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MOBIL OIL CORPORATION

RESEARCH DEPARTMENT

TECHNICAL MEMORANDUM NO. 66-6

STUDIES OF BEHAVIOR OF MIST IN GAS COMBUSTION RETORTING PROCESS

ANVIL POINTS OIL SHALE RESEARCH CENTER

Rifle, Colorado

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RH Cramer

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Program Manager

The primary object of the Anvil Points Oil Shale Research Center TECHNICAL MEMORANDUM is to advise authorized personnel employed by the Participating Parties[(1)] that various activities are in progress or that certain significant data have been obtained within the Research Center.

These TECHNICAL MEMORANDA have been prepared to provide rapid, on-the-spot reporting of research currently in progress at Anvil Points. The conclusions drawn by project personnel are tentative and may be subject to change as work progresses. The TECHNICAL MEMORANDA have not been edited in detail.

[(1)]Mobil Oil Corporation, Project Manager

Humble Oil and Refining Company
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STUDIES OF BEHAVIOR OF MIST IN GAS COMBUSTION RETORTING PROCESS

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

FIGURES

STUDIES OF BEHAVIOR OF MIST IN GAS COMBUSTION RETORTING PROCESS

A short movie has been taken covering certain phases of this work. Its purpose was to give the reader a visual representation of what is being discussed. A commentary of this movie is located in the Appendix.

STUDIES OF BEHAVIOR OF MIST IN GAS COMBUSTION RETORTING PROCESS

I. INTRODUCTION

In the retorting of oil shale by the Gas Combustion Process the oil is removed from the retort through the incoming raw shale in the form of a mist. The physical properties of this mist are determined by the conditions under which it was formed, and in turn determine how it will behave in flowing through the upper portion of the retort and through the mist recovery section.

In the Gas Combustion Process the mist leaving the top of the retort has generally been found to be log-normally distributed. The three properties of a log-normally distributed aerosol which completely describe it are (1)its median mass diameter, Dmmd, (2)its geometric standard deviation, σg, and (3)its loading. The median mass diameter is defined as that diameter below which half of the total mass of the mist exists. Compared with other averages the Dmmd favors the larger particles because of their much larger masses. The geometric standard deviation, σg, is a measure of the homogeneity of the aerosol. This quantity varies from 1 to ∞ with unity indicating a completely homogeneous mist and ∞ complete hetrogeneity. The loading is simply a measure of how much oil exists in a cubic foot of gas. The higher the loading the greater the probability of particle to particle interaction.

Because of the important position held by the mist in the Gas Combustion Process it was decided to initiate a group of studies aimed at a better understanding of how mist is formed and how it behaves when being transported through packed beds, piping and mist recovery devices. This report is therefore a group of reports on such subjects as (1)the physical properties of the mist found in the retort offgas, (2)the impaction properties of a mist as it flows through a packed bed of shale, (3)the changes in the mist properties both in the bed and above the bed, and (4)its impaction characteristics when flowing through straight circular ducts and around elbows. These studies are all designed to give a semi-quantitative understanding of the mist's characteristics as found in this type of process. The reader will find that each section of this report has been subdivided into the topics mentioned above.

II. SUMMARY

A. Retort Offgas Study

The purpose of determining the properties of the retort offgas mist was to obtain an understanding of any existing relationships between retort operating variables and the mist properties. All determinations in the retort offgas study were made by sampling the gas just as it left the top of the shale bed. Typical retort offgas mist properties were obtained during the latter part of the Demonstration Run (Series B-817). These results gave a D_{mmd} of 2.5 μ and a loading of 8 to 10 lbs oil/MSCF. This loading agreed well with the calculated value assuming 100% yield and negligible refluxing. It was also observed that generally during flooded operation, that is, operation with a region of high pressure drop near the retorting zone, the mist properties are characterized by a D_{mmd} of 3.0 μ or greater while loadings are 3 to 4 lbs oil/MSCF below the calculated value.

An attempt was also made to correlate the gas cooling rate in the 800 to 900° F region of the retort with the mist size found at the top of the retort. The results are plotted in Figure 1 and a good correlation was obtained for those runs which were not flooded. From this it was concluded that the mist was nucleated in this temperature region and that the cooling rate in this region strongly affects the mist size obtained.

B. Impaction Study

The purpose of this study was to determine quantitatively the percentage impaction, or impaction efficiency, as a function of mist particle diameter with superficial gas velocity, bed height, average shale particle diameter, and mist loading as parameters.

In order to investigate these variables, a model was built which would enable a drag stream of retort offgas to be passed through a test bed of shale. The impaction that took place in the test bed was determined by sampling the mist as it entered and left the bed. Table 1 gives a summary of the experimental conditions studied. With a mist loading in the range of 1 to 2 lbs oil/MSCF the experimental results are correlated by the following semi-theoretical equation:

$$E = 1 - e^{-0.438 Pp \sqrt{Dp^3/18 \mu Dc} \lambda}$$

Where E = particle impaction efficiency, %
Pp = density of mist particle, g/cc
V = supervicial velocity, cm/sec
Dp = diameter of particle, cm
μ = viscosity of gas, g/cm sec
$Dc = \frac{1}{10}$ APD, cm
λ = mean free path of gas, cm

This equation was derived from a theoretical equation by Jackson and Calvert[1]. With a mist loading in the range of 8 to 10 lbs oil/MSCF the experimental results are correlated by an empirical equation of the form

$$E = 1 - e^{-0.39Dp + 0.34}$$

This equation is valid only for particle diameters in the range of 1 to 6 microns.

Incipient flooding velocities were also determined for the nominal shale sizes of 1/4 to 1 inch and 1 1/2 to 3 inches. They were found to be 2.7 ft/sec and 3.3 ft/sec respectively.

The main conclusion drawn from the low mist loading work was that the equation used correlates well the experimental results. This correlation extends over all superficial gas velocities up to the flooding limit, and over all shale sizes studied. Also, as predicted by the equation there seems to be little effect of bed height over the range studied - 0.5 to 1 foot with low mist loadings. From the results obtained with the heavily loaded mist it was concluded that an inertial impaction mechanism was too simple to describe the experimental results. With this relatively unstable mist it is believed that other mechanisms such as growth or coagulation are occurring simultaneously. It is therefore much more difficult to describe theoretically.

C. Vertical Profile Study

Two vertical profiles were obtained. One was taken within the shale bed in the gas cooling zone during the Demonstration Run (Series B-817), and the other profile was taken in the vapor space above the bed. The profile taken within the bed showed a steady decrease in both the mist size and loading as the combustion zone was approached. The mist also became more homogeneous as its point of origin was approached. The main conclusion drawn from this profile was that under non-flooded conditions once nucleation occurs no additional nuclei are formed. The mist continues to grow on these nuclei as the gas moves up the retort and cools.

The purpose of the second vertical profile was to determine if there was a need for vapor take-off devices in Retort No. 3. It had been postulated that if large droplets of oil existed in the vapor space above the bed these could be removed more effectively through the use of a take-off device. The conclusion drawn from the results was that little or no change in the mist properties occurred in the vapor space above the bed, and therefore take-off devices were not necessary.

D. Basic Flow Study

The purpose of the basic flow study was to obtain information of an exploratory nature on the flow properties of the heavily loaded retort offgas. Earlier studies indicated that mist loadings dropped rapidly in the piping between the retort and the first recovery device, the multiclone. Flow in both a straight glass pipe and a 90° glass ell was studied. The results at various gas velocities and pipe configurations are presented in Table 2.

The main conclusion drawn from this work was that appreciable quantities of oil (up to 50% of the total amount of oil leaving the retort) could be removed from the mist phase by the series of elbows which existed between the retort and the multiclone.

