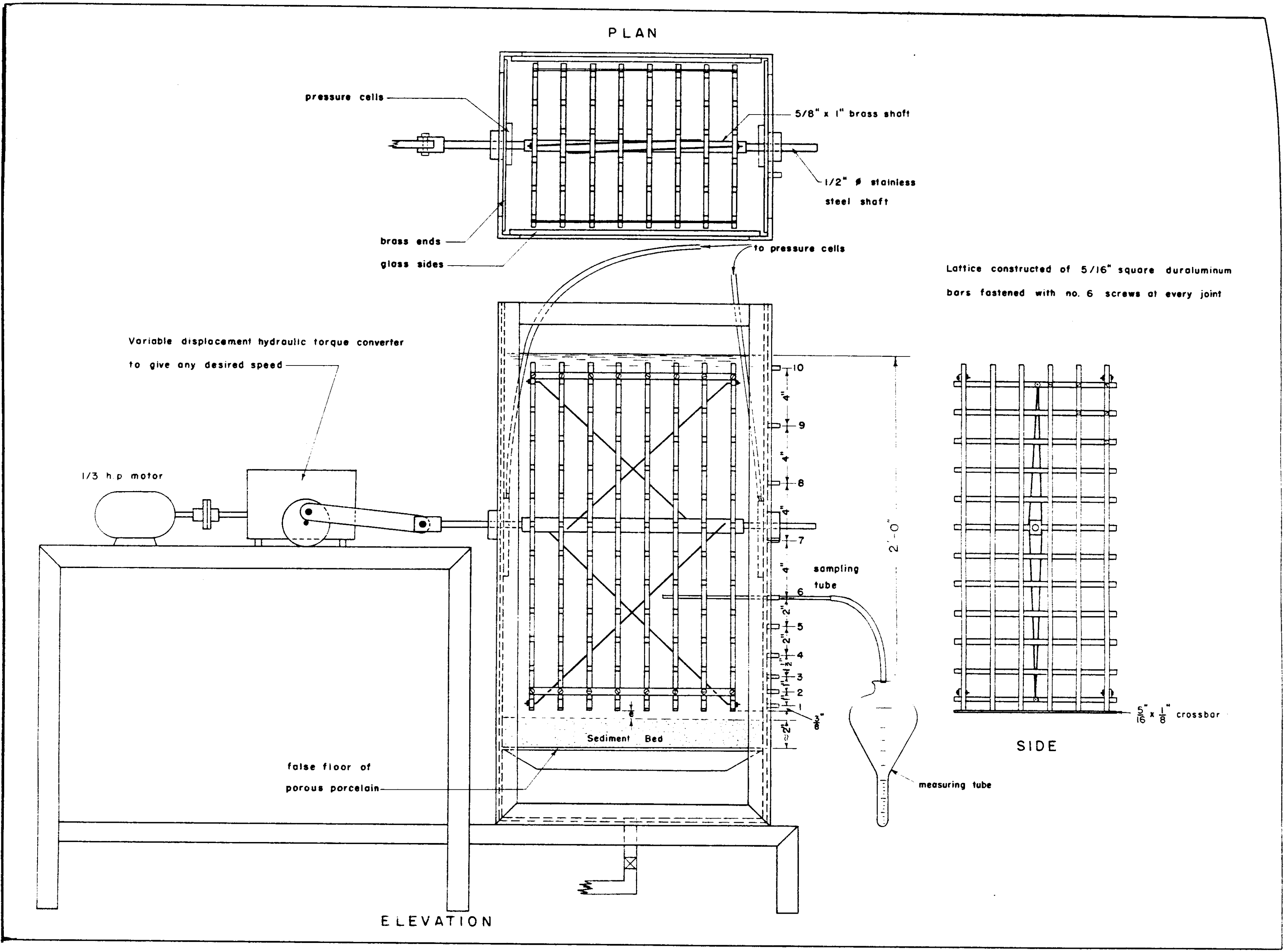


Fig. 8

Schematic Drawing of the Turbulence Tank & Auxiliary Equipment

DISCUSSION OF RESULTS

The results of the tests described in the foregoing section may be divided into the effects of temperature, the effects of seepage, and the effects of turbulence on the fall velocity. Because of the limitations of both time and equipment, these tests are by no means exhaustive or final. They do show certain trends, however, that are very important and in some cases may supply quantitative information which can be used for design purposes.

Fundamental equation for suspended sediment

As discussed earlier, the basic diffusion equation may be expressed as Eq. 3.

$$c/c_a = e^{-\frac{w}{\epsilon}(y - a)}$$

This equation has been verified experimentally by Rouse (1) to be true for a sediment with a narrow size range and for a uniform turbulence or diffusion coefficient . An equation in terms of the average concentration for a vertical section has also been developed in the form of Eq. 6.

$$C/c_o = \frac{\epsilon}{wh}\left(1 - e^{-\frac{wh}{\epsilon}}\right)$$

In Fig. 13, C/c_o is plotted against ϵ/wh and the results indicate that the above equation is valid for the experimental conditions of uniform turbulence. Data from the sediments with a wide size range still fit the plot very well so it appears that a narrow size range is not required. The methods used to determine the values of each of the variables in the equation is explained in the following paragraph.

The depth of water h was measured directly with a scale. For each run, a plot was made of depth y vs concentration c. These plots were on semi-log paper with ordinate y on the arithmetic scale and abscissa c on the logarithmic scale. Each curve was integrated graphically to obtain the average concentration, and the concentration c_o was evaluated by extrapolating the concentration curve to the bed.

The bed elevation was determined before and after each run and although the amount of sediment in suspension caused the bed elevation to change slightly while the agitator was in motion, the bed elevation as measured was the elevation used in the extrapolation of c_o. Several runs were adjusted to correct the bed elevation to running conditions, but the effect on c_o was always less than 3 percent. In plotting the sediment distribution curves, there was always some leeway in choosing the exact location of the curve. This leeway in choice could often affect c_o by more than 3 percent. For this reason no attempt was made to correct the bed elevation to running conditions.

The value of w/ϵ was determined from the slope of the sediment distribution curve on semi-log plots. Analysis of the basic diffusion equation indicates that the slope of the sediment distribution curve is the term w/ϵ. The coefficient of 2.3 enters into the determination as the conversion factor changing from natural logrithms to logrithms to the base 10. A plot of the theoretical equation, Eq. 3, using c vs y results in a straight line on semi-log paper. Most of the data in this experiment did not result in straight lines on semi-log paper, but the vast majority of the sediment distribution curves were straight lines for more than 50 percent of the depth y. In determining w/ϵ, the straight line portion of the curve was used. The deviation from a straight line was much less pronounced in the data for the small glass spheres than for the larger size. However, integration of the curved line fitting all the data and the straight line extrapolated from the data fitting a straight line in the lower half of the tank, resulted in variations of 2 percent or less in the average concentration. Since this was true for the large spheres as well as the small ones, the determination of w/ϵ from the slope of the straight line portion of the curve appeared to be satisfactory.

In summary then the various terms in the equation were obtained from the experiments in the following way:

1. h was measured directly in the tank.
2. C resulted from a graphical integration of the sediment distribution curve.
3. c_o was determined by extrapolating the sediment distribution curve to the bed.
4. w/ϵ was calculated from the slope of the straight line portion of the sediment distribution curve.

Effect of temperature

Since the derived equation for determining the average concentration appeared to fit the data satisfactorily, a study was required to determine the effect of temperature upon each of the variables involved in the equation. In studying the effect on ϵ , Fig. 14 appeared to indicate that for a given size range, ϵ is not effected by temperature. The variation in the results was apparently normal experimental scatter, with the possible exception of the influence of concentration. For example, the method of evaluating ϵ was a tedious process and was probably subject to some error. The value of ϵ/w as calculated from the slope of the sediment distribution curve was multiplied by the fall velocity w to give a value for ϵ . However, w was the fall velocity corrected for the effect of concentration on fall velocity and the steps involved in its calculation may be summarized as follows (4):

1. Using the water temperature and the mean sphere diameter for the sediment sample the fall velocity w_o was calculated from Stokes equation. The plots for w_o are given in Figs. 26 and 27.

2. Using the average concentration, the fall velocity was then corrected according to the equation

   $$w/w_o = 1 + 1.2 \sqrt[3]{c}$$

   where c equals concentration by submerged weight. Since all concentrations were measured in percent by volume, all average concentrations required a conversion to submerged weight. To convert from percent concentration by volume to concentration by submerged weight a porosity of 35 percent was assumed for both sizes of glass spheres. From studies made on the porosity of the glass spheres (5) 35 percent was a reasonable assumption.

In spite of all these preliminary calculations, ϵ for a given size of sediment still appeared to be independent of temperature.

A study of Fig. 14 might imply that ϵ varies with concentration. In order to determine what trend existed between concentration and ϵ , Fig. 15 was plotted dimensionlessly as ϵ/wh vs ν/wh with concentration as the third variable. A study of Fig. 15 indicated that there was no systematic variation of concentration. From Fig. 15 the conclusion was drawn that any effect of concentration on the value of ϵ was within the range of scatter of the data and therefore the effect of concentration was assumed to be negligible.

A plot of C/c_o vs ν/wh and C/c_o vs ν/w_oh is shown in Fig. 16. These curves are drawn as straight lines on log-log paper and the slopes are the same. The slope is 2 to 1 which shows that the concentration ratio C/c_o is a direct function of the viscosity since $\nu/wh \approx \nu^2/h$. The 2 to 1 slope would naturally be expected if viscosity were the only factor affecting C/c_o. Furthermore, this plot also shows that within the Stokes range the ratio C/c_o is inversely proportional to the fall velocity w. A plot omitting fall velocity has been drawn in Fig. 17, where d is the particle diameter in millimeters, h is in feet and ν is in feet squared per second. The fall velocity was eliminated by introducing Stokes equation. However, in order to determine the effect of temperature on the average concentration of suspended sediment, information was needed concerning the change of c_o with temperature.

In order to determine the effect of temperature on c_o, Fig. 18 was constructed. The results of this plot clearly indicate that c_o decreases with decreasing temperature. This phenomenon might possibly be a peculiarity of the turbulence tank, but it supports the theory that for a given amount of turbulent energy dissipated the sediment carrying capacity tends to remain constant. For an increase in temperature, the sediment distribution was changed so that more sediment was in suspension near the bed even though the concentrations considerably above the bed showed a marked decrease.

A study of the typical concentration curves indicated that for the larger glass spheres, an increase of temperature increased the concentration for only the bottom 5 percent of the depth while for the smaller glass spheres the concentrations were increased in the bottom 10 percent of the depth. Since the increase of concentration for increased temperature was usually within the bottom 10 or 15 percent of the depth, the possibility existed that field measurements would tend to miss that portion of the sampling section. Therefore, field measurements might tend to show greater decreases of sediment concentration than actually existed for given increases in temperature.

Fig. 18 also indicates that the actual magnitude of the change of c_o was about the same irrespective of size and of total load. However, for equal turbulence conditions, the percentage change of c_o for a given temperature change was greater for the larger sediment. The change of c_o for a 40 degree change of temperature was approximately 0.25 percent by volume. This concentration change was independent of the size of sediment and of the average concentration. For the 60 micron glass spheres this represented a change of 15 - 20 percent of the value of c_o while for the 20 micron glass spheres the change was only 10 - 12 percent for similar operating conditions in the tank.

In conclusion, the effect of temperature on the concentration of suspended sediment is not a simple relationship. However, the experimental results using uniform turbulence and glass spheres as the sediment, show several definite trends which may be summarized as follows:

1. The equation $C/c_o = \epsilon/wh\ (1-e^{-\frac{wh}{\epsilon}})$ is valid for calculating the average sediment concentration in suspension. This equation fits the data for sand and vermiculite as well for the glass spheres.
2. Temperature does not change the value of the mixing coefficient ϵ for a given size of sediment.
3. The magnitude of c_o, which is obtained by extrapolating the concentration curve to the bed, increases with an increase in temperature.
4. The magnitude of C/c_o may be predicted for given values of viscosity, sediment size, and depth of water.

The following example is included at this point to illustrate the usefulness of the above conclusions. The assumption is made that the following data are available at a given station: (1) average sediment concentration, (2) water depth, (3) water temperature, and (4) average diameter of the suspended sediment based on the intermediate axis for sand grains. From the known data, ν^2/gd^2h may be calculated. By entering Fig. 17 the value of C/c_o may be determined from the curve. Since the average concentration C is known, c_o may be computed. Now assuming that the concentration C is desired for some temperature other than the measured temperature, the new value of ν^2/gd^2h may be determined and from Fig. 17 the new value of C/c_o may be obtained. In order to determine the average concentration C, the value of c_o is required. Although the quantitative effect of temperature on c_o is not known, c_o may be estimated quite logically from the general statement that c_o increases with an increase in temperature. For an increase in temperature of 40 degrees Fahrenheit, an estimated increase in c_o should be limited to 20 percent for sediments smaller than 60 microns in diameter. Of course if c_o is assumed to be constant with temperature, the change of average concentration may be readily determined. In fact if c_o is assumed to be constant with temperature, it may be removed from the abscissa of Fig. 17 and Fig. 17 could be plotted as ν^2/gd^2h vs C. Application of this method should be limited to narrow size ranges of sediments and to sediments found in abundance in the bed material.

Effect of seepage

According to Eq. 11 of the dimensional analysis, curves were plotted for average concentration versus seepage rates with the temperature, the agitator speed, and the ratio h/e held constant for each size of sediment. Although the temperature and the agitator speed were easily controlled, the distance from the agitator to the bed was difficult to control but was held as closely as possible to a standard e. All concentrations were then corrected to a standard e which was selected arbitrarily as 29/64 in.

To approximate more nearly the actual running conditions, all values of e were adjusted to an e_a value which was the distance from the bottom of the agitator to the bed when the agitator was moving. This adjustment was made by multiplying the total depth by the average concentration and subtracting the resulting depth of sediment from the elevation of the bed. A plot was then made of average sediment concentration C vs e_a for all runs with zero seepage. Although there was considerable scatter in the data, a curve approximating the data was drawn as shown in Fig. 19 . From Fig. 19 a standard e_a of 29/64 in. was chosen and Fig. 20 was prepared. By using Fig. 20 the average sediment concentrations for all the seepage runs on the 60 micron glass spheres were corrected to correspond to an e_a of 29/64 in.

Since an adjustment of e to e_a made only a small change in the seepage curve for the 60 micron sediment, no such adjustment was made for the 20 micron material. Furthermore, e was held reasonably constant during all of the runs on the 20 micron sediment.

Fig. 21 was then constructed to show the effect of seepage rates on the average sediment concentrations. The data for Fig. 21 show considerable scatter. Part of this scatter may be a result of the two adjustments which the data suffered. Cracks also developed in the porous bottom and although the cracks were fixed as soon as they were noticed poor seepage distribution may have affected some of the tests.

The seepage curves in Figs. 21 and 22 show that seepage into the canal affects the suspended sediment concentration more than a corresponding seepage out of the canal. Both curves also indicate that for seepage rates in either direction of 3.5 cu ft/sq ft/day or less the average sediment concentration is affected less than 10 percent. However for the small glass spheres, seepage rates into the canal of about 20 cu ft/sq ft/day caused an increase of 100 percent in the average sediment concentration. As the seepage velocity approaches the fall velocity of the sediment, more and more sediment is carried into suspension by the drag on the sediment particles. When the seepage velocity through the sediment exceeds the fall velocity of the sediment particles, the sediment will be carried into suspension independently of the pick-up action of the artificially created turbulence.

Effect of turbulence on fall velocity

The shape of sediment particles is known to have a major influence upon the fall velocity of the particle. A spherical particle on the one hand has a symmetrical and stable flow pattern around it which results in a symmetrical and balanced distribution of pressure. Particles with a flat shape, on the other hand, have an unstable flow pattern so that the slightest change in particle orientation results in side thrusts caused by the unsymmetrical pressure distribution. The general and most usual orientation of flat particles is with the minor axis parallel to the direction of motion. In other words, the particle generally orients itself so that the greatest drag results. The stability of this orientation depends upon not only the shape of the particle but also the Reynolds number of the flow past the particle. As the Reynolds number is increased a separation zone forms behind the particle and becomes increasingly erratic as the Reynolds number increases.

The foregoing discussion describes the motion of particles of various shapes in quiet water only. When the water is turbulent, however, the particles receive intermittant thrusts and accelerations in all directions because of the eddies in the suspending fluid which are moving in a random fashion in all directions. Because the eddies are continually changing the orientation of the particles, the effective fall velocity is, in all probability, changed materially from the fall velocity in still water.

In order to determine the effect of turbulence on the fall velocity of flat particles, a sample of vermiculite sediment was studied. Determination of the type of motion involved in the fall velocities of the vermiculite particles in still water was difficult. As a first approximation, laminar flow was assumed and the Stokes equation was used to determine the sedimentation diameters. This method resulted in sedimentation diameters which indicated laminar flow in the case of most particles. Careful observation of the particles as they fell also implied that the motion was laminar, because of the stability which seemed to prevail as the particles fell. Although there was a definite turbulent motion in the wake of some of the larger particles, most of the particles did not appreciably change their orientation as they fell.

By using the average sieve diameter as the length term in the Reynolds number, the flow was found to be out of the Stokes range for more than half of the particles. However, visual observation did not verify this situation, and owing to their flat nature the particles probably fell more slowly than the sieve diameter indicated. Therefore, the assumption has been made that the particles fell with laminar motion.

Eq. 8 expresses the general variation of average concentration with parameters describing the geometry and various fluid and sediment properties. In order to simplify the expression it may be assumed that σ/w is of secondary importance and ρ_s/ρ and sf are adequately included in the fall velocity. It must be remembered, however, that such simplification may be omitting important variables.

From the plot of local concentration vs depth, the ratio ϵ/w was determined for the vermiculite and ϵ/wh was plotted against average concentration as shown in Fig. 23. By interpolation it was possible then to determine the parameter ν/wh and the fall velocity in turbulent water. The fall velocities had to be adjusted to 70°F for comparison with the fall velocities measured in quiet water. This adjustment was made by assuming that the fall velocity varied inversely with the viscosity. In the following table the fall velocity in turbulent water is compared with the fall velocity in quiet water in terms of percent.

No. of particles dropped	Time of measurement in minutes	Distance travelled by each particle in feet	Average fall velocity of sample in ft/sec	Measured sample in terms of % of volume of total sample*	Fall velocity in the turbulence tank as % of fall velocity in still water
1073	11	2.43	0.0086	100%	190
877	8	2.43	0.01142	95 or more	143
751	6	2.43	0.01342	92 or more	121

* volume is based on the calculated volume of the solids alone.

In spite of the difficulty in determining the true fall velocity of the vermiculite in still water, it is significant that in each case the fall velocity in turbulent water exceeded the fall velocity in quiet water. The table shows that as more of the fine particles are ignored in determining the average fall velocity in still water, the apparent effect of turbulence on the fall velocity decreases. The point at which the comparison between turbulent and quiet conditions should be made is difficult to choose, but apparently it can be safely stated that turbulence does affect the fall velocity of flat particles falling with a Reynolds number of less than 2. Quantitatively a figure of 25 percent increase in fall velocity might be reasonable to use as an indication of the effect of turbulence on the fall velocity as compared to the fall velocity in still water.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Temperature has certain effects on the concentration of suspended sediment.

   a. The average concentration of suspended sediment increases with a decrease in temperature and decreases with an increase in temperature. For uniform turbulence and a fairly narrow size range, the average concentration in a vertical section may be predicted according to the equation:

   $$C = c_o \frac{\epsilon}{wh}\left(1 - e^{-\frac{wh}{\epsilon}}\right)$$

   b. The mixing coefficient ϵ is independent of temperature but is a function of the fall velocity of the sediment.

   c. The concentration c_o increases with an increase in temperature and decreases with a decrease in temperature. However, the percentage change of c_o becomes smaller as the size of the sediment decreases.