III. DISCUSSION OF RESULTS

A. Retort Offgas Study

The major portion of the time spent on mist studies was spent in taking samples from the top of the bed. Taking these samples consisted of inserting a pipe down through the top of the retort to within one inch of the bed and then sucking the mist sample through the Cascade jet impactor for one minute. These results are then plotted on log-probability paper, and from this the median mass diameter, D_{mmd}, and the geometric standard deviation, σg, are obtained. An example of a typical retort offgas mist is shown in Figure 2. The D_{mmd} is that diameter where the line crosses the 50% point, and the σg is the ratio of the 84.1% diameter to the D_{mmd}. The loading is also obtained at this time knowing the total weight of oil collected and the total amount of gas sampled.

During the retort offgas study many samples were taken from both Retorts No. 1 and No. 2. These samples were taken under a variety of operating conditions. When the various median mass diameters were plotted against their corresponding gas cooling rates a good correlation was obtained. This plot is presented in Figure 1. The gas cooling rate, dT/dt, was obtained by graphically determining the rate of change of temperature with length, dT/dL, from the temperature profile and multiplying this by the interstitial gas velocity at the desired temperature. By trial and error this temperature was found to be in the 800 to 900^{o} F range. It was later determined that this temperature range closely corresponded to the dew point of the oil in the offgas.

During the Demonstration Run (Series B-817) typical retort offgas mist data were obtained. During the initial portion of this run (through B-817J) the D_{mmd} increased gradually until it reached a value of 3.2 μ. At that time it dropped to a value of 2.5 μ and remained there for the remainder of the run. During that time in which the D_{mmd} was increasing the pressure drop in the lower portion of the retorting zone was abnormally high. Also during this period of high pressure drop and increasing D_{mmd} the measured loadings were 3 to 4 lbs oil/MSCF below the calculated value. After adjustments were made in both the air and recycle rates (after B-817J) the mist size dropped back down to around 2.5 μ. No region of high pressure drop was observed, and the measured loadings were close to the calculated values. During this run yields reached their highest level when this latter condition existed.

B. Impaction Study

The impaction characteristics of the newly formed mist as it passes up through the raw shale preheating zone are very important. The overall amount of mist impacted, Eo, determines the amount of oil refluxing which in turn determines the amount of thermal cracking to be expected. Refluxing of impacted oil to the retorting zone in conjunction with spent shale fines is also believed to be the cause of the cohesive flow character of the shale in this region. It was therefore decided to study the quantitative effect of four parameters (1)shale average particle size, (2)bed height, (3)superficial gas velocity, and (4)mist loading on the amount impacted as a function of mist particle size. A schematic flow diagram of the unit which was used in this study is presented in Figure 3. Retort No. 2 was used as a source of the mist. An attempt was made during the initial phase of this study to generate the mist using transformer oil, Univolt 33. This approach was unsatisfactory in that sufficiently high loadings at the desired mist size could not be obtained.

Table 1 gives a summary of the experimental conditions studied. Figures 4 through 14 show the experimental results for each of the conditions listed in the table. Also shown in these figures, as a dashed line, is the correlating equation of the form

$$E = 1 - e^{-0.438 Pp \, V \, Dp^3 / 18 \mu Dc \lambda}$$

Where E = particle impaction efficiency, %

Pp = density of mist particle, g/cc

V = superficial gas velocity, cm/sec

Dp = diameter of particle, cm

μ = viscosity of gas, g/cm sec

$Dc = \frac{1}{10}$ APD, cm

λ = mean free path of gas, cm

This equation is a modification of the one proposed by Calvert and Jackson of Pennsylvania State University[1]. Their theoretical equation assumed a simple inertial impaction mechanism. The main modification is the change of the exponent on the variable Dp from 2 to 3. This was found to be essential in order to obtain a correlation. It was accomplished, however, by adding the term Dp/λ to the exponent of e so that the entire exponent would remain dimensionless. The dimensionless ratio Dp/λ is known to be an important factor when these two variables are of the same order of magnitude, but since this is not the case with these mists it will have to be considered an empirical correlation factor. The reader will note that the correlating equation predicts no effect of bed height and no effect of particle to particle interaction or mist loading. The equation was first tested using a low loading mist (1 to 2 lbs oil/MSCF). The equation was found to correlate the data with a wide variation of APD, average shale particle diameter, and up to the flooding velocity. As predicted by the equation there also seemed to be little effect of bed height.

In order to test the equation using a heavily loaded mist the position of the impactor unit had to be changed. It was moved to a position where it obtained mist directly off of the top of the retort. In this new position the loading varied from 8 to 10 lbs oil/MSCF. The results at two different bed heights (0.5 and 1.5 feet) in this high loading position are shown in Figures 10 and 11. At both bed heights the experimental curves lie well above the dashed line of the correlating equation. The measured impaction efficiency seems to be abnormally high at the lower mist particle sizes while it is somewhat low at the larger mist sizes. The abnormally high impaction efficiency observed with the smaller mist sizes may be attributed to growth of the particles. That is, the loss of particles in this size range may be due to both loss by impaction and loss by growth into the larger sizes. The same argument can also be applied to explain the lower than expected impaction efficiency of the larger particles. That is, that these particles have been somewhat replenished by growth and therefore show a lower than expected impaction efficiency.

C. Vertical Profile Study

During the course of this work two vertical mist profiles were taken. The first profile was taken within the bed itself while the second was taken in the vapor space above the bed.

The first vertical profile was taken during the Demonstration Run (B-817L); its purpose was to determine the extent of change in mist properties in the upper portion of the bed. The results are presented in Table 3. This profile shows a steady decrease in both the mist size and loading as the combustion zone is approached. The mist also becomes more homogeneous as its point of origin is approached. Calculations show that the number of particles per unit volume is roughly constant at all levels in the retort.

The purpose of the second profile was to determine whether or not there was a need for vapor take-off devices in Retort No. 3. The particle size distributions of two samples, taken simultaneously but five vertical feet apart, as shown in Figure 15. As the reader can see there is a negligible difference between these two distributions. It was thus concluded that take-off devices were not needed.

D. Basic Flow Study

The gas leaving the top of the retort and going to the mist recovery section is by most standards heavily loaded with mist. It is therefore safe to assume that its stability is very low and that its physical properties are subject to rapid change. This mist is conveyed to the various components of the mist recovery section through a series of straight pipes and elbows. During an early study of the mist recovery train it was noted that approximately 55% of the mist had been removed from the gas by the time it reached the first mist recovery device, the multiclone. Although surprising at first this high rate of removal soon becomes plausible when one considers the instability of the mist and the fact that each elbow may act as a crude cyclone. Because of this rapid drop in loading it was decided to study the flow characteristics of this mist in straight glass pipe and a glass elbow. Table 2 presents the average overall impaction efficiency obtained with the various pipe configurations at the velocities studied. Two criteria were used to establish the velocities to be studied. The calculations were based on the proposed conditions of Retort No. 3. The similar impaction parameter criterion gave a velocity of 12.9 ft/sec; while the similar velocity criterion gave a velocity of 64.7 ft/sec. As the reader can see using the straight vertical pipe with upflow very little impaction occurred with the 12.9 ft/sec velocity. Because of this an intermediate velocity of 43.5 ft/sec was used instead of the low velocity with the 90° elbow. In those runs in which a film of oil was observed to be flowing on the inside wall of the glass pipe (vertical upflow and downflow at 64.7 ft/sec) an abnormally high overall impaction was observed. This abnormally high impaction is believed to be caused by the presence of the film of oil. It was postulated that with a high gas to film contact area high impaction efficiencies result. In the case of the vertical downflow pipe configuration the film was believed to be caused by a faulty upstream skimmer.

Using the results obtained with the 90° elbow at the 43.5 ft/sec velocity it was calculated that approximately 50%

of the mist would impact in seven elbows. This closely approximates the results obtained on Retort No. 2. Seven elbows existed in the piping between the top of the retort and the multiclone and the measured loading before the multiclone was around 55% of the loading at the top of the retort.

From these results and observations it was concluded that the scrubbing action of a thick film of oil on the inside wall of the pipe may lead to higher than expected impaction efficiencies. It was also concluded that on Retort No. 3 premature impaction will probably be highest in the elbows. This conclusion is based on the zero impaction efficiency obtained with the similar impaction parameter velocity of 12.9 ft/sec.

IV. CONCLUSIONS

Following is a list of conclusions which have been drawn from the results of the various studies.

A. Retort Offgas Study

1. During non-flooded operation the median mass diameter of the mist leaving the top of the retort is directly related to the gas cooling rate in the 800 to 900° F region of the retort.

2. Non-flooded operation is characterized by a median mass diameter of around 2.5 microns and a measured loading close to the calculated value.

3. Flooded operation is characterized by a median mass diameter of 3 microns or greater and a loading of 3 to 4 lbs oil/MSCF below the calculated value. It is postulated that the remainder of the oil (the difference between the oil rate leaving the retort as a mist and the oil recovered in the mist recovery section) is leaving the retort by an entrainment mechanism the size of which is much too large to be sampled by the Cascade jet impactor.

B. Impaction Study

4. With low mist loadings (1 to 2 lbs oil/MSCF) the semi-theoretical equation correlates with the observed impaction efficiency with the particle diameter. This correlation holds up to the incipient flooding velocity and with all size ranges of shale studied.

5. As predicted by the correlating equation which applies to low mist loadings there seems to be little effect of bed height over the range studied - 0.5 to 1.0 foot.

6. Heavily loaded mist (8 to 10 lbs oil/MSCF) are not correlated by the semi-theoretical equation. A purely empirical equation was found to work over a range of particle sizes of 1 to 6 microns. The reason for the failure of the semi-theoretical equation to correlate the data was postulated to be the mechanism of growth or coagulation. This is a mechanism by which smaller particles form larger ones.

C. Vertical Profile Study

7. From the results of the profile taken within the bed it was concluded that once nuclation occurs no additional nuclei are formed; the mist continues to grow on these nuclei as the gas moves up the bed and cools.

8. Since little or no change in the mist properties occurred in the vapor space above the bed and since the size of these particles are such as to have very low terminal velocities relative to that of the gas, it was concluded that vapor take-off devices were not needed in Retort No. 3.

D. Basic Flow Study

10. From the limited results of the basic flow study it was concluded that the presence of a film of oil on the inside wall of a pipe could materially influence the rate of impaction of mist flowing through the pipe. It was also concluded from the results with the 90^{o} elbow that with the number of elbows existing on Retort No. 2 it was possible to collect 50% of the oil before the first mist recovery device, the multiclone.

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(3) Brink, J. A., Ind. Eng. Chem., 50, 645-8, (1958).

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APPENDIX A

Description of Cascade Jet Impactor

The instrument used in this work to obtain the particle size distributions was the Model CI-S-6 Cascade Jet Impactor. It was purchased from Scientific Advances, Inc. of Columbus, Ohio. This instrument was composed of six impaction stages and a final filter. The characteristic diameters of the six stages were 16, 8, 4, 2, 1 and 0.5 microns. The principle by which the impactor works is shown schematically in Figure 16. When preparing to take a sample of mist the jet impactor was installed in an isothermal box and preheated to the desired sampling temperature. Mist was then pumped through the by-pass system for approximately 30 seconds and then switched to the impactor for the proper sampling time. The weight of oil obtained on each planchet from each stage was determined, and from this the particle size distribution plotted. Some references (2), (3) and (4) concerning the design of the Cascade jet impactor are given in the bibliography.

APPENDIX B

COMMENTARY FOR TECHNICAL FILM 66-1

STUDIES OF BEHAVIOR OF MIST IN GAS COMBUSTION RETORTING PROCESS

Approximate Length of Film - 200 Feet
Approximate Projection Time - 8 Minutes

During various portions of the mist studies movies were taken. These movies were made in order to give the reader a better understanding of the physical phenomena which occur both inside the retort and inside a pipe carrying mist from the retort. Both lucite and glass were used as materials of construction. Lucite was used to construct the impactor, the unit used in the mist impaction work; while glass was used in the basic flow study through pipes.

There are four sections in the film. The first section shows the results when mist is fed to a packed bed of one foot diameter and one foot bed depth. The second, third and fourth sections of the movie show the results of flow in both a straight pipe and an elbow. It is suggested that the reader first read the commentary and then watch the film.

I. Mist Impaction Study

The conditions of these tests were:

Superficial Gas Velocity = 2.0 ft/sec
Nominal Shale Size = 1/4 to 3 inches
Bed Height = 1 foot

The initial condition shown is with the bed oil wet and drained and with no gas flowing (0800 hours). The mist laden gas is then turned on as seen by the yellow gas in the void space above the bed. As impaction begins to occur and oil accumulates in the bed small rivulets of oil may be seen running countercurrent to the gas. One can also see the reflection of light off of drops of oil which have collected on the undersides of pieces of shale.

In order to show the bed in a flooded condition at 0830 the superficial velocity was increased to 3.0 ft/sec. If the reader will watch the lower portion of the bed he will see the gradual filling up of the interstices with oil. This is especially noticeable initially in the middle of the lower portion of the bed. Gradually the flood works its way up the bed until entrainment of large drops of oil is visible in the vapor space above the bed. Several closeups of the bed are given in order to show the flow of gas up through the flooded zone.

II. Flow of Mist in Vertical Pipe

Initially the pipe is shown with no flow. The mist ladened gas is then turned on and the velocity is set at 63.4 ft/sec. A rapid buildup of a turbulent film on the inside wall of the pipe is soon seen. This buildup continues until the film is so thick as to make it impossible to see inside the pipe.

III. Flow of Mist in a Horizontal Pipe

Initially the pipe is shown clean and empty. The gas is then turned on and the velocity is set at 64.7 ft/sec. This is clearly shown by the yellow color which rapidly fills the pipe. Small rivulets of oil and water soon form. They flow down the pipe and feed into a larger stream of oil and water flowing along the bottom of the pipe. A closeup of this larger river of liquid product flowing along the bottom of the pipe is also shown.

IV. Flow in a 90° Elbow

The glass elbow used in this experiment was a very sharp 90° elbow. The velocity used in this test was 64.7 ft/sec. The elbow is shown initially with no flow; the gas is then turned on, and the entrance of the mist is easily seen by its yellow color. The sudden change from a bright yellow to a red color is due to a lapse in time in which a red film has built up on the inside surface of the glass. One can see the impaction of large droplets on the far wall of the turn and soon rivulets of oil form around the impaction area.

TABLE 1

SUMMARY OF IMPACTION STUDY RUN CONDITIONS

Shale Size, Inches	Bed Height, Feet	Superficial Velocity, ft/sec	Mist Loading lbs Oil/MSCF	Figure No.
1/4 - 3/4	1.0	1	1 - 2	4
1/4 - 1	0.5	2	1 - 2	5
3/4 - 1 1/2	1.0	2	1 - 2	6
3/4 - 1 1/2	1.0	3	1 - 2	7
3/4 - 1 1/2	0.5	2	1 - 2	8
3/4 - 1 1/2	0.5	3	1 - 2	9
3/4 - 1 1/2	0.5	2	8 - 10	10
3/4 - 1 1/2	1.5	2	8 - 10	11
1 1/2 - 3	1.0	3	1 - 2	12
1/4 - 3	1.0	2	1 - 2	13
Retorting Zone	1.0	0.5	1 - 2	14

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8/22/66

TABLE 2

BASIC FLOW STUDY RESULTS

Pipe Configuration	Velocity ft/sec	Average Overall Impaction Efficiency Eo, %
Vertical - Straight - 10 Ft (Up Flow)	12.9	0
Vertical - Straight - 10 Ft (Up Flow)	64.7	53.7
Horizontal - Straight - 10 Ft	64.7	0
90° Ell	64.7	24.3
90° Ell	43.5	7.6
Vertical - Straight - 10 Ft (Down Flow)	64.7	15.6

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TABLE 3

VERTICAL MIST PROFILE IN RAW SHALE PREHEATING ZONE

Distance Above Air Inlet, Ft[1]	8	6	4	2
Dmmd, μ	2.36	2.28	1.82	Plugged with fines
Geo. Std. Dev., σg	1.65	1.60	1.49	
Measured Loading, lbs Oil/MSCF	9.36	8.04	5.61	
Temperature, $^{\circ}$F	140	300	470	800

(1) Top of bed estimated to be one foot below bottom of feed chute.