2. Seepage has an effect on the suspended sediment concentration.

   a. For the sediments tested, a seepage into or out of the tank of 3.5 cu ft/sq ft/day changes the average sediment concentration by less than 10 percent.

   b. Large seepage rates into the tank increase the suspended sediment concentration considerably more than large seepage rates out of the tank tend to decrease the concentration.

   c. As the velocity of seepage into the tank approaches the fall velocity of the sediment particles, the average concentration may be increased by more than 100 percent over the average concentration for no seepage.

3. Turbulence increases the fall velocity of small flat particles when the Reynolds number is less than 2.0.

Recommendations

1. The temperature studies made in the turbulence tank should be correlated with data from flume experiments. A correlation of this type would result in information which could be applied more accurately to actual field conditions.

2. The scatter in the seepage studies could probably be decreased by using a different type of porous bottom which would withstand vibration better than the porous porcelain.

3. By using a vermiculite sediment with a very narrow size range, more accurate information could be obtained on the effect of turbulence on fall velocity.

4. Studies on the effect of size range of sediments (as expressed by the normal standard deviation) on the suspended sediment load could be effectively conducted in the turbulence tank.

5. Experiments could also be performed determining the effect of various mixtures of sizes in the bed on the suspended sediment load.

6. The turbulence tank offers real promise in studying the effect of various fluid environments on the suspended load.

    a. Various solutions involving different dispersing agents could be used as the fluid media. The pH of the suspending media may be important.

    b. Various mixtures of clay suspensions could be used as the suspending media to study their effect on the concentrations of silts and sands.

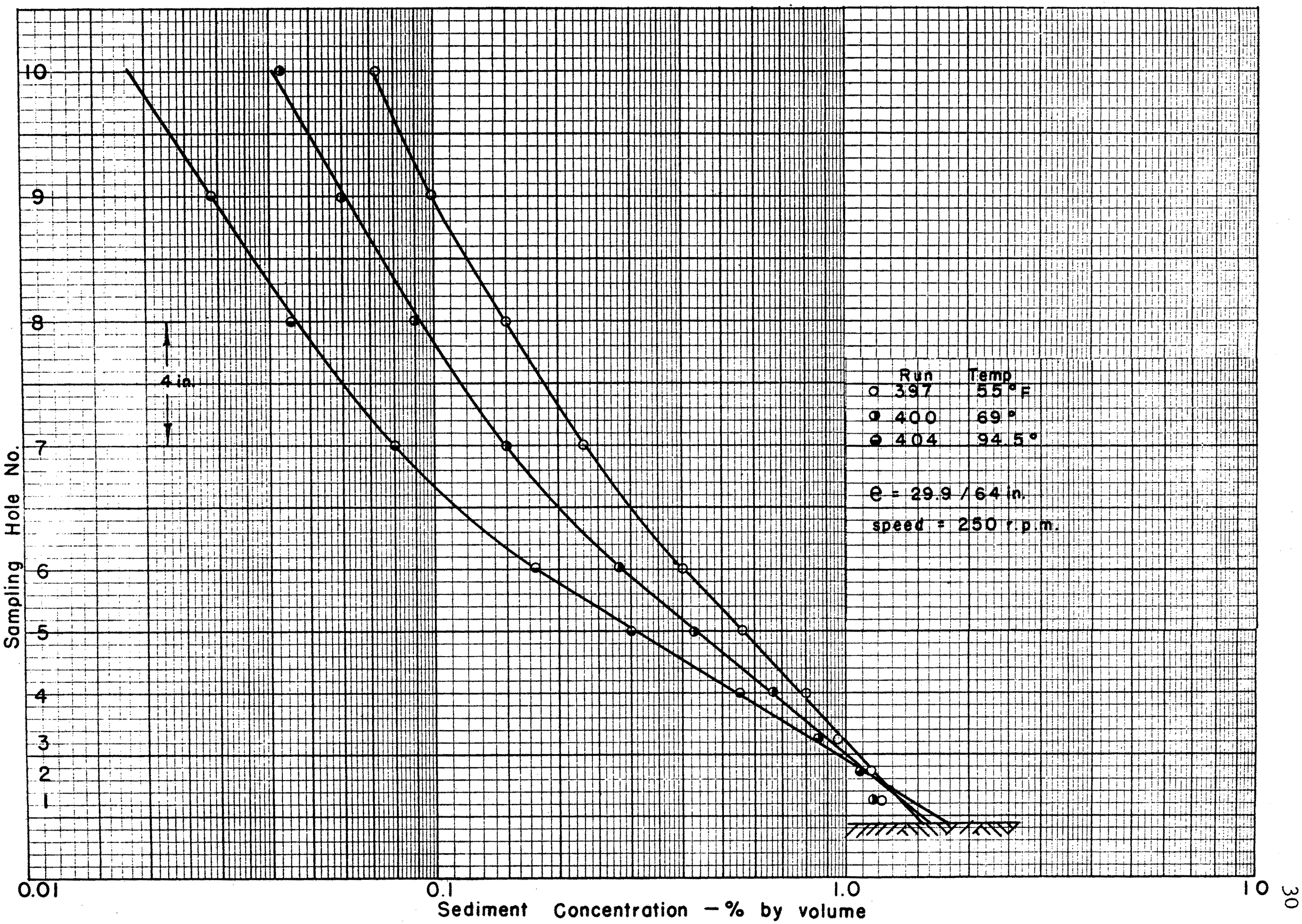
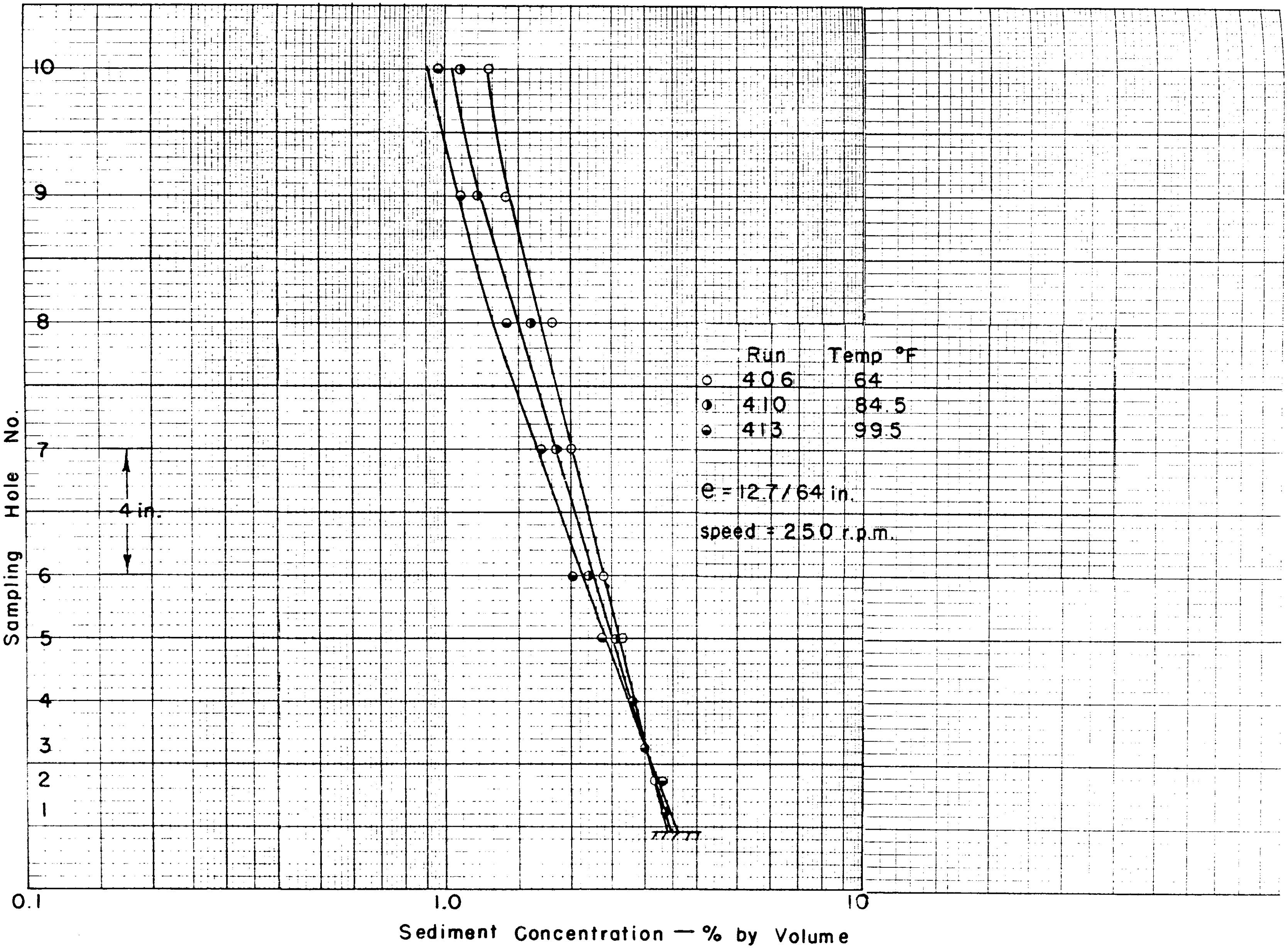


Fig. 9

Typical Concentration Curves
Showing the Effect of Temperature on Concentration
for 60-Micron Glass Spheres



Typical Concentration Curves
Showing the Effect of Temperature on Concentration
for 20-Micron Glass Spheres

Fig. 10

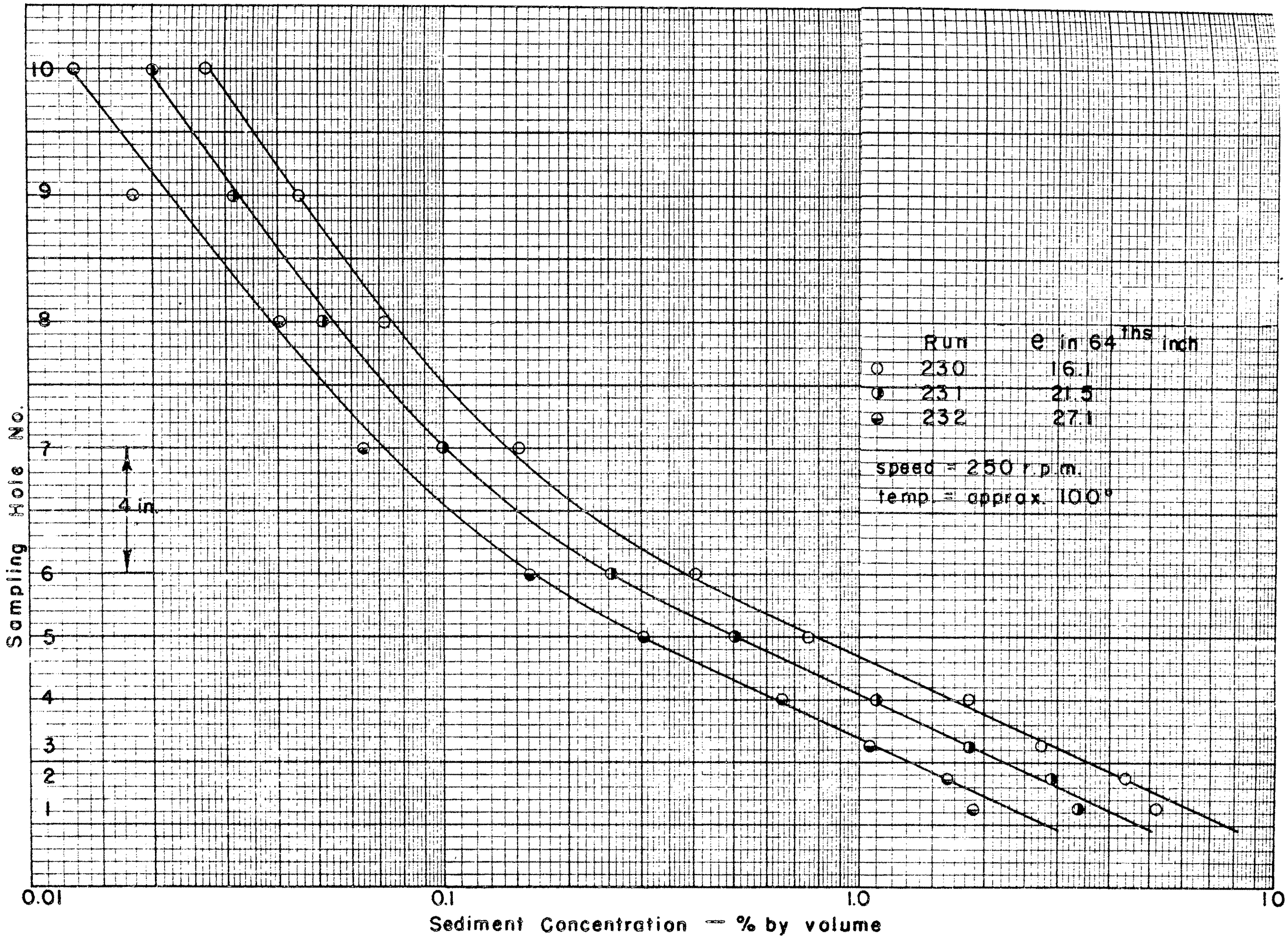


Fig. 11

Typica Concentration Curves
Showing the Effect of "e" on Concentration
for 60-Micron Glass Spheres

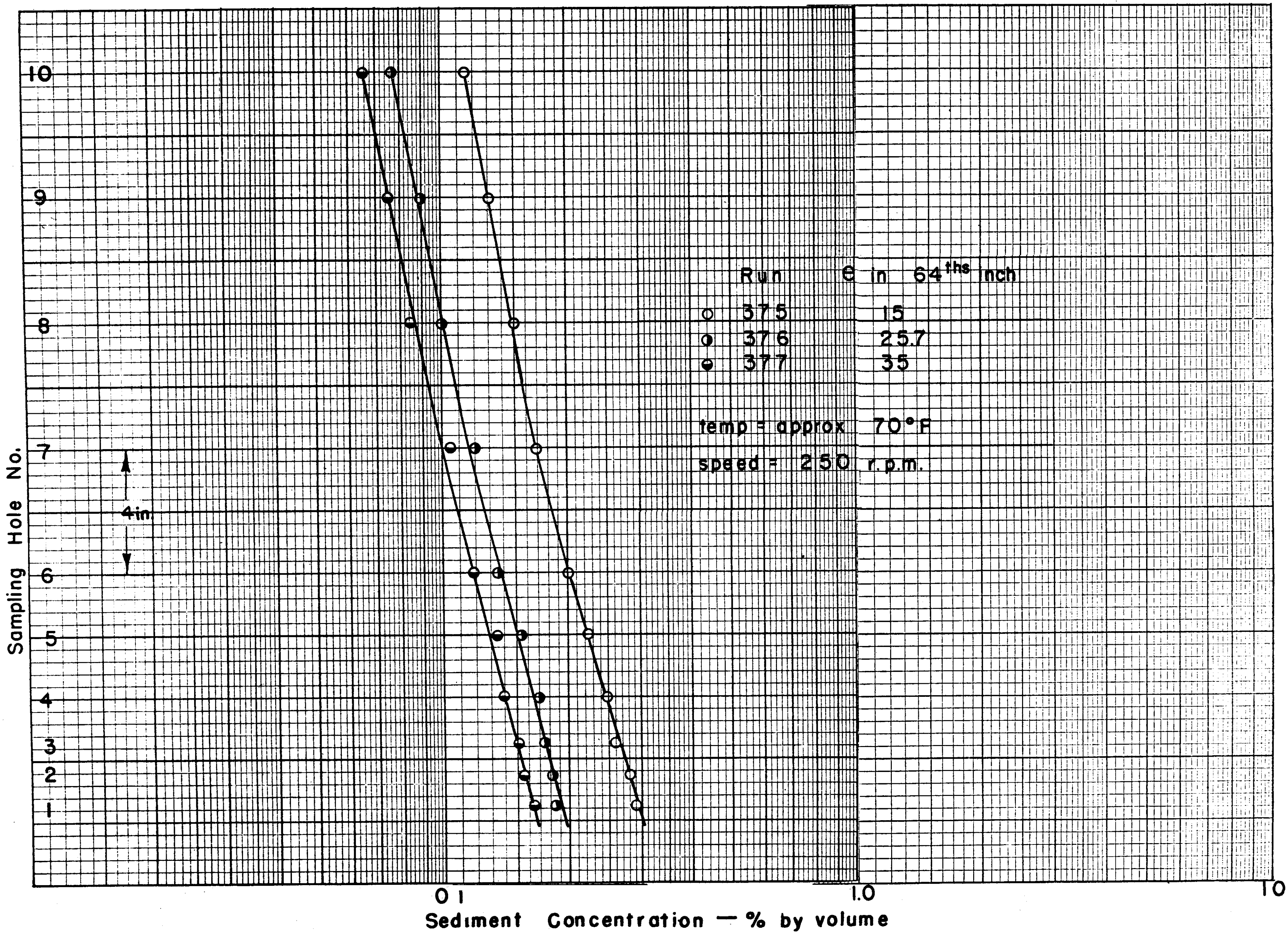
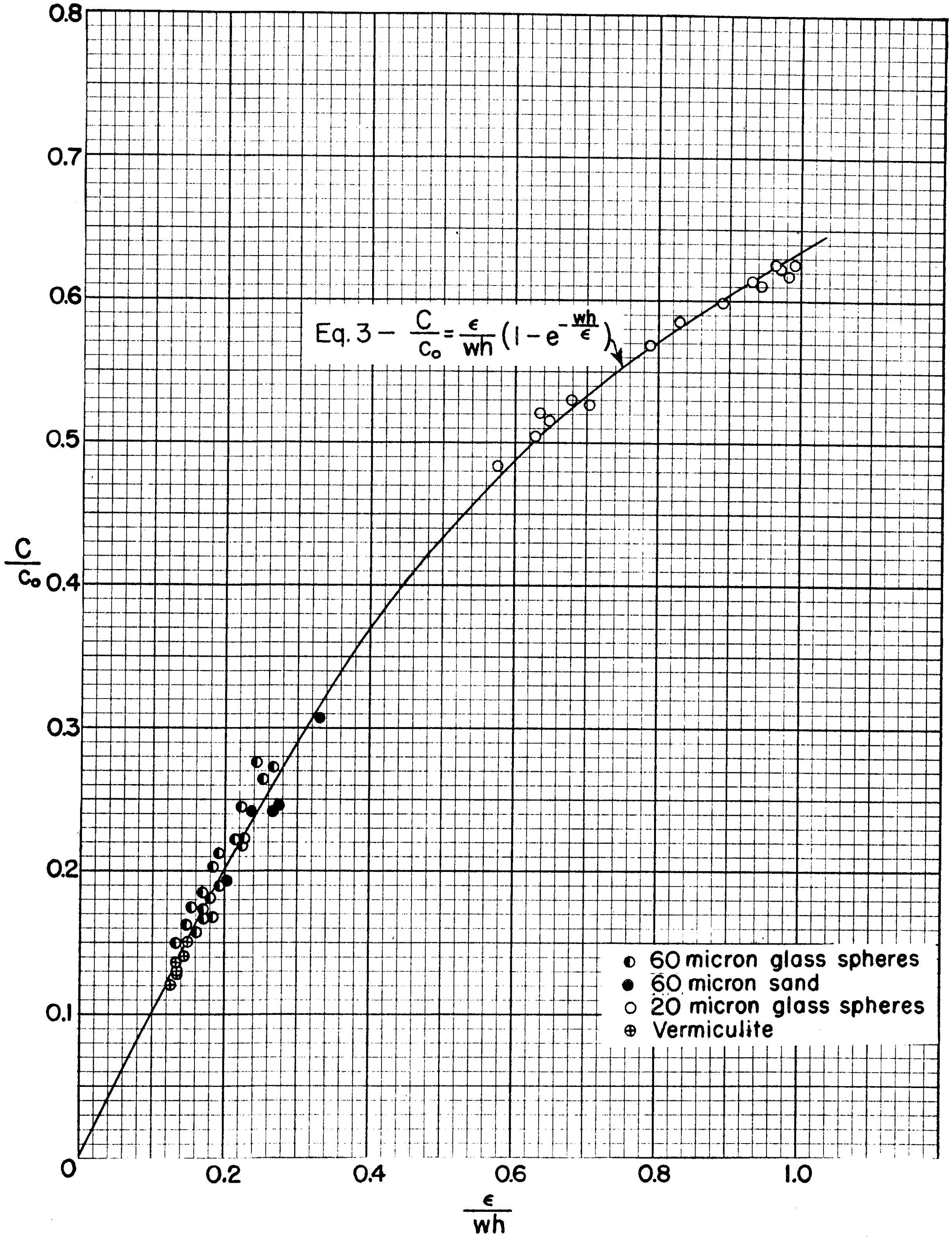