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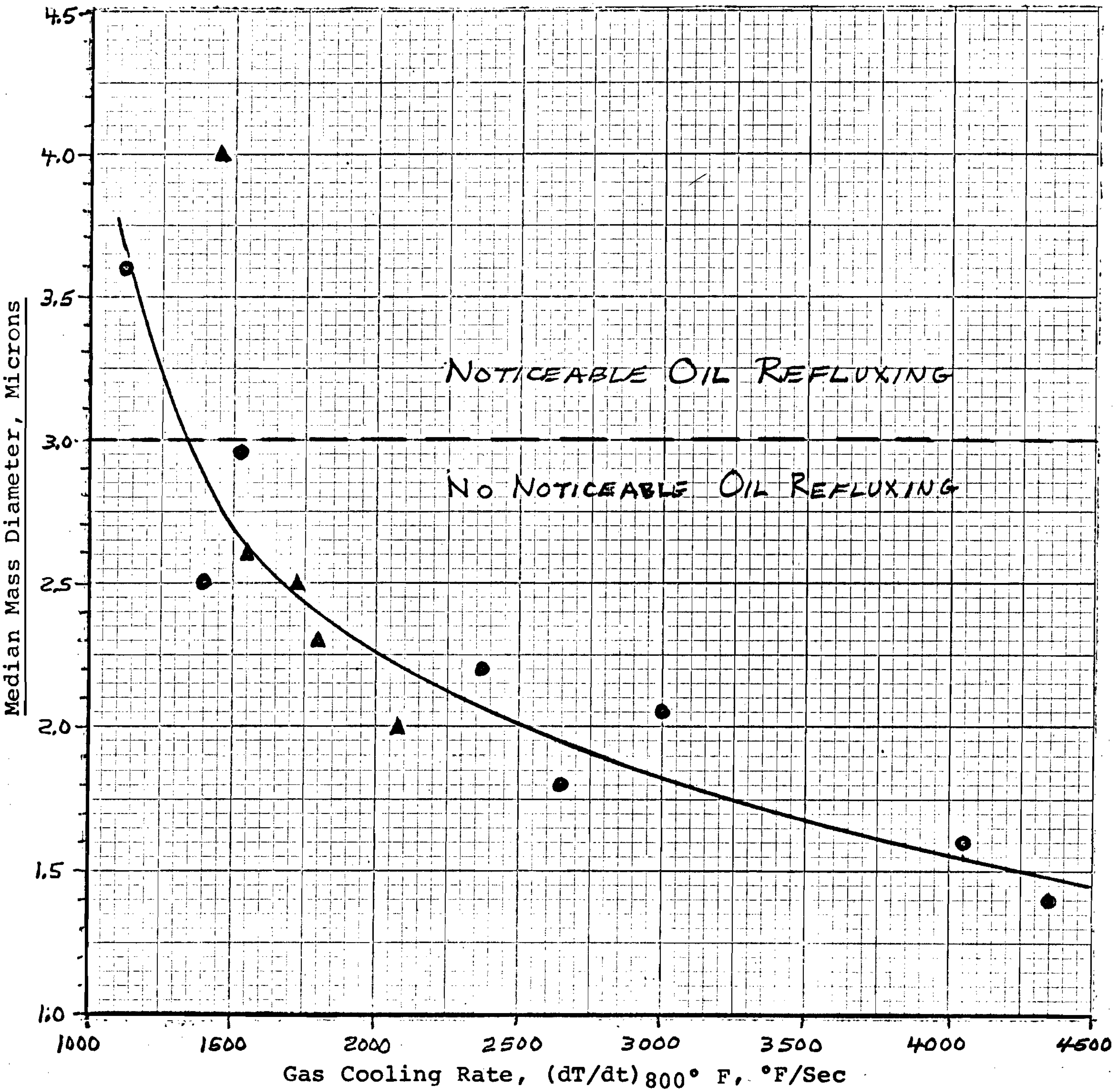
8/22/66

FIGURE 1

EFFECT OF GAS COOLING RATE ON
OIL MIST SIZE LEAVING RETORT

▲ - Retort No. 2

● - Retort No. 1



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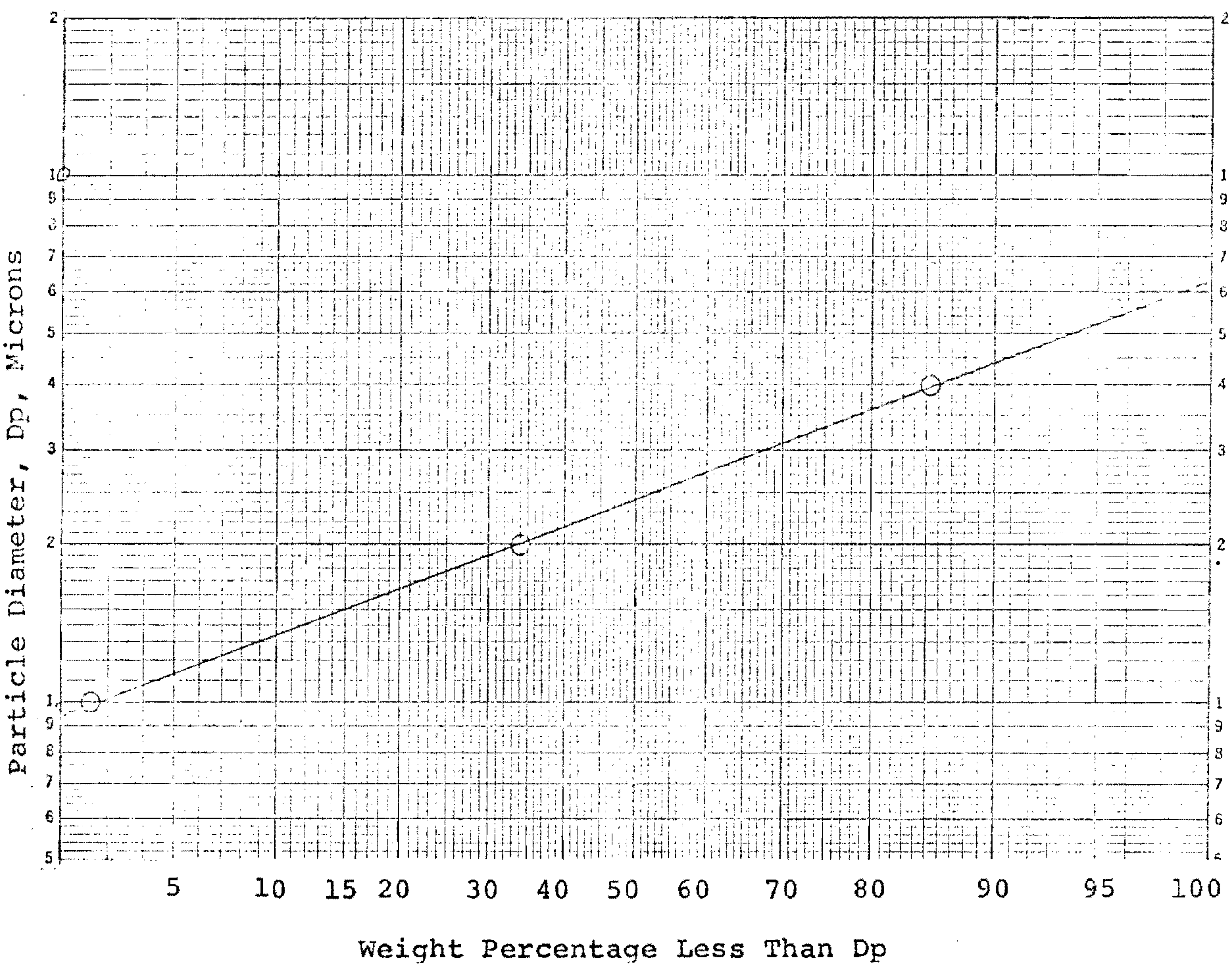
1/12/66

FIGURE 2

TYPICAL RETORT OFFGAS PARTICLE SIZE DISTRIBUTION

Test 48
Run 813
Retort No. 1
2-2-66

Dmmd = 2.43 μ
σg = 3.85/2.43 = 1.58
Lm = 8.69 #/MSCF (15%)



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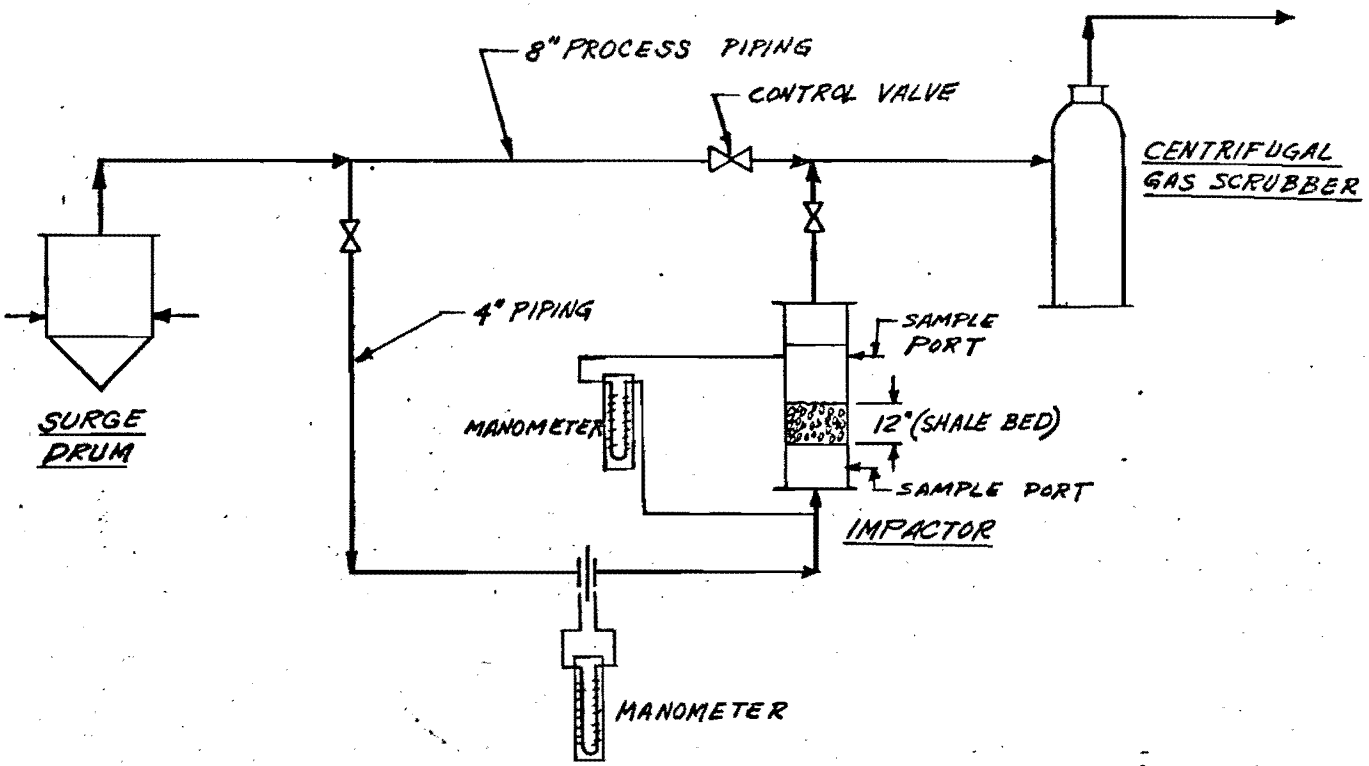
8/22/66

FIGURE 3



NO.	DATE	PRINT ISSUED TO

ANVIL POINTS
OIL SHALE RESEARCH CENTER
RIFLE, COLO.
PROJECT MANAGER-SOCONY MOBIL OIL CO., INC.

JOB NO.	CHARGE		
APPROVED	PROCESS	DESIGN	SAFETY

SCALE: None
DRAWN BY: J. Hamilton
STARTED: 2-1-66
COMPLETED: 2-1-66
DIMENS. CHECK

IMPACTOR UNIT
FLOW DIAGRAM

LOCATION

DRAWING NO. RE SK 75

D397 (8-55)

FIGURE 4

IMPACTION EFFICIENCY VERSUS PARTICLE DIAMETER FOR 1/4 TO 3/4 INCH SHALE AT 1 FT/SEC SUPERFICIAL VELOCITY

Conditions

Superficial Velocity - 1 ft/sec
Bed Height = 1 ft
Nominal Shale Size = 1/4 to 3/4 Inch
APD = 0.282 Inch