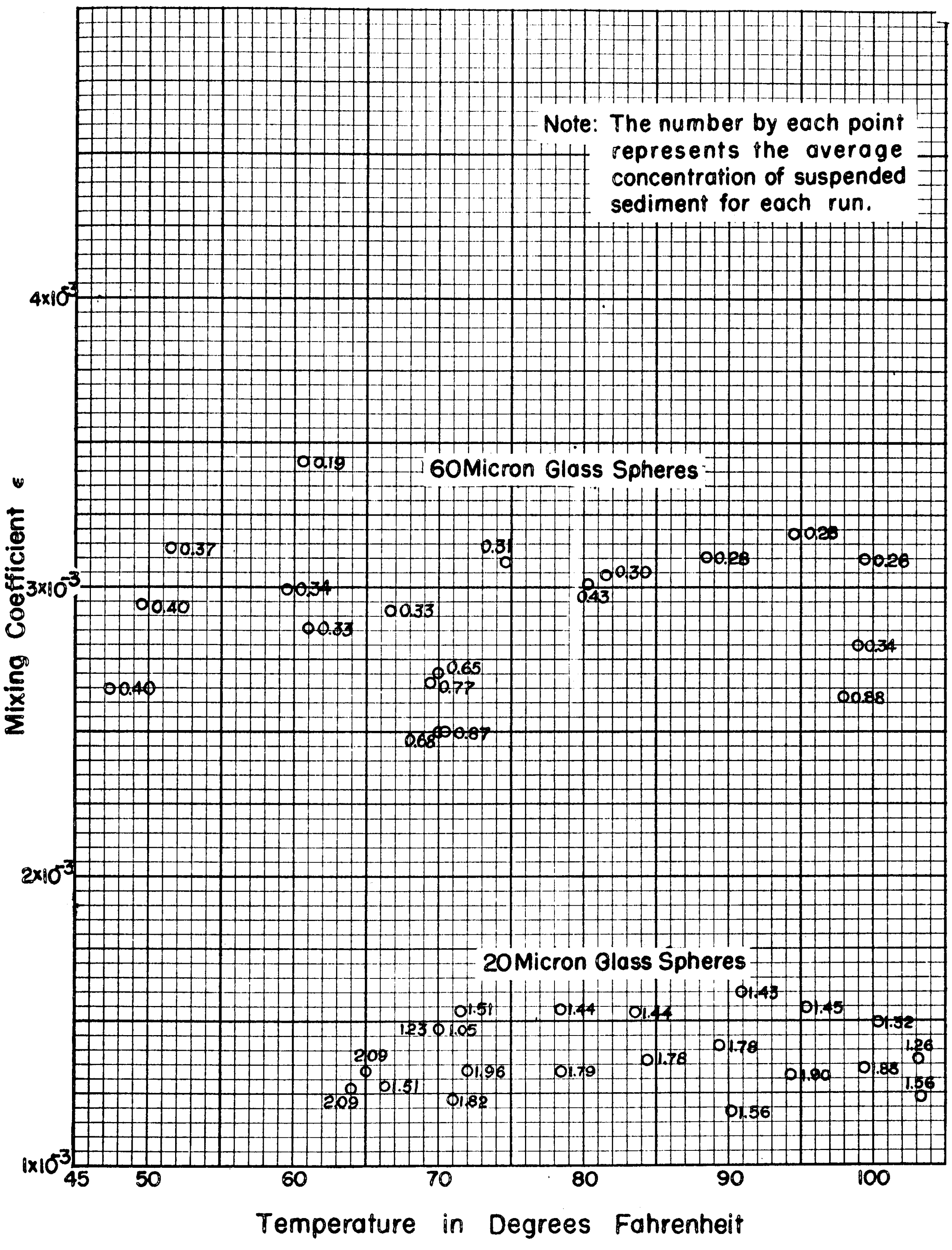
Fig.12

Typical Concentration Curves
Showing the Effect of "e" on Concentration
for 20-Micron Glass Speres



Comparison of Data with the Theoretical Equation

Fig. 13



Effect of Temperature on the Mixing Coefficient

Fig. 14

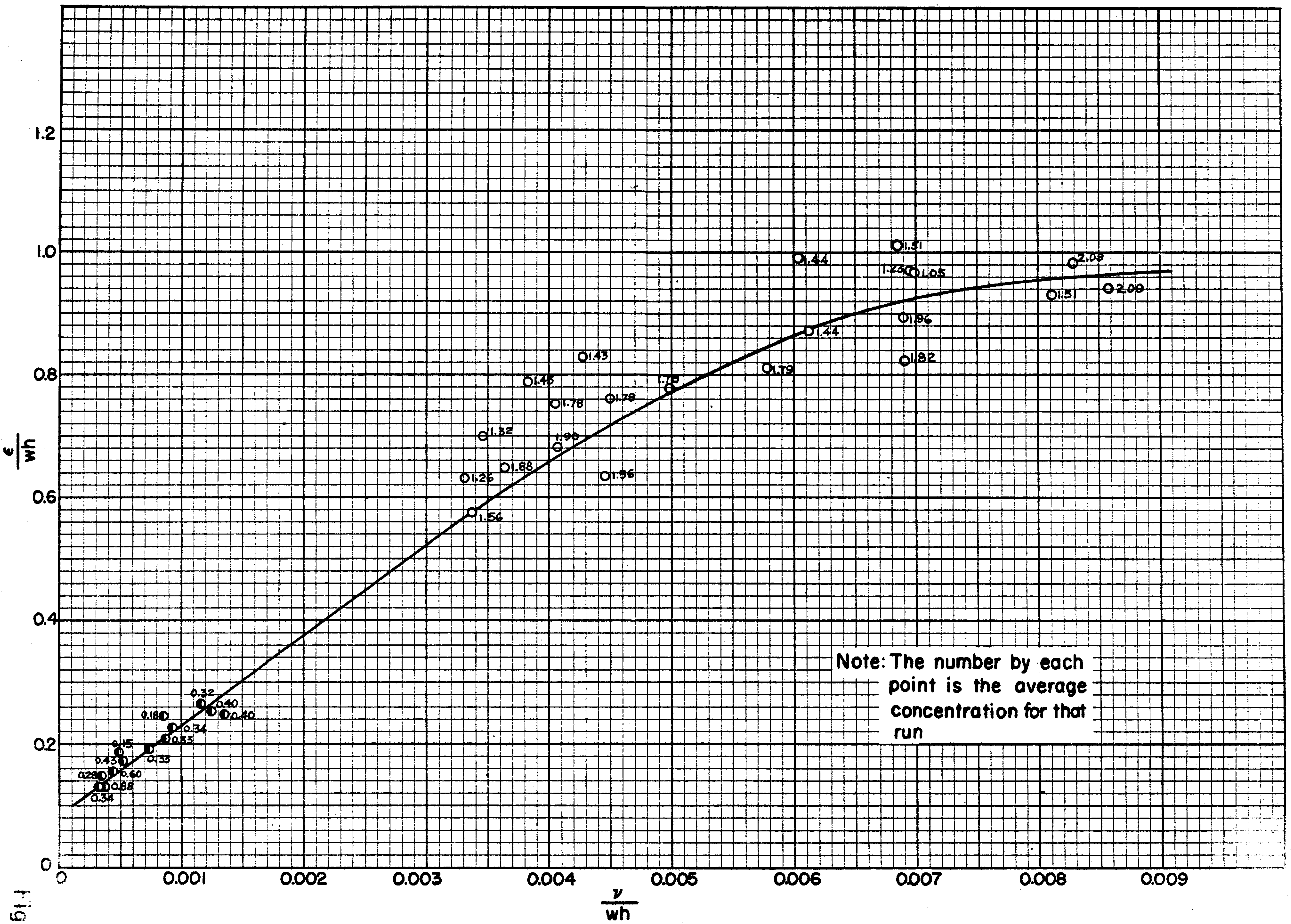
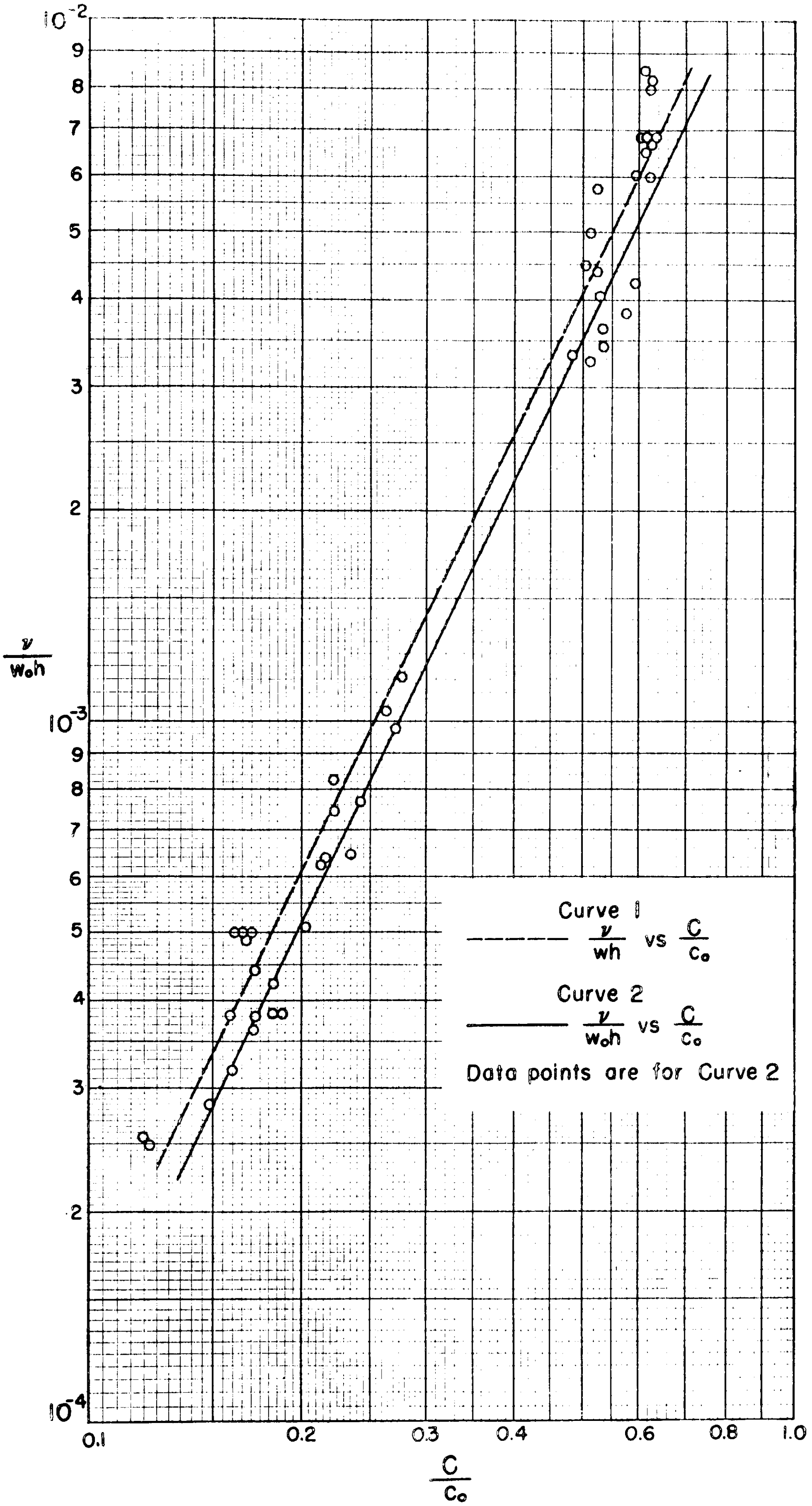


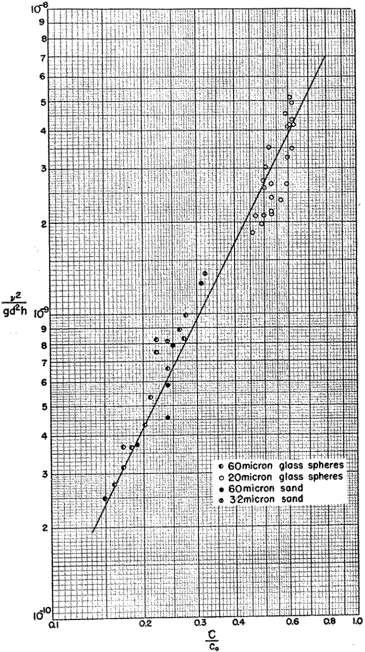
Fig. 15

Effect of $\frac{\nu}{wh}$ on $\frac{\epsilon}{wh}$ with Concentration as the Third Variable



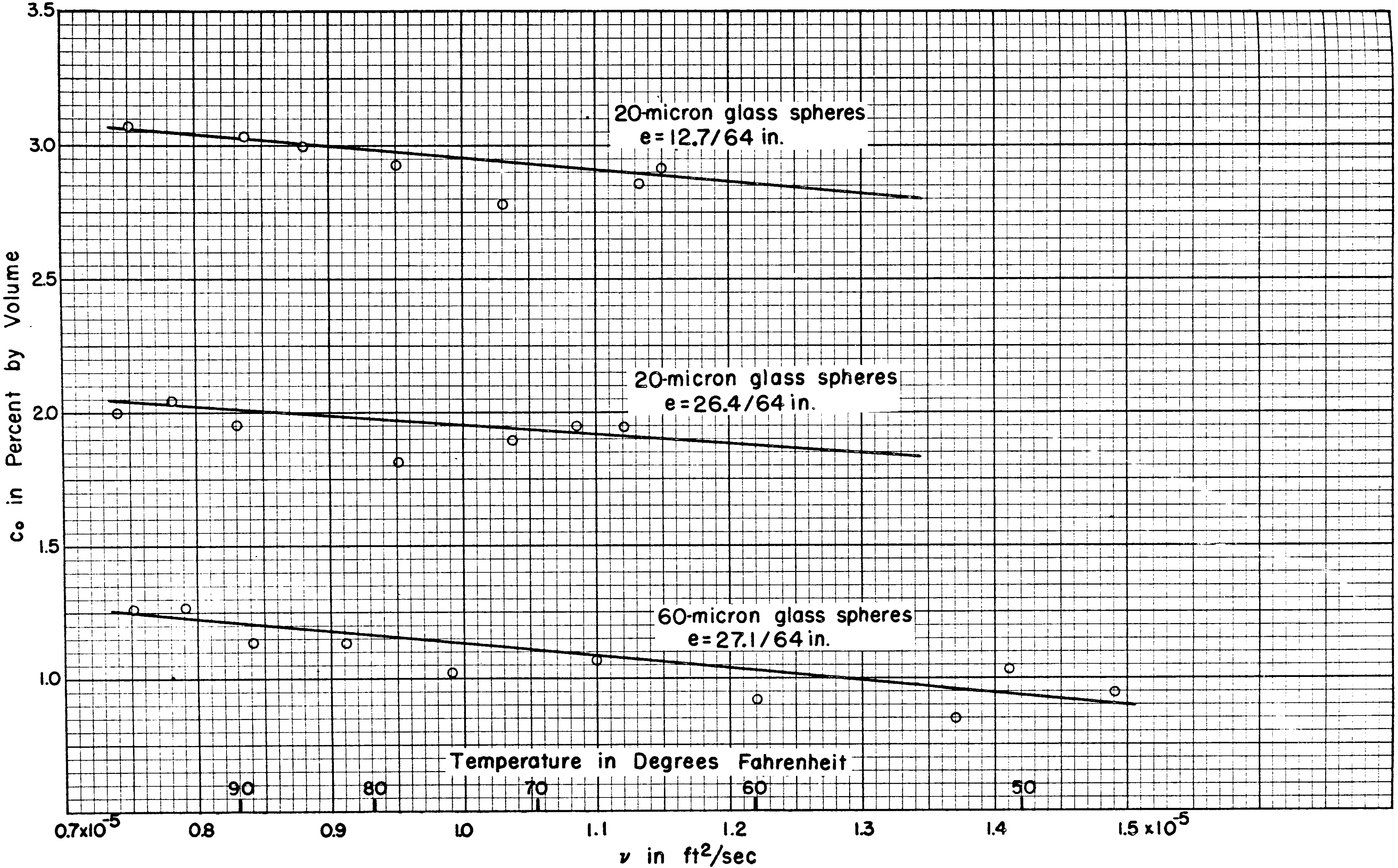
Effect of $\frac{\nu}{w_o h}$ on $\frac{C}{C_o}$