Test 97 ○ Eo = 15%
Test 98 △ Eo = 15.9%

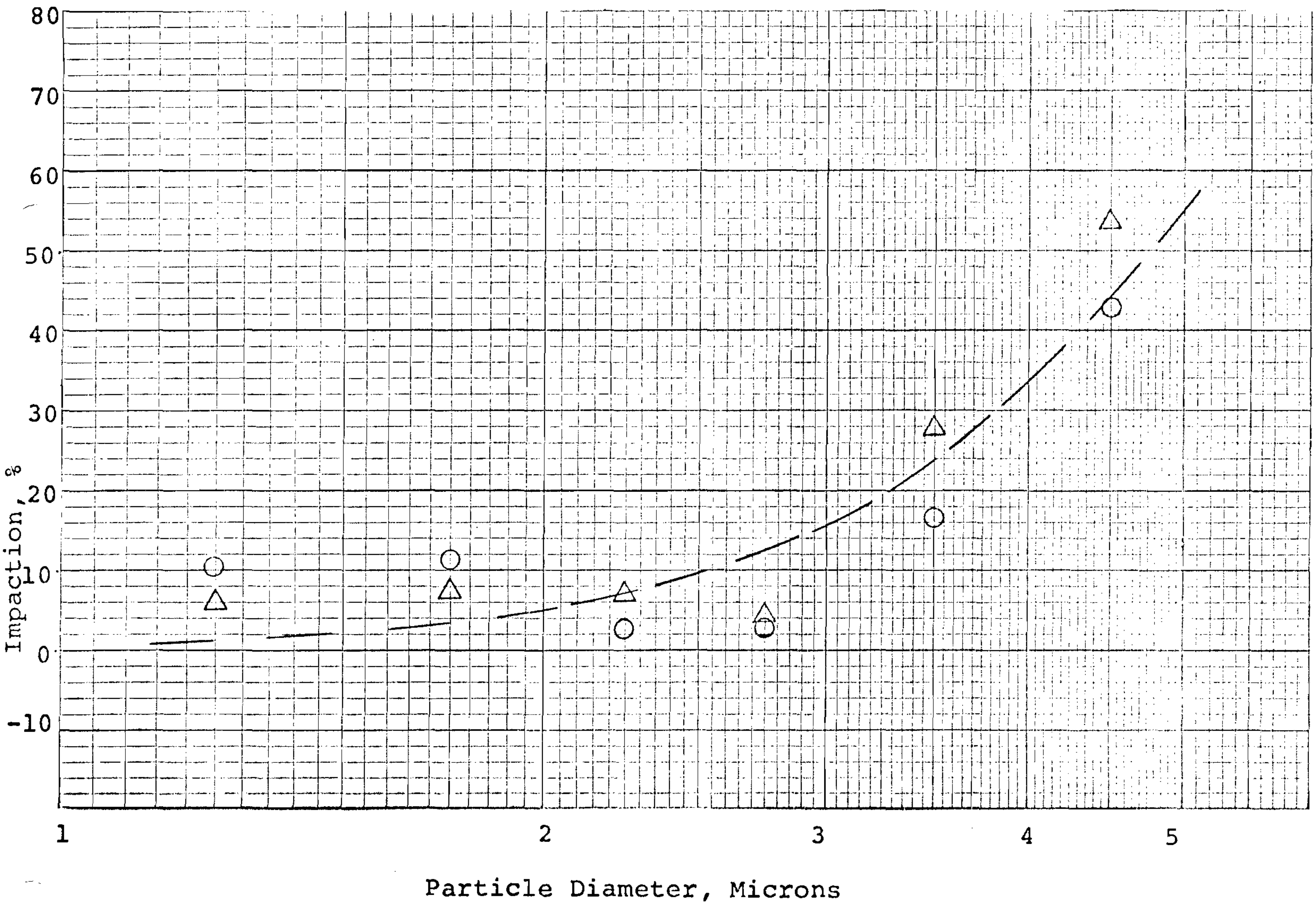


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FIGURE 5

IMPACTION EFFICIENCY VERSUS PARTICLE DIAMETER FOR
1/4 TO 1 INCH SHALE AT 2 FT/SEC SUPERFICIAL VELOCITY

Conditions

Superficial Velocity = 2 ft/sec
Bed Height = 0.5 ft
Nominal Shale Size = 1/4 to 1 Inch
APD = 0.50 Inch

Test 123 = ○ Eo = 26.3%
Test 127 = △ Eo = 19.4%

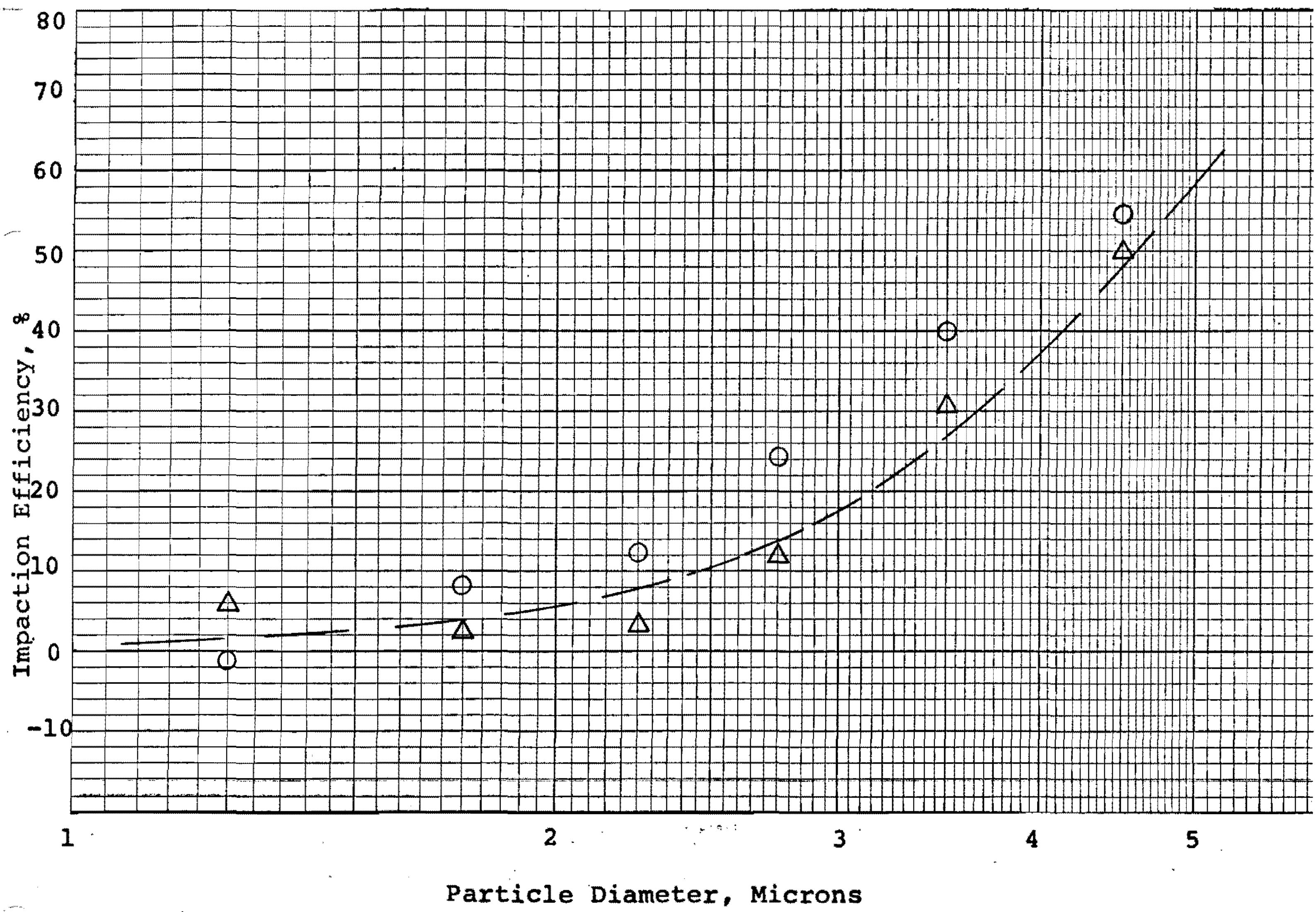

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FIGURE 6

IMPACTION EFFICIENCY VERSUS PARTICLE DIAMETER FOR
3/4 TO 1 1/2 INCH SHALE AT 2 FT/SEC SUPERFICIAL VELOCITY

Conditions

Superficial Velocity = 2.0 ft/sec
Bed Height = 1 ft
Nominal Shale Size = 3/4 to 1 1/2 Inch
APD = 0.41 Inch