Fig. 16



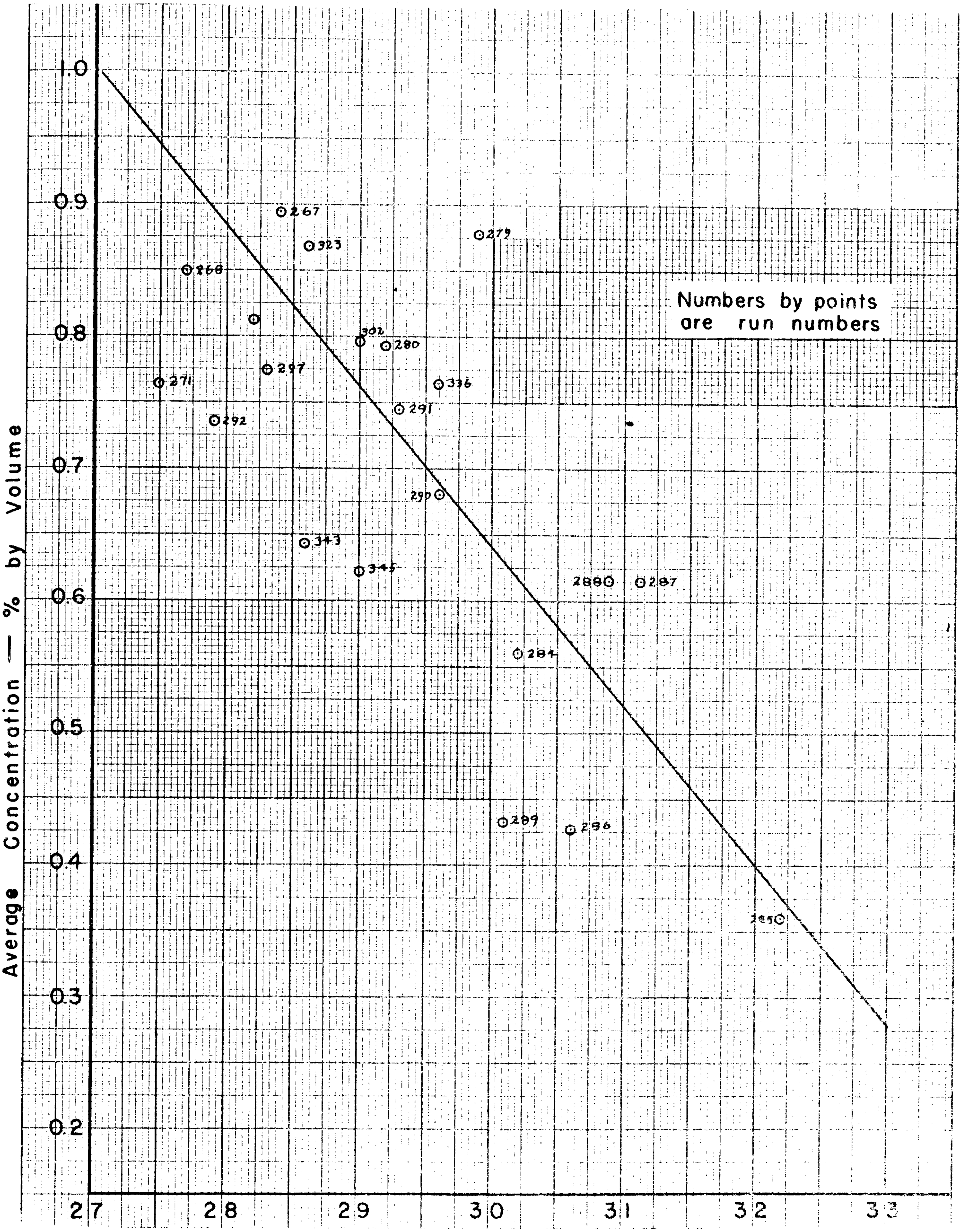
Effect of $\frac{\nu^2}{gd^2h}$ on $\frac{C}{C_o}$

Fig. 17



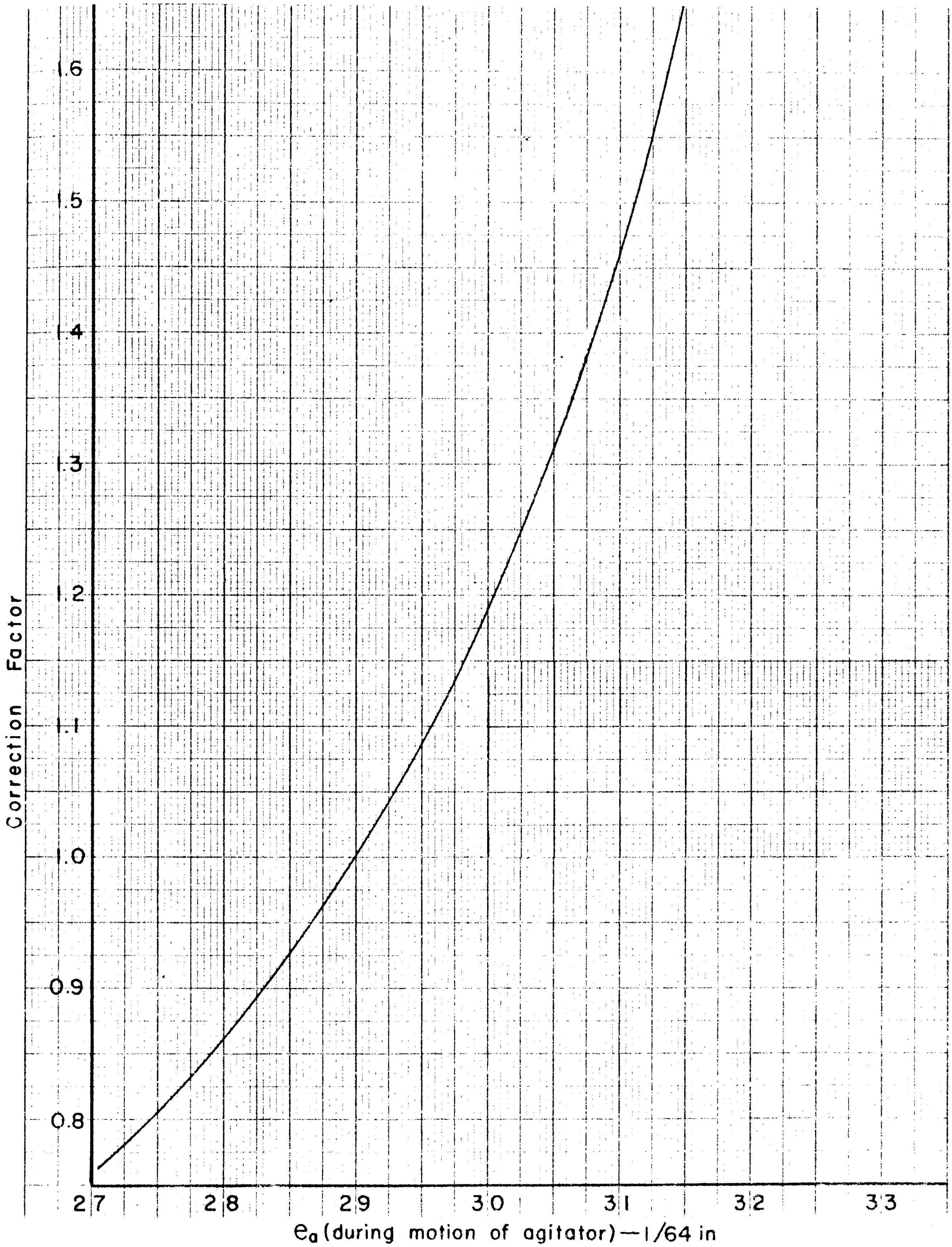
Effect of Viscosity on c_o

Fig. 18



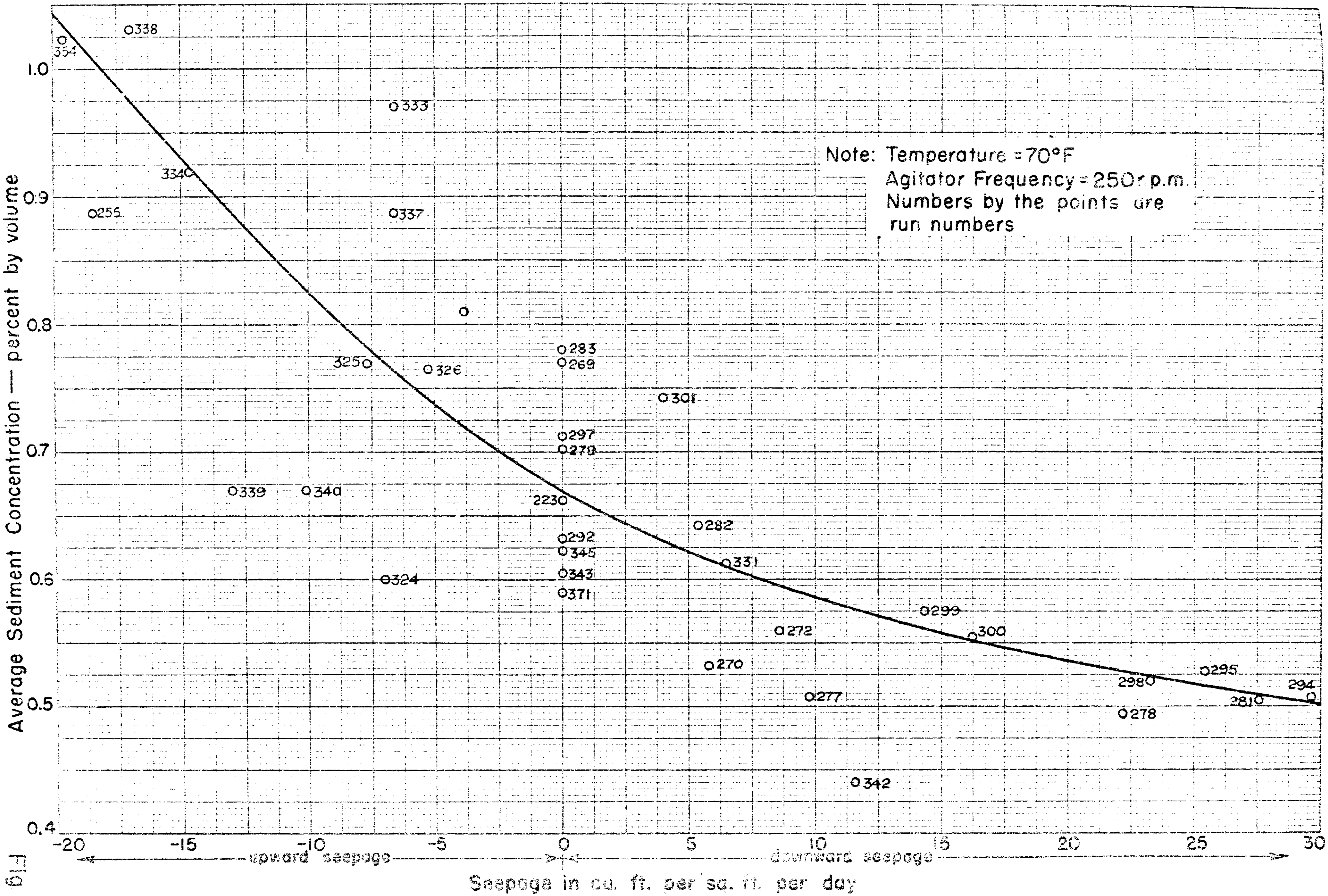
Effect of e_a on the Concentration of 60 micron Glass Spheres

Fig. 19



Correction Factors for Converting to a Standard e_a

Fig. 20



Effect of Seepage on Average Concentration of 60-Micron Glass Spheres

Fig 21

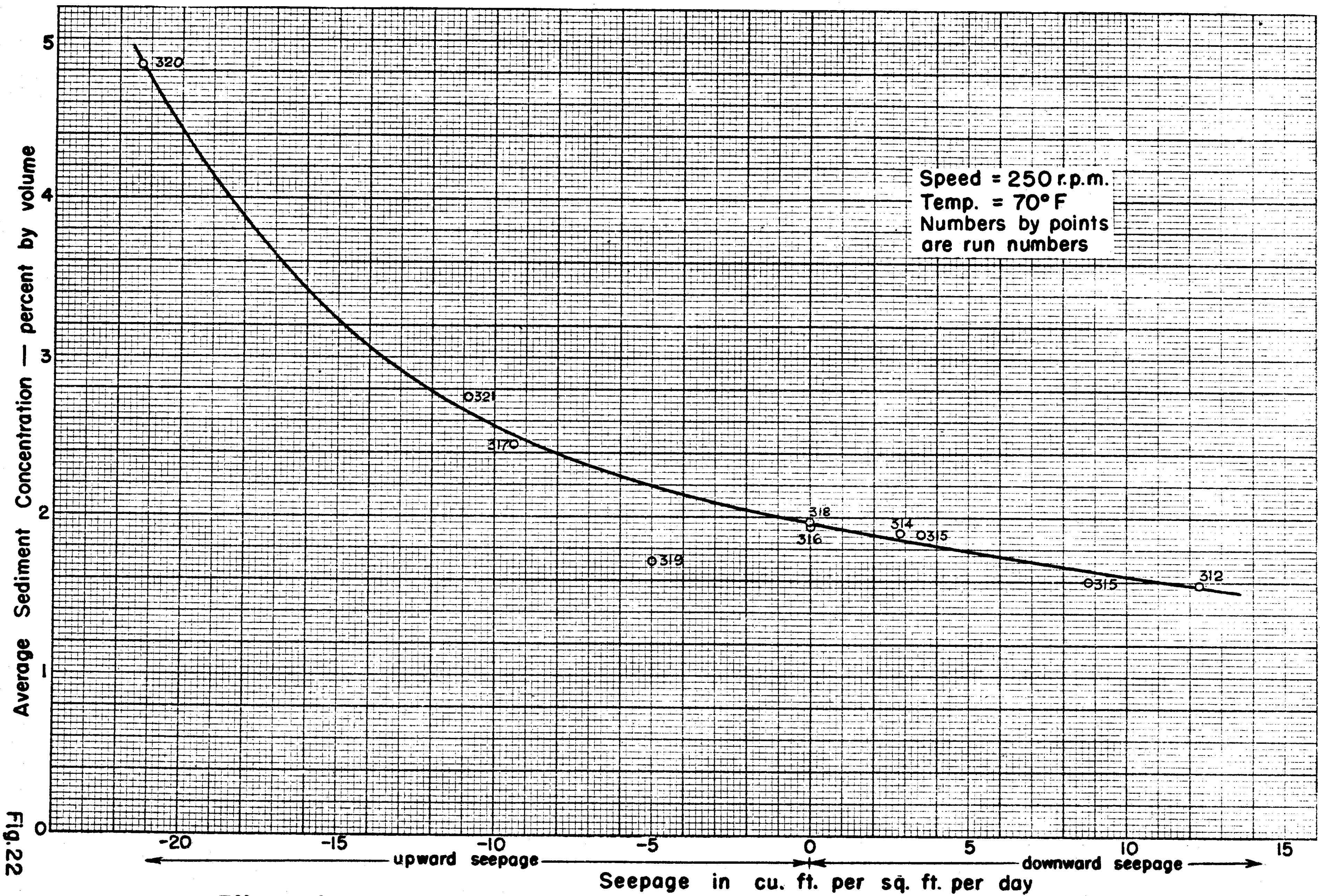
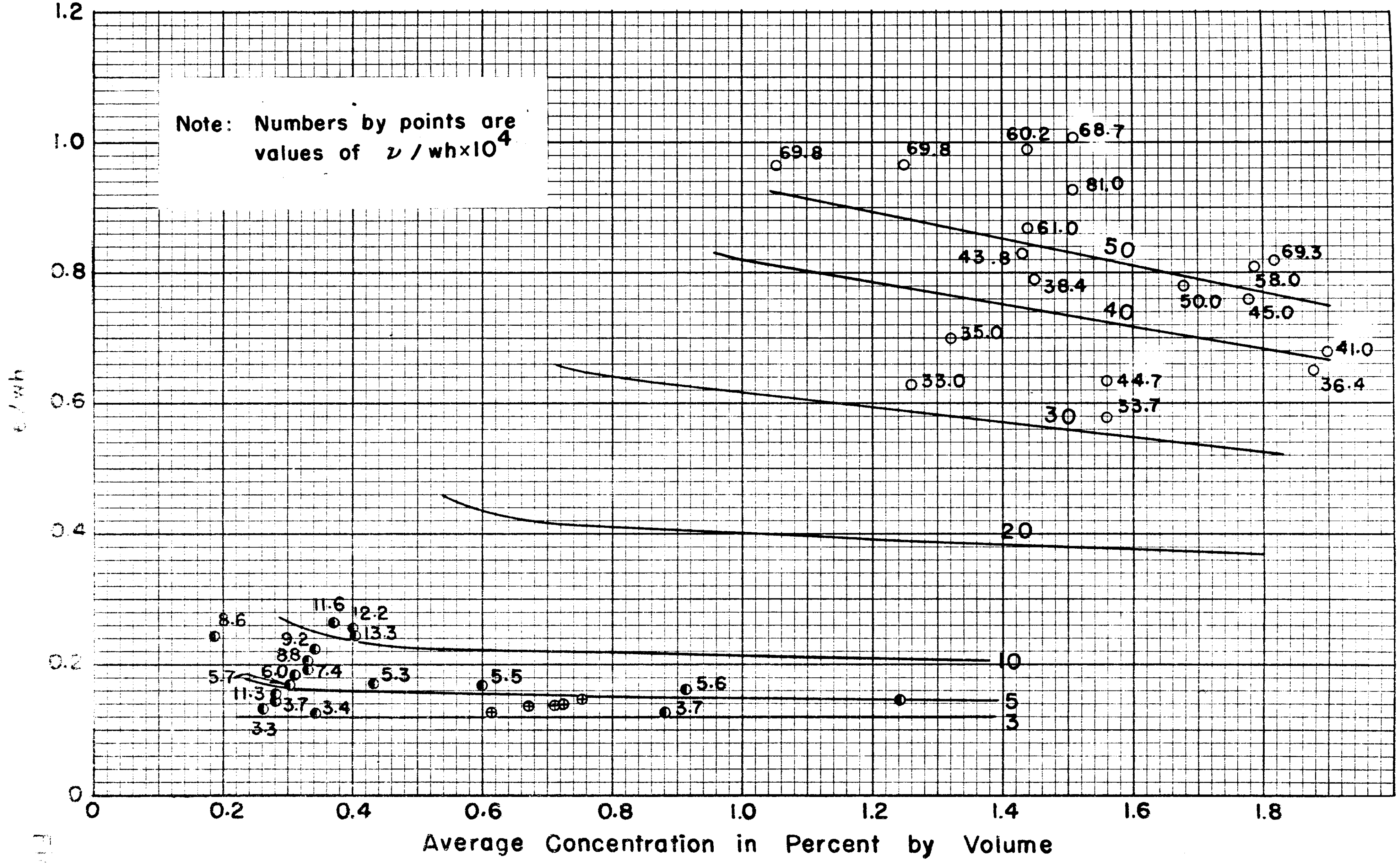


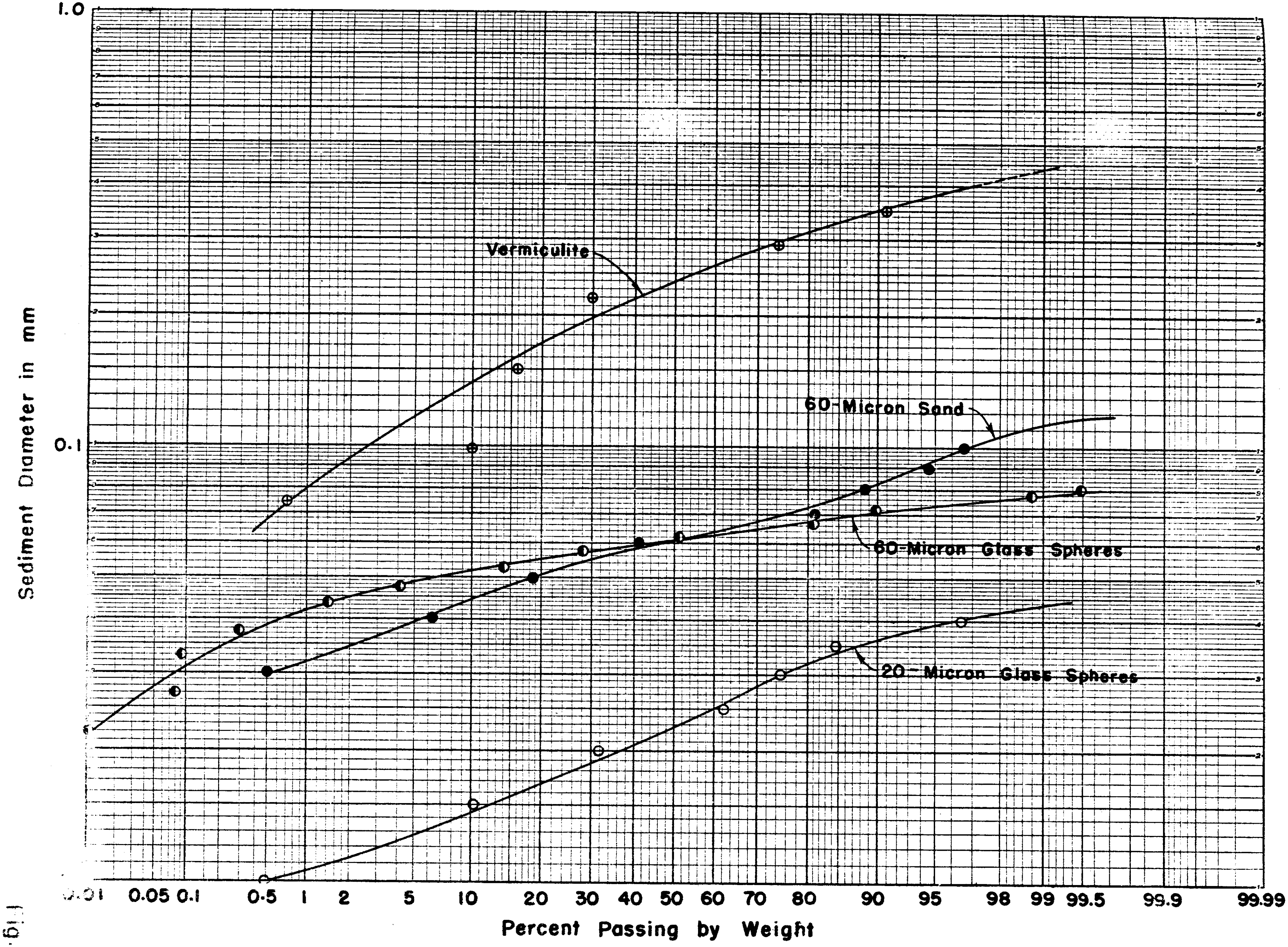
Fig. 22

Effect of Seepage on Average Concentration of 20 Micron Glass Spheres



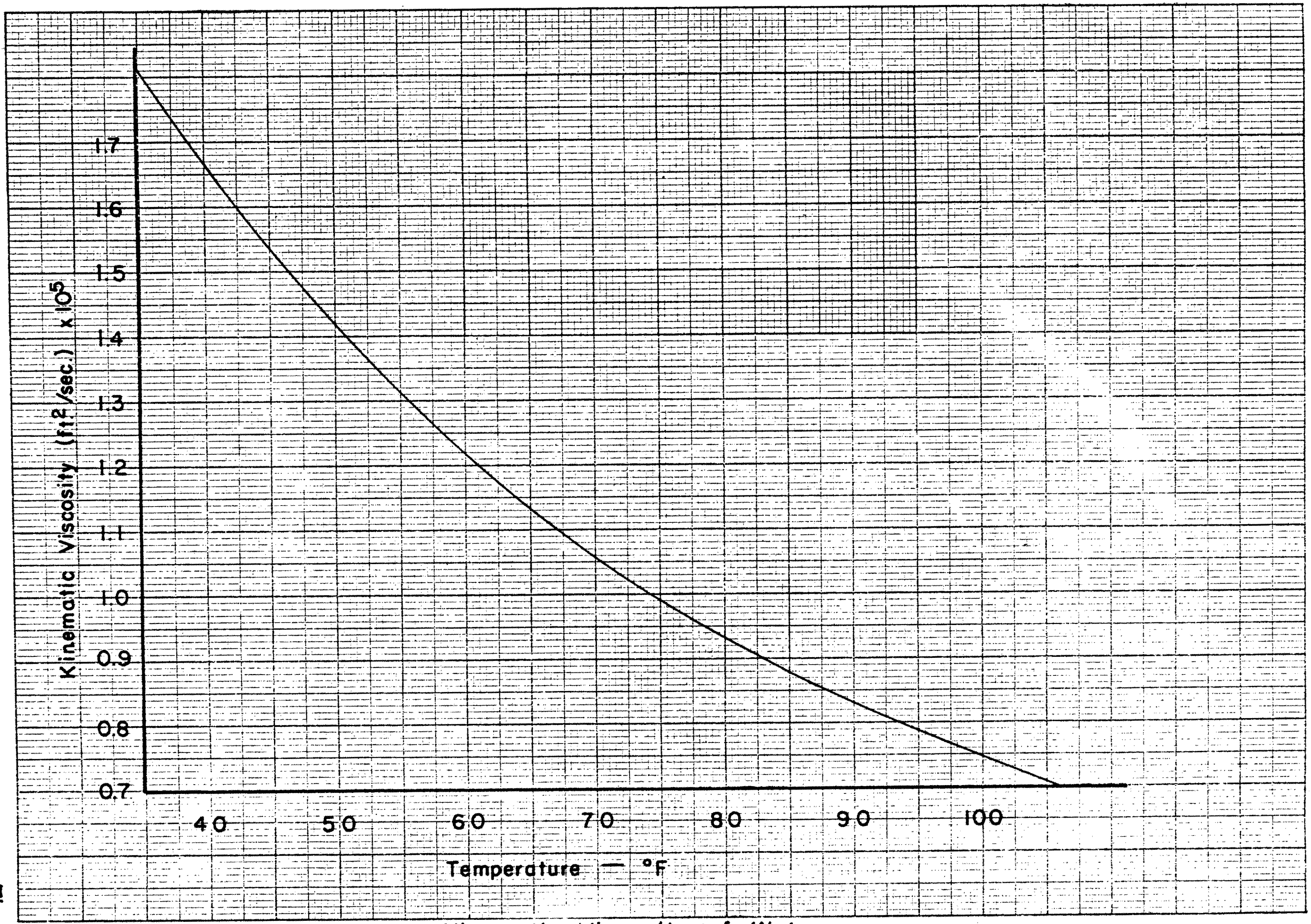
Effect of ϵ/wh on the Average Concentration with ν/wh as a Third Variable

FIG 23



Sediment Size Distribution Curves

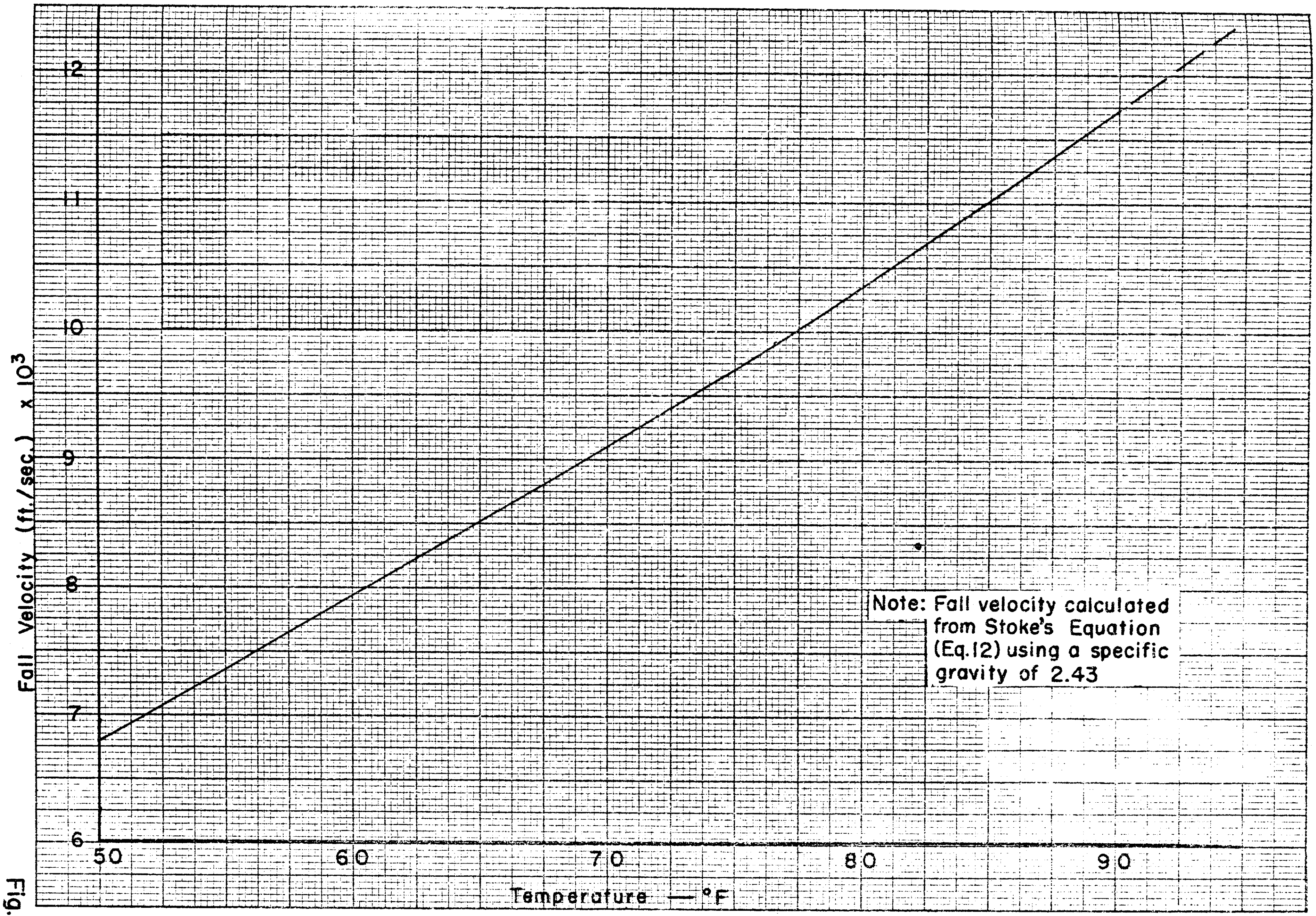
Fig. 24



Kinematic Viscosity of Water

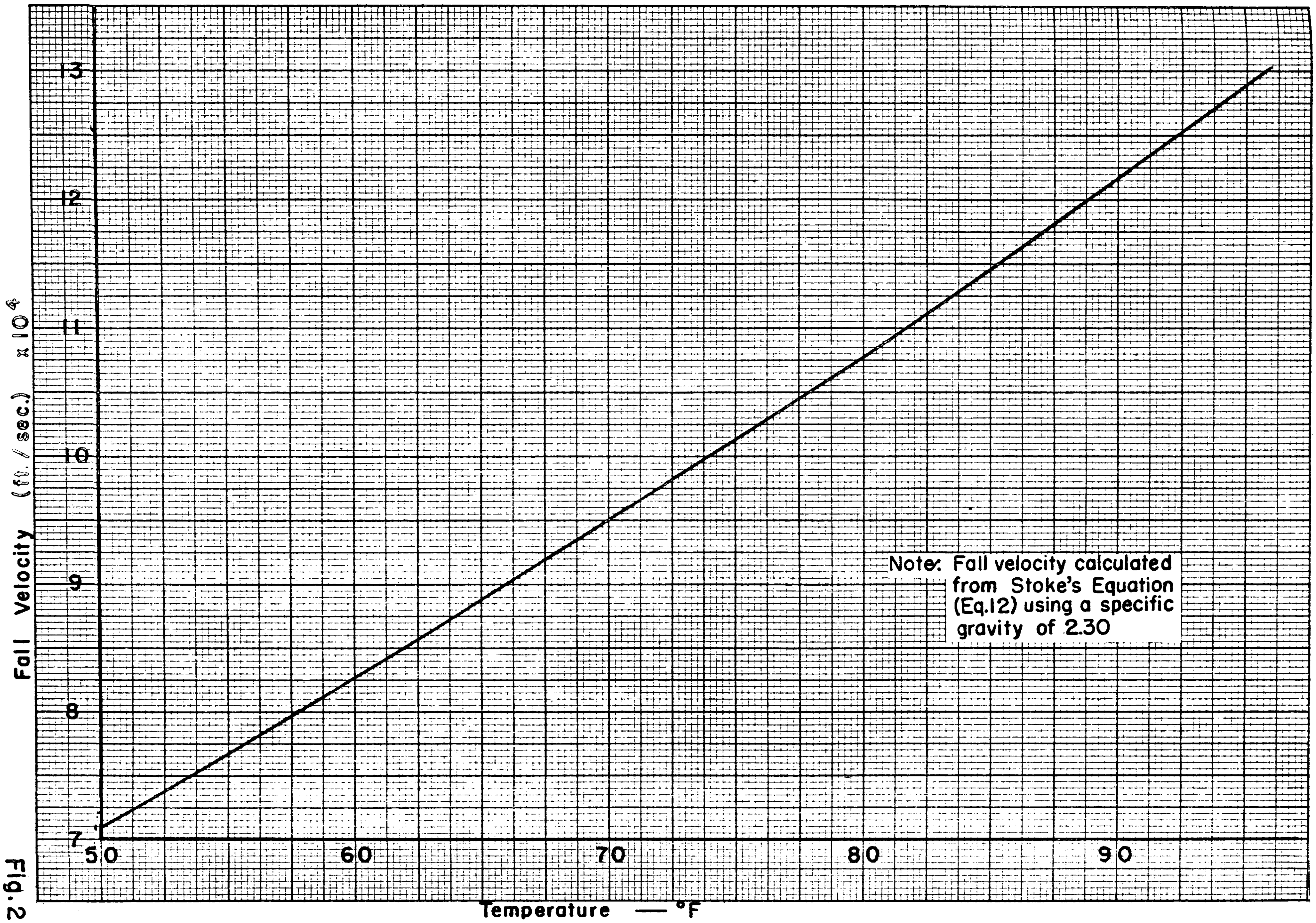
Fig. 25

Fig. 26



Note: Fall velocity calculated from Stoke's Equation (Eq. 12) using a specific gravity of 2.43

Fall Velocity Curve for 60micron Glass Spheres



Note: Fall velocity calculated from Stoke's Equation (Eq.12) using a specific gravity of 2.30

Fig. 27

Fall Velocity Curve for 20 micron Glass Spheres

APPENDIX

DEFINITIONS OF SYMBOLS

Symbol	
C	Average sediment concentration in percent by volume.
c	Sediment concentration at a point in percent by volume.
c_o	Sediment concentration obtained by extrapolating the sediment concentration curve to $y = 0$.
d	Mean particle diameter of sediment in mm.
e	Distance from sand bed to bottom of the agitator for stationary conditions.
e_a	Same as e except that the agitator is in motion.
L	Length of stroke of the agitator in inches.
f	Frequency of the agitator in cycles per second.
ω	Speed of rotation of the torque converter shaft in rpm.
S	Spacing of 5/16" duraluminum bars on each grid.
h	Depth of water in the turbulence tank in feet.
y	Depth measured from the sand bed.
w_o	Fall velocity of sediment particles in ft/sec based on Stokes Equation and the temperature of the water.
w	Fall velocity corrected for concentration given in ft/sec.
ν	Kinematic viscosity of the clear water in ft^2/sec.
ρ_s	Density of the solids in lbs-sec^2/ft^4.
ρ	Density of the liquid in lbs-sec^2/ft^4.
γ	Specific weight in lbs/ft^3.
$\Delta\gamma$	Difference in the specific weights of the sand and water in lbs/ft^3.

DEFINITIONS OF SYMBOLS (continued)

Symbol	Definitions
σ	Standard deviation of the sediment.
ϵ	Turbulent mixing coefficient or kinematic eddy viscosity in ft^2/sec.
P	Seepage rate in cu ft/sq ft/day.
m	Slope of the concentration curve plotted on semilogarithmic paper.

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LIST OF TABLES

Table 1

Preliminary data for temperature studies using
sand with a mean diameter of 60 microns
Agitator stroke = 1 7/8 in. Depth h = 2 ft

Run No.	Temp. F	e*	ω rpm	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10
1	46	28.4	189	--	0.624	0.460	0.420	0.310	0.205	0.125	0.087	0.060	0.050
2	52	28.4	145	0.176	0.162	0.139	0.111	0.070	0.046	0.031	0.018	0.020	0.011
3	47	48	188	0.424	0.405	0.351	0.285	0.223	0.149	0.087	0.051	0.033	0.032
15	44	44	240	1.075	1.025	0.935	0.850	0.680	0.525	0.360	0.250	0.200	0.195
16	47.5	44	185	0.540	0.505	0.452	0.400	0.252	0.210	0.140	0.110	0.082	0.079
17	71.5	44	186	0.535	0.610	0.455	0.390	0.237	0.170	0.100	0.077	0.046	0.040
18	71.5	44	242	1.10	1.07	0.89	0.80	0.58	0.44	0.255	0.175	0.117	0.105
19	45	40	156.5	0.31	0.28	0.22	0.18	0.109	0.085	0.049	0.039	0.028	0.025
20	71.5	40	156	0.24	0.21	0.16	0.105	0.059	0.036	0.020	0.012	0.011	0.010
30	42.5	48	152	3.00	2.62	1.90	1.60	1.10	0.77	0.44	0.30	0.22	0.16
31	45.2	43	153	4.10	3.65	2.70	2.18	1.43	0.92	0.50	0.33	0.23	0.16
32	44	32	153.5	6.20	5.80	4.00	3.15	2.00	1.11	0.59	0.36	0.21	0.14
33	45	24	153	8.00	7.80	5.20	4.00	2.65	1.60	0.84	0.45	0.28	0.25
34	45	20	153	9.25	8.60	6.00	4.50	2.80	1.90	0.95	0.52	0.33	0.26
35	46.5	20	153	10.2	9.3	6.5	4.7	--	2.25	1.22	0.70	0.45	0.33
36	43	14	148	13.0	12.0	--	5.45	--	2.2	1.22	0.66	0.40	0.32
37	45	3	153	14.5	13.3	--	7.0	--	2.9	1.30	0.70	0.43	0.35
38	85	3	148	23.0	19.5	8.8	5.2	2.45	1.30	0.47	0.21	0.14	0.09
39	84	3	186	18.0	15.5	10.0	6.3	3.6	2.10	0.85	0.41	0.27	0.19
40	83.5	3	222	17.0	16.0	11.0	9.0	5.3	3.6	1.52	0.79	0.45	0.33
41	67.5	3	224	14.5	12.5	10.5	8.2	5.5	3.9	1.95	1.08	0.65	0.52
42	67.5	3	185	16.0	14.5	9.3	6.9	4.1	2.70	1.18	0.60	0.38	0.27
43	67.7	3	150	17.5	14.0	8.2	5.0	2.9	1.70	.63	0.28	0.18	0.14
44	44	3	155	13.5	12.5	7.4	6.4	4.0	2.70	1.3	0.66	0.46	0.33
45	46	3	186	12.5	11.0	8.7	6.7	4.6	3.5	1.7	1.03	0.60	0.50
46	48	3	221	12.0	11.4	9.1	8.1	5.4	4.1	2.4	1.43	0.90	0.78

*e is recorded in 64ths of an inch.