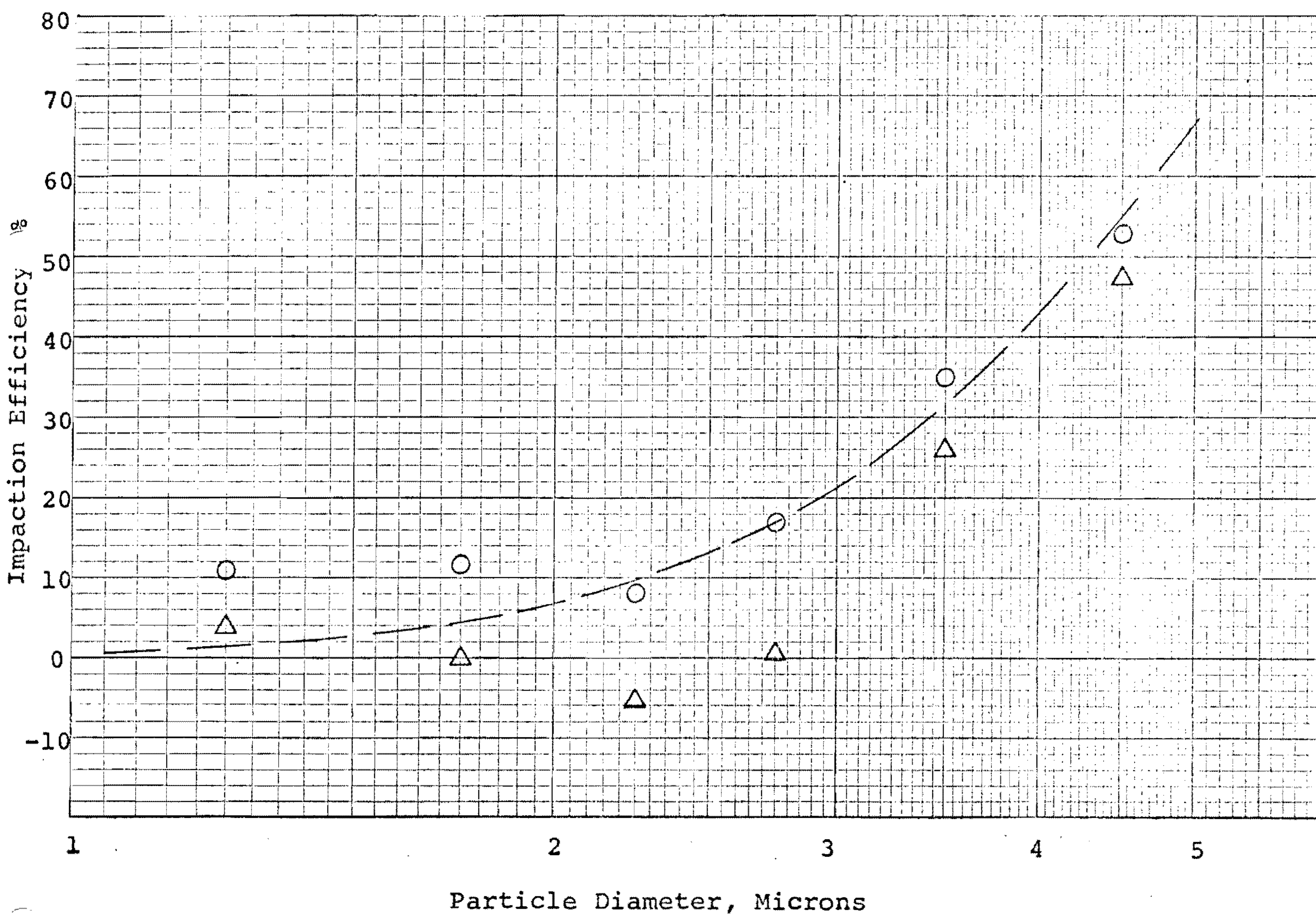

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FIGURE 7

IMPACTION EFFICIENCY VERSUS PARTICLE DIAMETER FOR
3/4 TO 1 1/2 INCH SHALE AT 3 FT/ SEC SUPERFICIAL VELOCITY

Conditions

Superficial Velocity = 3.0 ft/sec
Bed Height = 1 ft
Nominal Shale Size = 3/4 to 1 1/2 Inch
APD = 0.41 Inch

Test 77 = □ Eo = 18.3%
Test 78 = △ Eo = 25.5%
Test 79 = ○ Eo = 26.3%

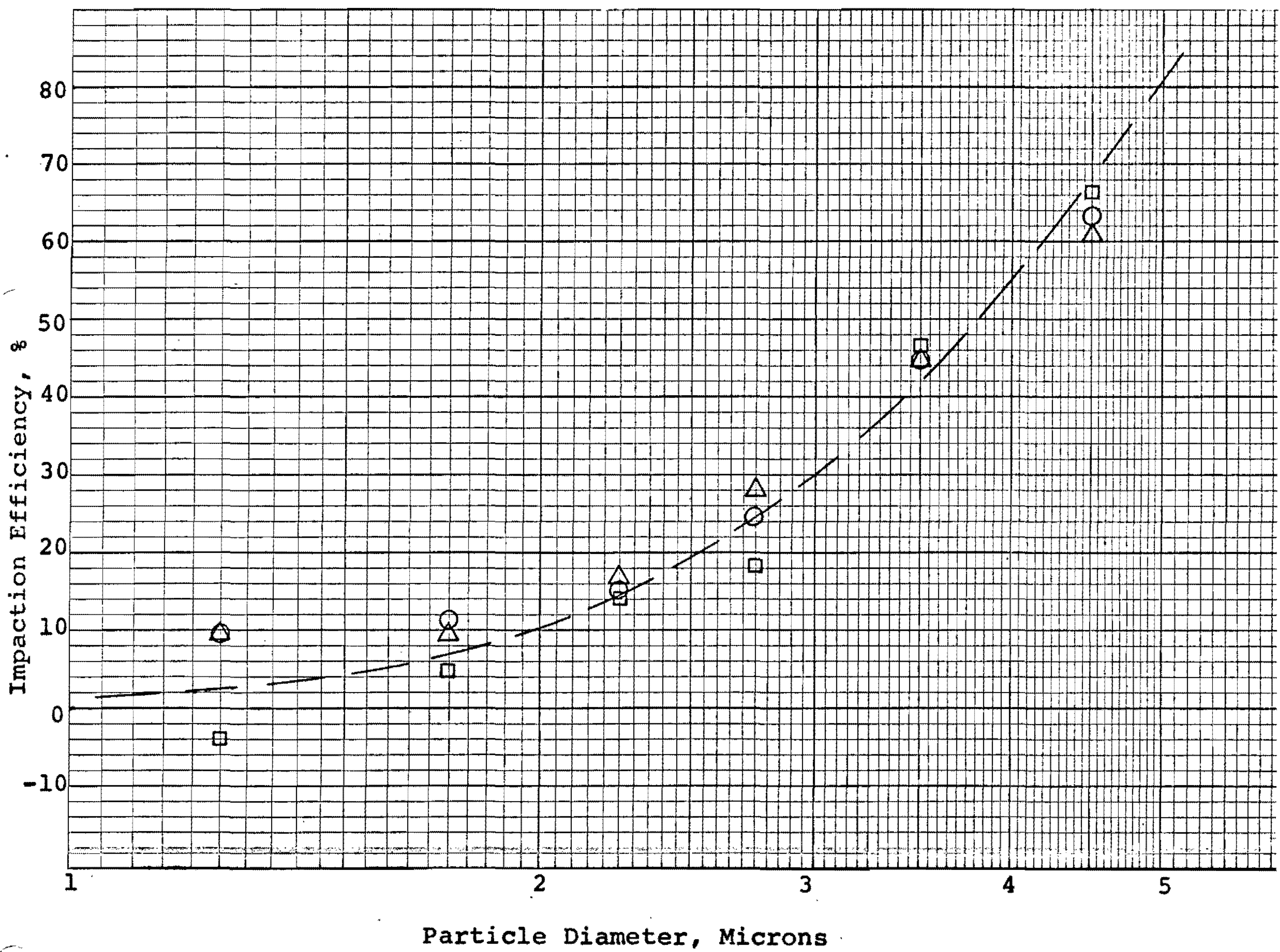

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FIGURE 8

IMPACTION EFFICIENCY VERSUS PARTICLE DIAMETER FOR
3/4 TO 1 1/2 INCH SHALE AT 2 FT/SEC SUPERFICIAL VELOCITY

Conditions

Superficial Velocity = 2.0 ft/sec
Bed Height = 0.5 ft
Nominal Shale Size = 3/4 to 1 1/2 Inch
APD = 0.54 Inch