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Table 1
(Continued)

Run No.	Temp. °F	θ	ω rpm	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10
47	43	3	153	13.0	11.8	8.1	6.4	4.0	2.8	1.31	0.72	0.46	0.37
48	45	-5	153	14.5	14.0	9.6	6.7	4.6	3.1	1.49	0.80	0.51	0.42
49	47	-12	153	16.5	15.5	10.5	8.1	4.8	3.3	1.49	0.82	0.56	0.42
50	49	-18	153	18	17.5	11.5	8.4	5.3	3.5	1.60	0.88	0.56	0.45
51	97.7	-18	147	30	25.4	12.5	6.4	2.92	1.55	0.50	0.21	0.13	0.09
52	98.5	-18	179	26	23	13.5	8.8	4.60	2.60	0.93	0.38	0.25	0.18
53	84	-18	183	22.5	19.0	12.9	8.60	4.80	3.10	1.32	0.60	0.40	0.27
54	83.2	-18	217	18.2	16.5	13.1	9.3	6.4	4.10	1.85	0.90	0.56	0.35
55	83.7	-18	154	24.5	21.9	10.8	6.2	3.3	1.80	0.64	0.27	0.20	0.12
60	45.2	32	225	1.50	1.40	1.18	1.05	0.75	0.59	0.35	0.25	0.191	0.162
61	45.5	32	251	2.20	2.05	1.80	1.60	1.22	0.98	0.62	0.40	0.30	0.25
62	60	32	251	2.35	2.20	1.85	1.54	1.13	0.83	0.50	0.30	0.21	0.18
63	60	32	223	1.55	1.41	1.13	0.94	0.64	0.50	0.275	0.175	0.120	0.095
64	60.5	32	200	1.00	0.92	0.72	0.60	0.40	0.32	0.160	0.102	0.071	0.056
65	60	32	174	0.59	0.54	0.44	0.34	0.24	0.17	0.085	0.053	0.039	0.028
66	69.7	32	175	--	--	--	--	0.38	0.125	0.08	0.039	0.03	0.02
67	69.9	32	225	1.50	1.37	1.11	0.93	0.63	0.42	0.25	0.146	0.095	0.075
68	70	30	200	1.03	1.00	0.71	0.55	0.40	0.25	0.138	0.086	0.053	0.049
69	70.5	28	149.5	0.23	0.23	0.165	0.116	0.071	0.048	0.020	0.010	0.012	--
70	70	26	249.5	2.20	2.10	1.85	1.45	1.0	0.70	0.40	0.22	0.148	0.105
71	89.2	26	250	2.70	2.40	1.92	1.50	0.96	0.64	0.30	0.18	0.102	0.073
72	88.7	26	223	1.70	1.52	1.15	0.90	0.58	0.35	0.17	0.090	0.060	0.048
73	90	26	199	0.93	0.82	0.60	0.45	0.25	0.18	0.073	0.041	0.027	0.015
74	90	26	175	0.58	0.48	0.36	0.27	0.150	0.090	0.040	0.019	0.010	--
75	80	26	176	0.60	0.50	0.39	0.32	0.160	0.120	0.050	0.030	0.020	0.010
77	79.7	26	225	1.82	1.59	1.30	1.02	0.56	0.43	0.24	0.127	0.08	0.059
78	79.9	26	248.5	2.82	2.35	1.85	1.50	1.05	0.79	0.40	0.25	0.16	0.12
79	44.5	36	174	0.54	0.51	0.42	0.34	0.23	0.17	0.102	0.070	0.042	0.030
80	46.2	36	198	0.97	0.86	0.71	0.63	0.43	0.33	0.210	0.144	0.100	0.082
81	47.2	36	224	1.55	1.45	1.22	0.98	0.77	0.60	0.35	0.25	0.171	0.145

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Table 1
(Continued)

Run No.	Temp. °F	e	ω rpm	Sediment concentration percent by volume Sample hole No. 1	2	3	4	5	6	7	8	9	10
82	46.7	36	250	2.10	2.00	1.72	1.50	1.18	0.95	0.60	0.44	0.32	0.24
85	45	16	199	1.92	1.80	1.47	1.30	0.86	0.66	0.40	0.23	0.168	0.130
86	46.5	16	223	2.9	2.8	2.3	2.0	1.5	1.3	0.8	0.52	0.35	0.27
87	45	16	250.3	4.3	4.1	3.5	3.05	2.4	1.9	1.25	0.86	0.60	0.49
88	90	16	250	5.0	4.5	3.5	2.6-	1.7	1.2	0.56	0.34	0.19	0.138
89	89.8	16	223	3.4	3.0	2.15	1.65	1.07	0.65	0.33	0.18	0.105	0.08
90	88.5	16	200.5	2.5	2.3	1.6	1.25	0.7	0.46	0.22	0.115	0.065	0.055
91	69.5	16	250	4.35	4.2	3.2	2.6	2.0	1.42	0.79	0.47	0.30	0.25
92	70	16	225	3.3	3.1	2.3	2.0	1.3	0.9	0.5	0.28	0.18	0.135
93	70	16	199	1.9	1.75	1.45	0.95	0.65	0.48	0.25	0.14	0.109	0.08
94	60	16	199	2.1	1.9	1.6	1.2	0.80	0.59	0.34	0.206	0.138	0.104
95	60	16	225	3.4	3.05	2.55	2.10	1.45	1.02	0.55	0.36	0.21	0.175
96	60	16	250	4.2	3.85	3.35	2.80	1.97	1.55	0.88	0.58	0.37	0.27
97	46.5	40	251	1.40	1.40	1.30	1.15	0.83	0.70	0.43	0.32	0.215	0.170
98	47	40	224	0.95	0.88	0.79	0.68	0.57	0.38	0.22	0.16	0.12	0.091
99	47.2	40	201	0.72	0.65	0.54	0.45	0.33	0.28	0.17	0.12	0.080	0.065
100	60	40	201	0.78	0.65	0.54	0.41	0.30	0.21	0.123	0.078	0.060	0.045
101	60	40	225	1.05	0.97	0.75	0.66	0.45	0.35	0.200	0.133	0.094	0.074
102	60.5	40	250	1.40	1.30	1.08	0990	0.63	0.50	--	0.211	0.142	0.103
103	89.1	40	249	1.68	1.53	1.12	0.92	0.60	0.38	0.21	0.13	0.075	0.058
104	89.2	40	226	1.15	1.05	0.74	0.59	0.35	0.23	0.122	0.076	0.050	0.038
105	89.2	40	201	0.67	0.57	0.50	0.36	0.20	0.15	0.064	0.040	0.030	0.020
106	70.2	40	200.5	0.60	0.54	0.43	0.35	0.20	0.16	0.082	0.057	0.041	0.030
107	70	40	225	1.13	1.06	0.85	0.70	0.46	0.35	0.190	0.124	0.085	0.065
108	70	40	250.5	1.42	1.30	1.10	0.88	0.61	0.48	0.260	0.19	0.116	0.093
109	47.2	48	199	0.54	0.48	0.40	0.35	0.26	0.21	0.125	0.095	0.061	0.049
110	47.2	48	250	1.01	0.99	0.86	0.80	0.60	0.49	0.33	0.24	0.175	0.136
111	60.9	48	251	1.18	1.12	0.90	0.80	0.55	0.45	0.27	0.20	0.140	0.104
112	60	48	199	0.60	0.58	0.45	0.39	0.25	0.19	0.12	0.09	0.050	0.049
113	47.5	48	218	0.67	0.64	0.53	0.46	0.32	0.25	0.15	0.10	0.072	0.068
114	50.5	48	248	0.80	0.71	0.66	0.58	0.40	0.33	0.20	0.13	0.08	0.062
115	51.5	48	201	0.44	0.35	0.32	0.24	0.18	0.14	0.075	0.047	0.030	0.029

Table 2

Preliminary data for temperature studies using
sand with a mean diameter of 125 microns
Agitator stroke = 1 7/8 in. Depth h = 2 ft

Run No.	Temp °F	e*	ω rpm	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10
4	44	24	191	0.39	0.33	0.144	0.090	0.043	0.022	0.014	0.009	0.008	0.0075
5	46	24	225	0.84	0.624	0.280	0.147	0.067	0.032	0.018	0.012	0.008	0.003
83	46.7	32	251	1.20	0.94	0.45	0.28	0.12	0.06	0.019	0.014	0.011	0.003
84	45	32	225	0.62	0.45	0.23	0.103	--	0.027	--	0.010	0.003	--

*e is recorded in 64ths of an inch.

Table 3

Preliminary data for temperature studies using sand with a mean diameter of 32.7 microns

Agitator stroke = 1 7/8 in. Depth h = 2 ft

Run No.	Temp. °F	e*	ω rpm	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10
6	43	46	123	0.070	0.080	0.089	0.078	0.082	0.071	0.052	0.040	0.029	0.030
7	48	46	149	0.194	0.195	0.182	0.163	0.127	0.107	0.081	0.060	0.050	0.042
8	43.5	46	174	0.422	0.400	0.396	0.378	0.316	0.275	0.210	0.175	0.148	0.135
9	46.5	46	196	0.612	0.586	0.552	0.470	0.424	0.390	0.310	0.242	0.215	0.194
10	48	40	238	1.187	1.182	1.120	1.004	0.965	0.88	0.68	0.59	0.44	0.38
11	46	40	148	0.34	0.32	0.25	0.24	0.20	0.17	0.13	0.08	0.059	0.055
12	42.5	40	149	0.29	0.26	0.25	0.21	0.18	0.16	0.11	0.09	0.068	0.059
13	46	40	196.5	0.63	0.62	0.59	0.51	0.44	0.40	0.32	0.28	0.22	0.195
14	45	40	237	0.89	0.91	0.89	0.84	0.745	0.645	0.465	0.395	0.310	0.300
21	46	0	156	2.9	2.8	2.25	1.92	1.62	1.38	0.89	0.65	0.48	0.48
22	60	0	156.5	3.35	3.05	2.50	2.10	1.65	1.22	0.72	0.48	0.37	0.31
23	69	0	155.5	3.50	3.12	2.50	2.05	1.51	1.01	0.59	0.38	0.26	0.23
24	91	0	155.5	3.80	3.45	2.60	1.95	1.32	0.88	0.43	0.28	0.19	0.14
25	90.5	0	199	4.65	4.32	3.62	3.00	2.35	1.82	1.08	0.69	0.49	0.42
26	75	0	199	4.32	4.05	3.5	2.9	2.25	1.92	1.17	0.80	0.59	0.51
27	60	0	199	3.82	3.55	3.20	2.70	2.25	1.92	1.25	0.90	0.70	0.63
28	45.5	0	198.5	3.32	3.17	2.82	2.55	2.20	1.80	1.34	1.00	0.81	0.67
117	47	48	249	1.4	1.4	1.35	1.32	1.15	1.03	0.86	0.72	0.55	0.55
118	95.2	48	203	1.10	1.00	0.86	0.77	0.53	0.43	0.26	0.18	0.14	0.11
119	95.2	48	245	1.50	1.45	1.30	1.15	0.87	0.78	0.46	0.33	0.22	0.19
120	96.2	48	229	1.39	1.35	1.10	1.00	0.75	0.60	0.40	0.29	0.21	0.165
121	96	48	250	1.76	1.65	1.50	1.30	1.10	0.88	0.56	0.44	0.31	0.25
122	71.9	48	250	1.55	1.52	1.39	1.30	1.03	0.85	0.65	0.50	0.40	0.34
123	70.2	48	225	1.31	1.20	1.09	1.00	0.83	0.66	0.56	0.42	0.36	0.28
124	70	48	200	0.82	0.83	0.79	0.70	0.57	0.47	0.32	0.25	0.21	0.19

*e is recorded in 64ths of an inch.

(Continued on next page)

Table 3
(Continued)

Run No.	Temp °F	e	ω rpm	Sediment concentration percent by volume Sample Hole No.									
				1	2	3	4	5	6	7	8	9	10
125	60	48	201	0.88	0.80	0.75	0.65	0.59	0.45	0.38	0.28	0.21	0.19
126	61.4	48	225	1.00	1.00	0.91	0.84	0.71	0.60	0.45	0.39	0.31	0.30
127	61.1	48	250	1.35	1.35	1.25	1.18	0.98	0.85	0.70	0.56	0.47	0.38
128	95.8	18	249	5.0	4.5	4.0	3.7	3.0	2.4	1.65	1.12	0.84	0.63
129	94.8	18	201	3.1	2.9	2.6	2.2	1.6	1.25	0.80	0.55	0.36	0.30

Table 4

Preliminary data for temperature studies using sand with a mean diameter of 32.7 microns

Agitator stroke = 15.3/16 in. Depth h = 2 ft

Run No.	Temp °F	e*	ω rpm	Sediment concentration percent by volume Sample Hole No.									
				1	2	3	4	5	6	7	8	9	10
130	49	16	250	0.58	0.50	0.41	0.40	0.31	0.26	0.150	0.112	0.075	0.040
131	100	16	251	0.45	0.41	0.31	0.26	0.19	0.14	0.068	0.031	0.020	0.016
133	98.2	16	365	4.45	4.45	3.6	3.27	2.60	1.95	1.15	0.63	0.40	0.27
134	100.1	16	298	1.80	1.72	1.20	1.07	0.76	0.59	0.30	0.17	0.102	0.62
135	80.7	16	300	1.75	1.78	1.40	1.14	0.92	0.72	0.41	0.25	0.16	0.11
136	80.2	16	367	4.10	4.15	3.75	3.42	2.55	2.20	1.28	0.89	0.54	0.44
137	80	16	250	0.48	0.50	0.47	0.33	0.25	0.21	0.13	0.82	0.58	0.40
138	80	16	201	0.15	0.15	0.10	0.09	--	0.055	0.030	0.020	0.020	0.014
139	60.4	16	202	0.16	0.145	0.12	0.095	0.080	0.065	0.039	0.024	0.021	0.019
140	60	16	250	0.40	0.36	0.33	0.26	0.22	0.20	0.117	0.070	0.050	0.037
141	53	16	298	1.40	1.25	1.09	0.90	0.85	0.80	0.50	0.33	0.20	0.16
142	53	16-	298	1.30	1.30	1.13	1.09	0.82	0.74	0.48	0.30	0.23	--
143	52.2	16	296.5	1.22	1.27	1.05	0.90	0.76	0.63	0.45	0.31	0.22	0.16
144	52.7	16	296.5	1.27	1.18	1.00	0.92	0.73	0.60	0.41	0.27	0.20	0.135
145	53	16	296.5	1.25	1.30	1.06	0.88	0.73	0.62	0.44	0.29	0.20	0.15
146	53.5	16	296	1.20	1.05	0.95	0.87	0.70	0.56	0.40	0.25	0.19	0.125
147	54	16	296	1.25	1.30	1.05	0.90	0.75	0.61	0.43	0.28	0.20	0.14
148	55	16	295	1.22	1.13	1.02	0.93	0.74	0.60	0.42	0.30	0.20	0.15
149	70.1	16	357.5	3.65	3.50	3.20	3.00	2.40	1.87	1.16	0.80	0.50	0.31
150	55.9	16	358	3.30	3.20	3.00	2.80	2.30	1.85	1.28	0.89	0.57	0.39
151	60.1	12	355	4.60	4.30	4.00	3.70	3.20	2.80	2.25	1.80	1.50	1.20
152	87.4	12	255	4.95	4.80	4.20	3.75	3.00	2.60	1.90	1.40	1.10	0.79

*e recorded in 64ths of an inch.

Table 5

Data for temperature studies using glass spheres with a mean diameter of 60 microns

Agitator stroke = 1 15/16 in. Depth h = 2 ft

Run No.	Temp. °F	e*	ω rpm	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10	Reliability
153	54.7	64	249.5	0.25	0.22	0.20	0.15	0.12	0.10	0.050	0.038	0.023	0.019	
155	100	64	249.5	0.35	0.35	0.27	0.22	0.12	0.09	0.04	0.025	0.012	0.009	
156	99.6	64	224	0.15	0.15	0.10	0.09	0.05	0.04	0.02	0.015	0.007	0.005	Poor--conc. too low to read accurately
157	100	48	223	0.45	0.39	0.24	0.18	0.08	0.06	0.028	0.020	0.010	0.010	
158	98.6	48	250	0.73	0.69	0.48	0.36	0.20	0.13	0.06	0.035	0.020	0.016	
159	72	48	251	0.82	0.79	0.63	0.54	0.36	0.25	0.15	0.10	0.068	0.053	
160	71.1	48	223	0.49	0.45	0.34	0.25	0.20	0.15	0.082	0.065	0.046	0.039	
161	58.7	48	224.5	0.45	0.40	0.30	0.25	0.175	0.15	0.090	0.070	0.050	0.041	
162	58	18	225	3.00	2.75	1.99	1.58	1.03	0.70	0.40	0.23	0.161	0.141	
163	59	18	249	4.15	3.90	2.98	2.55	1.75	1.16	0.66	0.39	0.25	0.185	
164	59	18	182	1.08	0.97	0.72	0.52	0.30	0.22	0.136	0.083	0.060	0.047	
165	59.5	18	199	1.65	1.40	1.05	0.74	0.48	0.32	0.195	0.130	0.090	0.080	
166	97.9	16	198.5	2.60	2.10	1.22	0.75	0.37	0.21	0.10	0.050	0.040	0.025	
167	98.5	16	223.5	3.65	3.15	2.00	1.34	0.68	0.42	0.180	0.096	0.068	0.048	
168	100	16	250.5	5.5	4.75	3.20	2.40	1.30	0.79	0.35	0.19	0.118	0.076	
169	97	16	184	1.50	1.21	0.69	0.42	0.21	0.14	0.068	0.043	0.040	0.030	
170	75.6	16	184	1.40	1.20	0.75	0.48	0.27	0.16	0.095	0.061	0.048	0.045	
171	75	16	199	2.10	1.85	1.18	0.80	0.45	0.30	0.16	0.101	0.070	0.060	
172	75.7	16	224.5	3.40	3.02	2.05	1.49	0.89	0.58	0.30	0.168	0.109	0.084	
173	75	16	251	5.00	4.40	3.25	2.64	1.75	1.19	0.56	0.34	0.21	0.14	
174	58.9	16	225	3.15	2.77	2.10	1.67	1.10	0.75	0.40	0.23	0.16	0.115	
175	55	16	253	4.15	3.80	3.15	2.57	1.90	1.40	0.77	0.50	--	0.23	
176	55.3	15	251	4.35	4.00	3.25	2.70	1.90	1.45	0.83	0.52	0.37	0.24	
177	54.5	15	198.5	1.85	1.70	1.25	0.95	0.59	0.38	0.23	0.136	0.098	0.078	
178	67	15	199.5	2.03	1.85	1.33	0.95	0.53	0.35	0.17	0.095	0.070	0.050	

*e is recorded in 64ths of an inch.

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Table 5
(Continued)

Run No.	Temp. °F	e	ω rpm	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10	Reliability
179	67	15	249.5	4.5	4.05	3.10	2.55	1.77	1.20	0.60	0.35	0.23	0.132	
180	57	24.1	224.5	1.88	1.67	1.25	1.00	0.70	0.45	0.25	0.15	0.10	0.07	
181	58	24	249.5	3.10	3.05	2.12	1.80	1.27	0.90	0.50	0.30	0.21	0.135	
182	59	24	201	0.85	0.78	0.55	0.37	0.23	0.20	0.09	0.061	0.043	0.040	
183	84.5	24	199.5	0.77	0.65	0.43	0.27	0.18	0.10	0.043	0.030	0.023	0.014	Watch ran down, speed estimated
184	87	24	227.5	2.15	1.97	1.40	0.92	0.50	0.29	0.15	0.072	0.040	0.026	
185	85	24	249.5	3.70	3.15	2.20	1.72	1.10	0.66	0.31	0.15	0.094	0.060	
186	99.7	23.4	200	0.91	0.76	0.49	0.30	0.15	0.08	0.038	0.020	0.013	0.008	Too low for accuracy
187	100.2	23.4	225	2.20	1.85	1.12	0.74	0.38	0.23	0.094	0.050	0.030	0.020	
188	100	23.4	250.5	4.00	3.40	2.25	1.65	0.88	0.55	0.24	0.12	0.069	0.039	
189	100.5	41.8	201	0.31	0.25	0.17	0.105	0.05	--	0.025	0.015	--	0.009	Too low for accuracy
190	100.7	41.8	228	0.80	0.65	0.42	0.27	0.16	0.095	0.047	0.030	0.018	0.011	
191	99.5	41.8	250.5	1.53	1.25	0.88	0.65	0.39	0.245	0.114	0.061	0.036	0.024	
192	84.7	40.7	250	1.40	1.18	0.82	0.64	0.40	0.28	0.141	0.085	0.050	0.032	
193	85	40.7	225	0.75	0.62	0.40	0.29	0.19	0.14	0.060	0.040	0.025	0.019	
194	85	40.7	202	0.39	0.30	0.23	0.14	0.10	0.055	0.038	0.030	0.020	0.013	
195	85	50.7	250	0.83	0.77	0.58	0.45	0.28	0.20	0.10	0.069	0.040	0.021	
196	84.7	17.1	250.5	4.20	3.60	2.72	2.10	1.30	0.80	0.41	0.21	0.13	0.07	
197	85	17.1	223	2.60	2.30	1.57	1.08	0.61	0.35	0.17	0.082	0.06	0.036	
198	85	17.1	200.5	1.40	1.18	0.76	0.50	0.29	0.18	0.073	0.046	0.017	0.011	
199	85.2	15.3	251	5.3	4.4	3.17	2.45	1.52	0.93	0.45	0.23	0.142	0.074	
200	85	8.1	251	6.0	5.3	3.75	2.97	1.80	1.20	0.53	0.26	0.135	0.084	
201	70	16.9	200.5	2.10	1.87	1.20	0.84	0.47	0.30	0.15	0.090	0.066	0.045	
202	70	16.9	224	3.20	2.87	2.00	1.55	0.95	0.60	0.30	0.17	0.108	0.060	
203	70	17.1	251.5	4.4	4.0	2.95	2.40	1.60	1.10	0.58	0.325	0.195	0.118	
204	57	33.2	249.5	0.67	0.61	0.50	0.41	0.30	0.23	0.14	0.083	0.058	0.038	
205	58	33.2	224.5	0.45	0.43	0.35	0.26	0.19	0.13	0.070	0.040	0.022	0.017	

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Table 5
(Continued)

Run No.	Temp. °F	e	ω rpm	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10	Reliability
206	58	20.5	201	0.75	0.64	0.45	0.38	0.25	0.15	0.083	0.048	0.025	0.022	
207	70	20.5	250.5	2.10	1.90	1.41	1.00	0.62	0.45	0.24	0.12	0.069	0.043	
208	71	21.5	200	0.87	0.75	0.48	0.34	0.20	0.145	0.060	0.030	0.015	0.010	
209	70	21.5	251	2.12	1.90	1.42	1.10	0.66	0.46	0.30	0.14	0.080	0.058	
210	71	33.8	250	0.90	0.73	0.59	0.45	0.30	0.23	0.13	0.078	0.050	0.030	
211	85	33.8	252	1.04	0.88	0.58	0.42	0.29	0.19	0.093	0.058	0.034	0.020	
212	85.2	24.6	250.5	1.90	1.65	1.21	0.75	0.47	0.32	0.169	0.085	0.051	0.030	
213	58.7	24.6	250	1.50	1.34	1.11	0.79	0.57	0.40	0.23	0.14	0.085	0.058	
214	57	15.6	250	3.17	2.85	2.35	1.80	1.30	0.83	0.45	0.31	0.187	0.130	
215	70.2	16.5	250	3.45	3.00	2.40	1.80	1.06	0.71	0.36	0.20	0.124	0.080	
216	57.2	15.4	250.5	3.87	3.45	2.75	2.07	1.50	0.93	0.50	0.27	0.163	0.112	After run 215, bracing was added to the lattice so that the data before and after run 215 are not strictly comparable.
217	56.5	16.2	251.5	3.72	3.30	2.62	2.00	1.37	0.85	0.45	0.28	0.155	0.110	
218	58.7	17.6	251	3.65	3.22	2.55	1.95	1.30	0.78	0.40	0.27	0.150	0.106	
219	60	25.0	251	2.17	1.90	1.53	1.15	0.68	0.44	0.25	0.13	0.090	0.060	
220	61	31.8	251	1.32	1.15	0.83	0.66	0.43	0.26	0.148	0.085	0.052	0.035	
221	60.5	37.1	251	0.88	0.74	0.59	0.46	0.34	0.24	0.14	0.08	0.046	0.030	
222	60.7	42.2	251.5	0.60	0.57	0.46	0.37	0.28	0.19	0.092	0.055	0.030	0.020	
223	60.2	52.2	250.5	0.34	0.32	0.28	0.22	0.16	0.11	0.060	0.038	0.020	0.015	
224	80.2	50.5	249.3	0.33	0.31	0.24	0.19	0.12	0.075	0.040	0.020	0.014	0.008	
225	80	43.9	250	0.56	0.48	0.41	0.31	0.21	0.125	0.053	0.030	0.017	0.010	
226	80	36.7	250	0.97	0.85	0.64	0.47	0.28	0.19	0.071	0.042	0.024	0.015	
227	80.2	26.6	249.5	2.30	1.97	1.40	0.90	0.50	0.30	0.14	0.071	0.040	0.026	
228	80	21.3	249	3.30	2.80	1.96	1.30	0.69	0.41	0.19	0.091	0.050	0.030	
229	80	14.6	251.5	5.00	4.15	2.90	2.00	0.98	0.56	0.25	0.13	0.084	0.058	
230	98	16.1	250.5	5.10	4.25	2.65	1.80	0.75	0.40	0.15	0.072	0.045	0.027	
231	98.5	21.5	248.5	3.30	2.85	1.80	1.08	0.50	0.25	0.098	0.051	0.031	0.020	
232	99	27.1	250	1.85	1.59	1.05	0.65	0.30	0.16	0.064	0.040	0.018	0.013	
234	100.5	44.1	251	0.49	0.41	0.29	0.22	0.18	0.15	0.10	0.031	0.020	0.015	

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Table 5
(Continued)

Run No.	Temp °F	e	ω rpm	Sediment concentration percent by volume Sample Hole No.										
				1	2	3	4	5	6	7	8	9	10	Reliability
379	69	21	251.5	2.7	2.5	1.9	1.36	0.92	0.65	0.35	(h = 12 in.)			
380	70.7	21	251	2.5	2.3	1.75	1.25	0.81	0.57	0.37	(h = 12 in.)			
381	74.2	17	252	3.3	3.0	2.4	1.72	1.20	0.85		(h = 12 in.)			
382	75	18	250	3.1	2.95	2.1	1.55	1.0	0.70		(h = 12 in.)			
383	74.3	19	248.7	3.05	2.55	2.00	1.45	0.90	0.60	0.38	(h = 13 in.)			
384	70	19.8	249.5	2.8	2.6	2.0	1.30	0.89	0.63	0.38	(h = 13 in.)			
385	52.7	19.9	250	2.5	2.3	1.87	1.43	1.00	0.68	0.40	0.24	0.147	0.111	
386	55.5	20	250	2.7	2.5	2.0	1.49	1.03	0.70	0.39	0.24	0.145	0.100	
387	59.7	20	249	2.8	2.45	1.90	1.57	1.05	0.72	0.36	0.22	0.13	0.09	
396	47.2	27.1	249	1.21	1.15	0.94	0.80	0.55	0.395	0.225	0.150	0.091	0.069	
397	49.7	27.1	251.5	1.20	1.15	0.94	0.795	0.55	0.40	0.23	0.150	0.099	0.073	
398	51.7	27.1	249.5	1.14	1.04	0.88	0.725	0.51	0.355	0.205	0.140	0.087	0.069	
399	59.5	27.1	250	1.10	1.08	0.86	0.70	0.46	0.32	0.18	0.11	0.071	0.051	
400	66.7	27.1	249.5	1.16	1.09	0.86	0.665	0.425	0.28	0.15	0.090	0.060	0.043	
401	74.7	27.1	250	1.17	1.10	0.84	0.625	0.395	0.25	0.125	0.075	0.047	0.035	
402	81.5	27.1	249.5	1.19	1.10	0.83	0.63	0.35	0.22	0.11	0.060	0.040	0.030	
403	88.5	27.1	249.5	1.21	1.10	0.78	0.575	0.325	0.19	0.080	0.050	0.030	0.025	
404	94.5	27.1	249.5	1.20	1.09	0.76	0.55	0.30	0.175	0.080	0.045	0.029	—	
405	99.5	27.1	249.5	1.23	1.10	0.75	0.55	0.275	0.15	0.065	0.037	0.023	—	

Table 6

Date for temperature studies using glass spheres with a mean diameter of 20 microns
Agitator stroke = 1 15/16 in. Depth h = 2 ft

Run No.	Temp $^\circ$F	e*	ω rpm	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10
353	71.5	42.1	250	1.50	1.50	1.52	1.42	1.36	1.09	1.00	0.91	0.78	0.72
354	72.5	42.1	250.5	1.40	1.37	1.35	1.30	1.24	1.14	0.95	0.89	0.79	0.73
355	81	42.1	249.5	1.25	1.32	1.30	1.18	1.10	0.93	0.80	0.75	0.70	0.63
356	81	33.1	250	1.60	1.70	1.62	1.50	1.38	1.20	1.00	0.90	0.80	0.77
357	80.7	22.9	249.5	2.20	2.25	2.15	1.90	1.75	1.55	1.20	1.08	0.95	0.90
358	80.2	18.1	250	2.6	2.7	2.5	2.3	2.0	1.8	1.45	1.30	1.10	1.00
359	98.7	18.1	250	2.7	2.8	2.7	2.45	2.1	1.80	1.40	1.15	0.95	0.85
360	100	30.1	249.5	2.0	2.05	2.0	1.9	1.75	1.51	1.20	1.00	0.88	--
361	101	40.5	250	1.35	1.45	1.43	1.35	1.28	1.10	0.87	0.75	0.68	0.58
362	68	29.9	251	1.74	1.74	1.70	1.63	1.54	1.40	1.20	1.05	0.94	0.89
363	69	33.0	250.5	1.71	1.67	1.64	1.60	1.47	1.34	1.12	0.98	0.89	0.82
364	104	33.8	251.5	1.81	1.72	1.78	1.65	1.41	1.16	0.90	0.75	0.70	0.59
365	103.2	25.8	249.5	2.2	2.2	2.1	1.93	1.68	1.34	1.10	0.89	0.81	0.68
366	103.5	16.8	249.5	2.95	2.90	2.60	2.50	2.00	1.70	1.33	1.15	0.97	0.85
367	90.2	17.0	251.7	2.85	2.70	2.60	2.30	2.03	1.80	1.35	1.08	0.98	0.90
368	89.7	26.5	249.5	2.07	2.00	1.90	1.70	1.52	1.27	1.04	0.87	0.75	0.67
369	89.7	38.1	249	1.42	1.30	1.30	1.20	1.06	0.90	0.73	0.63	0.55	0.50
370	107	38.1	251	1.55	1.50	1.35	1.22	1.05	0.88	0.69	0.60	0.50	--
371	104.9	22.6	249.5	2.55	2.5	2.25	2.0	1.65	1.37	1.12	0.87	0.75	0.67
372	79.8	23.1	250	2.65	2.60	2.50	2.25	2.0	1.90	1.70	(h = 13 in.)		
373	78.3	23.1	250.5	2.65	2.60	2.50	2.35	2.20	2.10		(h = 9.5 in.)		
375	71	15	247.5	2.9	2.8	2.6	2.5	2.2	2.0	1.70	1.50	1.30	1.15
376	70	25.7	251	1.85	1.80	1.75	1.67	1.53	1.35	1.20	1.00	0.90	0.77
377	70.2	35	250	1.65	1.55	1.50	1.38	1.35	1.18	1.06	0.84	0.75	0.65

*e is recorded in 64ths of an inch.

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Table 6
(Continued)

Run No.	Temp °F	e	ω rpm	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10
406	64	12.7	251	3.4	3.2	3.0	2.85	2.60	2.40	2.0	1.8	1.4	1.28
407	65	12.7	251.5	3.3	3.1	2.9	2.8	2.60	2.30	2.0	1.75	1.36	1.23
408	72	12.7	249	3.2	3.1	2.8	2.7	2.4	2.2	1.85	1.60	1.22	1.18
409	78.5	12.7	249	3.3	3.2	2.95	2.8	2.5	2.2	1.85	1.62	1.24	1.15
410	84.5	12.7	250.5	3.4	3.2	3.0	2.8	2.65	2.20	1.85	1.60	1.20	1.09
411	89.5	12.7	251	3.4	3.2	3.0	2.8	2.62	2.20	1.80	1.58	1.20	1.07
412	94.5	12.7	250.5	3.4	3.25	3.0	2.8	2.4	2.15	1.77	1.50	1.12	1.00
413	99.5	12.7	250	3.42	3.28	3.0	2.8	2.4	2.02	1.70	1.40	1.09	0.97
414	66.2	26.4	250	2.4	2.3	2.15	2.0	1.88	1.75	1.60	1.40	1.23	--
415	71.5	26.4	249.5	2.25	2.20	2.10	1.97	1.80	1.65	1.48	1.30	1.02	--
416	78.5	26.4	250	2.15	2.12	2.05	1.89	1.70	1.57	1.35	1.15	0.96	--
417	83.6	26.4	250	2.28	2.20	2.10	1.98	1.80	1.60	1.33	1.17	0.90	--
418	91	26.4	249	2.30	2.25	2.10	2.00	1.80	1.62	1.30	1.10	0.87	0.71
419	95.5	26.4	249	2.35	2.32	2.20	2.02	1.85	1.65	1.30	1.07	0.79	0.71
420	100.5	26.4	249	2.30	2.25	2.10	2.00	1.80	1.60	1.23	0.99	0.73	0.65

Table 7

Data for seepage studies using glass spheres
with a mean diameter of 60 microns
Agitator stroke = 1 15/16 in. Depth h = 2 ft
Seepage area = 210 sq. in.

Run No.	Temp °F	e*	(ω) rpm	Seepage cc/min	Sediment concentration percent by volume Sample Hole No.										
					1	2	3	4	5	6	7	8	9	10	Reliability
235-239	(unreliable because of leakage thru bottom)														
240	68.2	12.9	249.5	830	3.10	2.85	2.08	1.31	0.74	0.46	0.25	0.148	0.108	0.070	Leakage thru bottom
241	61.7	21.2	251	850	1.75	1.62	1.10	0.75	0.45	0.30	0.18	0.098	0.069	0.045	
242	61.7	23.0	251.5	0	1.85	1.71	1.22	0.86	0.53	0.35	0.19	0.118	0.081	0.060	
243	62	24.8	250.5	820	1.50	1.35	1.01	0.64	0.40	0.26	0.145	0.090	0.064	0.049	
244	62	26.6	252	0	1.35	1.23	0.87	0.60	0.35	0.25	0.13	0.089	0.062	0.042	
245	62	28.4	251.5	750	1.18	1.10	0.80	0.51	0.31	0.21	0.11	0.078	0.054	0.032	
246	63.5	30.1	251	0	1.09	0.99	0.73	0.50	0.30	0.21	0.11	0.079	0.060	0.038	
247	63	33	252	730	0.95	0.86	0.61	0.40	0.25	0.17	0.10	0.064	0.045	0.030	
248	63	36	253	0	0.75	0.70	0.55	0.38	0.24	0.17	0.09	0.063	0.049	0.030	
249	70.5	19.1	251.5	0	2.5	2.1	1.50	1.06	0.59	0.36	0.20	0.120	0.080	0.050	Chamois bottom -- results questionable
250	69.7	20	252	-295	1.75	1.60	1.20	0.87	0.51	0.35	0.22	0.133	0.100	0.075	
251	70	20.9	252.5	0	2.10	1.82	1.35	0.93	0.55	0.38	0.23	0.143	0.108	0.081	
252	70	21.8	252	-280	1.90	1.75	1.33	0.98	0.60	0.43	0.26	0.183	0.130	0.093	
253	69.7	22	251	0	2.00	1.77	1.35	0.95	0.55	0.37	0.23	0.150	0.113	0.082	
254	69.7	22.1	250.5	-385	2.40	2.15	1.63	1.17	0.71	0.46	0.30	0.189	0.135	0.100	
255	70.2	22.3	249	0	2.00	1.82	1.30	0.90	0.55	0.40	0.24	0.166	0.122	0.085	
256	70.2	22.4	250	-455	3.50	3.00	2.15	1.49	0.90	0.59	0.35	0.22	0.165	0.116	
257	70.5	22.6	250	-170	2.25	2.10	1.70	1.22	0.69	0.45	0.27	0.183	0.131	0.092	
258	70	22.8	250	0	1.85	1.66	1.20	0.83	0.50	0.34	0.21	0.142	0.104	0.078	
259	70	23	251	-215	1.50	1.35	1.00	0.71	0.42	0.29	0.185	0.120	0.090	0.065	
260	70.5	20.3	249	-450	4.35	3.70	2.80	1.95	1.20	0.73	0.40	0.24	0.16	0.113	
261	70.2	21.5	254	0	1.88	1.68	1.28	0.91	0.55	0.35	0.20	0.13	0.10	0.069	
262	70	22.8	253	225	1.73	1.60	1.20	0.82	0.50	0.31	0.20	0.118	0.087	0.065	
263	73	24	253	0	1.80	1.65	1.25	0.88	0.52	0.33	0.20	0.115	0.085	0.057	

*e is recorded in 64ths of an inch.

Table 7
(Continued)

Run No.	Temp. °F	e*	ω rpm	Seepage cc/min	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10	Reliability
264	70.2	25.4	253	1190	1.35	1.22	0.90	0.61	0.37	0.21	0.15	0.080	0.060	0.047	Chamois bottom -- results questionable
269	70	15.5	250	0	3.70	3.35	2.40	1.85	1.12	0.68	0.39	0.22	0.152	0.098	
270	70	15.5	250.5	180	3.30	3.00	2.10	1.57	0.86	0.55	0.30	0.183	0.120	0.090	
271	70	15.6	250	0	3.40	3.05	2.20	1.62	0.95	0.60	0.34	0.215	0.139	0.097	
272	70	15.7	251	245	3.30	2.90	2.13	1.54	0.86	0.53	0.30	0.180	0.120	0.78	
273	70.5	15.7	250	0	3.55	3.10	2.30	1.71	1.00	0.62	0.35	0.200	0.130	0.091	
274	70	15.4	250	0	3.8	3.2	2.4	1.85	1.2	0.65	0.37	0.21	0.128	0.085	
275	70.1	15.2	249.5	0	3.60	3.2	2.22	1.74	1.05	0.65	0.34	0.20	0.123	0.095	
276	70.5	14.9	251	0	3.70	3.25	2.3	1.80	0.95	0.61	0.35	0.192	0.130	0.095	
277	70.5	15.6	251.5	282	3.40	2.85	2.08	1.60	0.80	0.51	0.27	0.158	0.108	0.080	
278	69.7	16.2	252	637	3.00	2.60	1.85	1.42	0.74	0.44	0.25	0.148	0.098	0.070	
279	69.7	16.9	251.5	0	3.40	3.07	2.15	1.70	0.93	0.55	0.31	0.190	0.121	0.090	
280	70.1	16.3	251	0	3.75	3.30	2.50	1.90	1.05	0.69	0.36	0.212	0.140	0.100	
281	69.5	16.6	250.5	800	3.10	2.77	1.95	1.49	0.75	0.50	0.27	0.158	0.100	0.075	
282	70	16.9	251	155	3.40	3.00	2.10	1.65	0.90	0.56	0.30	0.180	0.115	0.080	
283	70	17.2	250.5	0	3.40	2.95	2.15	1.67	0.93	0.60	0.34	0.208	0.140	0.093	
284	70	21.5	250	0	2.4	2.1	1.52	1.15	0.65	0.44	0.23	0.14	0.089	0.062	
285	71	26.5	251.5	0	1.53	1.37	1.05	0.68	0.40	0.26	0.145	0.086	0.060	0.040	
286	70.2	23.9	250.5	0	1.90	1.60	1.23	0.85	0.51	0.32	0.16	0.10	0.067	0.046	
287	69.5	21.5	252.5	0	2.6	2.4	1.8	1.22	0.77	0.48	0.25	0.146	0.093	0.065	
288	71	21.3	249	0	2.45	2.10	1.50	1.07	0.61	0.41	0.20	0.120	0.079	0.056	
289	70.7	23.3	250	0	2.00	1.7	1.30	0.88	0.53	0.32	0.17	0.092	0.060	0.041	
290	70	19.0	251	0	3.1	2.7	1.95	1.42	0.82	0.52	0.27	0.15	0.100	0.070	
291	70.2	17.7	250	0	3.3	2.9	2.2	1.46	0.86	0.55	0.28	0.157	0.103	0.072	
292	70	16.5	250.5	0	3.2	2.8	2.2	1.6	0.87	0.55	0.29	0.174	0.108	0.077	
293	69.5	18.3	251	1000	2.55	2.25	1.60	1.13	0.66	0.41	0.22	0.13	0.08	—	
294	70	16.0	249	850	2.90	2.70	1.90	1.30	0.75	0.45	0.22	0.11	0.07	0.046	
295	70.7	16.1	250.5	730	2.85	2.60	1.85	1.20	0.71	0.43	0.20	0.104	0.065	0.040	
296	70	16.1	250	225	3.10	2.70	2.00	1.30	0.78	0.46	0.22	0.115	0.070	0.040	
297	70	16.2	250	0	3.5	3.20	2.30	1.60	0.96	0.58	0.26	0.150	0.090	0.060	

Table 7
(Continued)

Run No.	Temp °F	e	ω rpm	Seepage cc/min	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10	Reliability
298	70	16.3	251	670	2.90	2.65	1.90	1.31	0.75	0.48	0.21	0.11	0.070	0.042	
299	70	16.3	250.5	410	3.20	2.80	2.10	1.45	0.81	0.51	0.24	0.125	0.078	0.050	Chamois bottom -- results questionable
300	70	16.3	250	470	3.05	2.70	1.90	1.35	0.80	0.46	0.23	0.115	0.071	0.048	
301	70	16.3	250	115	3.5	3.10	2.25	1.60	0.94	0.57	0.29	0.145	0.090	0.056	
302	70	16.6	250	0	3.6	3.15	2.40	1.60	1.01	0.63	0.33	0.170	0.10	0.070	
303	69.5	17.6	250	980	2.75	2.50	1.80	1.30	0.79	0.50	0.24	0.12	0.078	0.050	
304	70	18.7	250.5	720	3.00	2.75	1.95	1.36	0.84	0.53	0.26	0.13	0.080	0.053	
305	69.2	17.2	251.5	0	3.45	3.15	2.40	1.60	1.07	0.70	0.35	0.170	0.105	0.070	
323	70.5	15.1	250	0	4.0	3.4	2.6	1.9	1.12	0.68	0.31	0.16	0.09	--	
324	72	15.1	249.5	-200	3.4	3.1	2.2	1.7	0.93	0.60	0.30	0.15	0.10	0.068	
325	69.7	15.5	250.5	-220	3.6	3.2	2.4	1.85	1.01	0.66	0.33	0.18	0.11	0.075	
326	72	15.9	249.5	-150	3.7	3.3	2.3	1.8	1.00	0.65	0.30	0.16	0.103	0.067	
327	70	16.3	250.5	0	3.0	2.85	2.0	1.55	0.85	0.55	0.25	0.13	0.082	0.060	
328	71.5	16.7	250	-110	3.5	3.1	2.35	1.75	1.00	0.61	0.29	0.15	0.092	0.061	
329	68.5	6.9	250	0	3.3	3.1	2.25	1.70	0.98	0.65	0.30	0.163	0.10	0.068	
330	70.2	16.9	250	-160	3.4	3.2	2.35	1.8	1.00	0.64	0.30	0.166	0.10	0.071	
331	71.7	16.9	249	190	3.2	3.0	2.1	1.6	0.88	0.55	0.24	0.125	0.075	0.050	
332	68.2	16.9	249.5	310	2.9	2.7	2.0	1.5	0.85	0.50	0.23	0.13	0.078	0.050	
333	70	17.3	250.5	-190	3.4	3.2	2.25	1.75	1.0	0.65	0.32	0.17	0.108	0.078	
334	71	17.5	250	-420	3.4	3.0	2.3	1.75	1.0	0.65	0.31	0.17	0.11	0.070	
335	72	17.7	249	0	3.3	3.05	2.2	1.65	0.97	0.58	0.27	0.14	0.086	0.055	
336	69.5	17.7	249.5	0	3.2	3.1	2.3	1.73	1.00	0.62	0.31	0.17	0.10	0.068	
337	71.2	17.2	250	-190	3.5	3.3	2.5	1.8	1.09	0.67	0.33	0.172	0.105	0.070	
338	72.7	16.8	248.5	-490	3.5	3.4	2.5	1.85	1.08	0.69	0.35	0.19	0.11	0.074	
339	70.5	16.4	248.5	-370	3.2	3.0	2.1	1.65	0.93	0.60	0.29	0.158	0.096	0.060	
340	69.7	16.7	250.5	-290	3.2	3.05	2.25	1.67	0.99	0.61	0.30	0.161	0.10	0.065	
341	71.2	17.0	250.5	-525	3.5	3.3	2.3	1.75	1.06	0.69	0.32	0.18	0.11	0.078	
342	68.7	17.3	250	330	2.75	2.55	1.9	1.42	0.80	0.50	0.23	0.126	0.076	0.050	
343	70.2	18.5	250	0	2.8	2.6	1.9	1.5	0.83	0.55	0.25	0.141	0.090	0.060	
344	71.5	19.0	250	-560	3.35	3.1	2.2	1.65	1.00	0.65	0.30	0.17	0.11	0.079	

Table 7
(Continued)

Run No.	Temp °F	e	ω rpm	Seepage cc/min	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10	Reliability
345	73	19.3	250.5	0	2.8	2.6	1.9	1.4	0.82	0.51	0.24	0.138	0.090	0.060	
346	80	19.6	251	0	3.1	2.9	2.0	1.45	0.82	0.51	0.24	0.138	0.080	0.050	Doubtful sand leakage
347	80	--	249.5	0	3.0	2.8	2.0	2.34	0.81	0.47	0.22	0.120	0.072	0.043	
348	72	17.7	254.5	0	3.5	3.3	2.4	1.8	1.07	0.66	0.31	0.178	0.105	0.068	
349	73.5	17.7	250.5	0	3.3	3.0	2.2	1.65	0.90	0.55	0.27	0.15	0.093	0.055	
350	80	17.7	250	0	3.2	2.9	2.0	1.5	0.77	0.49	0.20	0.115	0.077	--	
351	80	17.7	248	0	3.2	2.9	2.0	1.5	0.75	0.45	0.20	0.11	0.072	0.050	
352	80.2	17.7	248.5	0	3.2	2.8	1.95	1.4	0.72	0.44	0.20	0.105	0.068	0.050	

Table 8

Data for seepage studies using glass spheres
with a mean diameter of 20 microns
Agitator stroke = 1 15/16 in. Depth h = 2 ft
Seepage area = 210 sq. in.

Run No.	Temp. °F	e*	ω rpm	Seepage cc/min	Sediment concentration percent by volume Sample Hole No. 1	2	3	4	5	6	7	8	9	10	Reliability
306	72.5		251.5	250	1.18	1.17	1.10	1.10	0.95	0.94	0.90	0.81	0.71	--	)Chamois
307	73		251	0	2.35	2.30	2.30	2.20	2.10	2.00	1.75	—	1.32	1.25	)
308	70		226	0	3.00	2.90	2.65	2.50	2.25	2.05	1.75	1.55	1.17	1.08	
309	71.7		226	320	2.25	2.10	2.05	1.85	1.70	1.55	1.25	1.05	0.76	0.68	
310	72		226	-635	8.0	8.0	7.6	7.0	6.3	5.4	4.7	4.2	3.6	3.3	
311	71	14.3	249.5	0	3.2	3.1	3.0	2.9	2.8	2.5	2.2	2.0	1.75	1.50	Doubtful
312	72	14.5	250	350	2.4	2.3	2.25	2.10	1.95	1.80	1.60	1.35	1.08	0.95	
313	74	14.7	250	240	2.4	2.3	2.25	2.10	1.95	1.80	1.55	1.35	1.08	0.95	
314	75	14.8	249	90	2.8	2.8	2.75	2.50	2.35	2.20	1.85	1.65	1.23	1.10	
315	71.5	15.0	251	100	2.7	2.6	2.6	2.4	2.3	2.1	1.85	1.63	1.33	1.20	
316	72.5	15.1	250	0	2.85	2.75	2.70	2.60	2.40	2.20	1.90	1.65	1.55	1.26	
317	73.5	15.3	250	-300	3.6	3.6	3.55	3.45	3.15	2.90	2.50	2.05	1.90	1.80	
318	69.5	15.3	250.5	0	2.7	2.6	2.6	2.5	2.35	2.20	1.90	1.65	1.52	1.30	
319	71	15.8	250	-140	2.4	2.4	2.35	2.25	2.10	1.90	1.65	1.45	1.35	1.15	
320	72.5	16.3	249.5	-610	7.0	7.5	7.0	6.6	6.1	5.2	4.2	3.9	3.4	3.2	
321	73	16.8	246	-310	3.9	3.9	3.8	3.6	3.4	2.9	2.5	2.2	1.95	1.90	
322	73	17.3	248	-280	3.5	3.45	3.3	3.1	3.0	2.7	2.35	2.1	1.90	1.70	

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*e is recorded in 64ths of an inch.

Table 9

Data for vermiculite sediment
Agitator stroke = 1 15/16 in.-Depth h = 2 ft

Run No.	Temp °F	e*	ω rpm	Sediment concentration percent by volume Sample Hole No.										
				1	2	3	4	5	6	7	8	9	10	Reliability
378	67	--	250	3.2	2.8	2.2	1.7	1.2	0.72	0.55	0.42	0.35	0.30	Poor-contained coarses & fines
388	67	--	249	6.5	5.6	3.4	2.4	1.3	0.85	0.40	0.25	0.19	0.15	
389	67	19.8	247.5	3.7	3.1	2.0	1.45	0.85	0.55	0.30	0.17	0.140	0.105	
390	80	20	250.5	3.8	3.2	1.95	1.50	0.75	0.47	0.23	0.155	1.122	--	
391	58	20.6	250.5	3.8	3.2	2.05	1.45	0.80	0.48	0.25	0.14	0.11	0.085	
392	58.3	20.6	249.5	3.5	3.2	1.95	1.40	0.71	0.45	0.23	0.13	0.10	0.070	
393	62.7	20.6	249.5	3.7	3.2	1.95	1.30	0.71	0.45	0.23	0.13	0.10	0.080	
394	70	--	249	3.6	3.0	1.8	1.25	0.63	0.37	0.175	0.10	0.080	0.062	
395	70.2	--	249	3.5	3.0	1.7	1.24	0.65	0.38	0.18	0.11	0.090	0.070	

e* is recorded in 64ths of an inch.

Table 10

Calculated data for glass spheres used in temperature studies

Run	Temp. °F	$\nu \times 10^5$	C	c_o	C/c_o	ϵ/wh	$\epsilon \times 10^3$	$\nu/w_oh \times 10^4$	$\nu/wh \times 10^4$	$\nu^2/gd^2h \times 10^{10}$
60 Micron Glass Spheres										
220	61	1.20	0.329	1.53	0.215	0.207	2.86	7.48	8.80	6.4
222	60.7	1.21	0.185	0.79	0.234	0.246	3.44	7.48	8.60	6.5
225	80	0.93	0.153	0.81	0.189	0.196		4.49		3.84
226	80	0.93	0.232	1.28	0.181	0.181		4.49		3.84
227	80.2	0.93	0.43	2.50	0.172	0.174	3.01	4.42	5.26	3.84
228	80	0.93	0.60	3.50	0.172	0.171		4.49	5.46	3.84
229	80	0.93	0.91	5.80	0.157	0.161		4.49	5.63	3.84
230	98	0.76	0.88	7.40	0.119	0.127	2.62	2.95	3.69	2.56
232	99	0.75	0.34	2.80	0.122	0.127	2.80	2.91	3.41	2.50
323	70.5	1.05	0.87	5.2	0.167	0.170	2.50	5.73		4.90
327	70	1.06	0.68	4.25	0.160	0.169	2.50	5.83		5.0
336	69.5	1.06	0.77	4.55	0.168	0.183	2.67	5.85		5.0
343	70.2	1.06	0.65	3.95	0.164	0.181	2.70	5.79		5.0
385	52.7	1.36	0.69	3.10	0.222	0.228		9.58		8.26
386	55.5	1.30	0.73	3.30	0.221	0.218		8.76		7.51
396	47.2	1.49	0.40	1.45	0.276	0.245	2.65	11.58	13.75	9.91
397	49.7	1.41	0.40	1.54	0.264	0.255	2.94	10.38	12.20	8.89
398	51.7	1.37	0.37	1.35	0.272	0.266	3.14	9.8	11.60	8.36
399	59.5	1.22	0.34	1.42	0.242	0.224	2.99	7.74	9.15	6.62
400	66.7	1.10	0.33	1.56	0.212	0.196	2.92	6.26	7.39	5.38
401	74.7	0.99	0.31	1.52	0.202	0.187	3.09	5.10	5.99	4.32
402	81.5	0.91	0.30	1.63	0.183	0.171	3.04	4.26	5.06	3.69
403	88.5	0.84	0.28	1.64	0.171	0.158	3.10	3.65	4.27	3.16
404	94.5	0.79	0.28	1.77	0.160	0.150	3.19	3.20	3.72	2.78
405	99.5	0.75	0.26	1.76	0.149	0.138	3.10	2.86	3.34	2.50

(Continued on next page)

Table 10
(Continued)

Run	Temp. °F	ν x 10^5	C	c_o	C/c_o	ϵ/wh	ϵ x 10^3	$\nu/w_o h$ x 10^4	ν/wh x 10^4	ν^2/gd^2h x 10^{10}
20 Micron Glass Spheres										
355	81.0	0.92	0.90	1.50	0.60	0.83		42.2		32.9
364	104.0	0.71	1.03	2.10	0.49	0.59		25.2		19.6
365	103.2	0.72	1.26	2.50	0.50	0.63	1.37	26.1-	33.0	21.0
366	103.6	0.72	1.56	3.30	0.47	0.58	1.24	26.1	33.7	21.0
367	90.2	0.82	1.56	3.10	0.50	0.64	1.15	34.5	44.7	26.2
369	89.7	0.83	0.82	1.54	0.53	0.75		34.6		26.8
370	107	0.69	0.76	1.66	0.46	0.60		23.8		18.5
375	71.0	1.04	1.82	2.98	0.61	0.82	1.23	53.6	69.3	42.0
376	70.0	1.06	1.23	1.99	0.62	0.97	1.47	55.8	69.8	43.6
377	70.2	1.06	1.05	1.67	0.63	0.97	1.47	55.8	69.8	43.6
406	64.0	1.15	2.09	3.42	0.61	0.94	1.26	65.5	86.0	51.4
407	65.0	1.13	2.09	3.36	0.62	0.98	1.33	63.4	83.0	49.8
408	72.0	1.03	1.96	3.28	0.60	0.89	1.33	52.8	69.0	41.3
409	78.5	0.95	1.79	3.43	0.52	0.81	1.33	45.0	58.0	35.1
410	84.5	0.88	1.78	3.50	0.51	0.78	1.36	38.8	50.0	30.3
411	89.5	0.84	1.78	3.54	0.50	0.76	1.42	34.8	45.0	27.4
412	94.5	0.79	1.90	3.58	0.53	0.68	1.31	30.8	40.7	24.4
413	99.5	0.75	1.88	3.57	0.53	0.65	1.34	27.8	36.4	21.9
414	66.2	1.12	1.51	2.45	0.62	0.93	1.28	62.3	81.1	49.0
415	71.5	1.04	1.51	2.40	0.62	1.01	1.53	53.5	68.7	42.0
416	78.5	0.95	1.44	2.31	0.62	0.99	1.55	45.0	60.2	35.1
417	83.6	1.08	1.44	2.45	0.59	0.87	1.53	47.9	61.3	45.5
418	91.0	0.83	1.43	2.45	0.59	0.83	1.60	33.8	42.8	26.8
419	95.5	0.78	1.45	2.55	0.57	0.79	1.55	29.4	38.4	23.7
420	100.2	0.74	1.32	2.50	0.53	0.70	1.50	27.0	34.6	21.4

Note: Frequency of agitator for all runs was 250 rpm.

Table 11

Data and calculations for determining the average fall velocity of vermiculite in still water

Sample	Number of particles	Temp. °F	Ave. fall velocity ft/sec.	Ave. fall velocity adjusted to 70°F ft/sec.
1	97	76.5	0.0098	0.0090
2	29	76.5	0.0075	0.0070
3	119	76.5	0.0090	0.0083
4	294	76.5	0.0105	0.0097
5	185	72.5	0.0090	0.0088
6	83	72.5	0.0082	0.0079
7	266	72.5	0.0079	0.0077
Total	1073			

Weighted average fall velocity at 70°F is equal to 0.0086 ft/sec

Table 12

Data and calculations for determining the fall velocity of vermiculite in turbulent water

Run	Temp °F	C/c_o	C in % by volume	ϵ/wh	ν/wh from Fig. 23	$w \times 10^2$ ft/sec	$w_o \times 10^2$ ft/sec	$w_o \times 10^2$ at 70°F ft/sec
388	67	0.141	1.24	0.146	5.0	1.06	1.33	1.39
389	67	0.15	0.75	0.15	4.9	1.11	1.36	1.42
390	80	0.132	0.71	0.139	4.1	1.11	1.35	1.19
391	58	0.129	0.72	0.139	4.2	1.46	1.78	2.08
393	62.5	0.134	0.67	0.139	4.1	1.41	1.70	1.89
394	70	0.120	0.61	0.126	3.5	1.49	1.78	1.78

Average fall velocity at 70°F is equal to 0.0163 ft/sec