Test 135 = ○ Eo = 17.7%
Test 136 = △ Eo = 22.8%

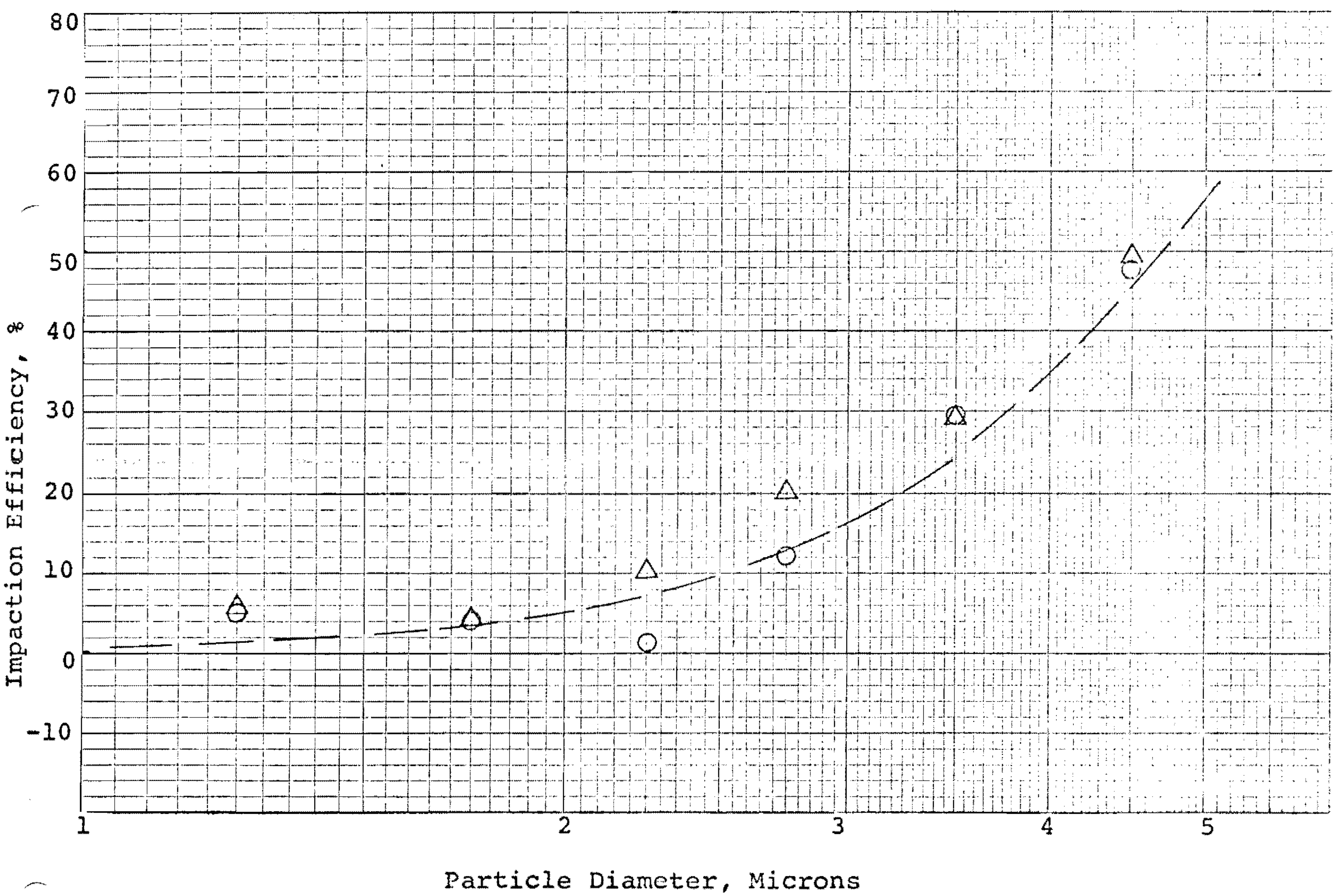

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FIGURE 9

IMPACTION EFFICIENCY VERSUS PARTICLE DIAMETER FOR
3/4 TO 1 1/2 INCH SHALE AT 3 FT/SEC SUPERFICIAL VELOCITY

Conditions

Superficial Velocity = 3.0 ft/sec
Bed Height = 0.5 ft
Nominal Shale Size = 3/4 to 1 1/2 Inch
APD = 0.54 Inch

Test 132 = ○ Eo = 16.2%
Test 133 = △ EO = 21.6%
Test 134 = + Eo = 27.0%

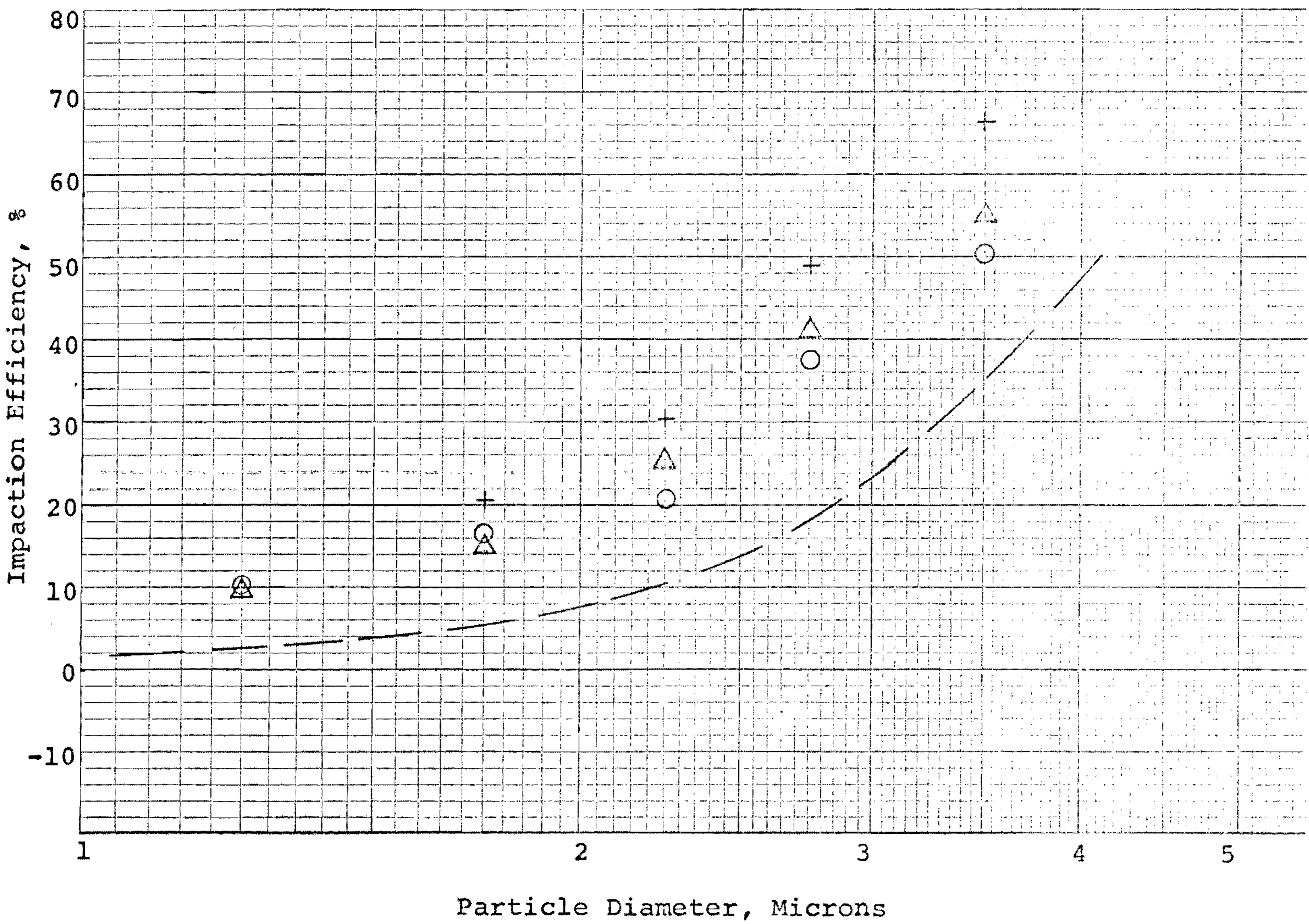

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FIGURE 10

IMPACTION EFFICIENCY VERSUS PARTICLE DIAMETER FOR
3/4 TO 1 1/2 INCH SHALE AT 2 FT/SEC SUPERFICIAL VELOCITY

Conditions

Superficial Velocity = 2.0 ft/sec
Bed Height = 0.5 ft
Nominal Shale Size = 3/4 to 1 1/2 Inch
APD = 0.54 Inch

Test 143 = ○ Eo = 54.9%
Test 144 = △ Eo = 59.9%

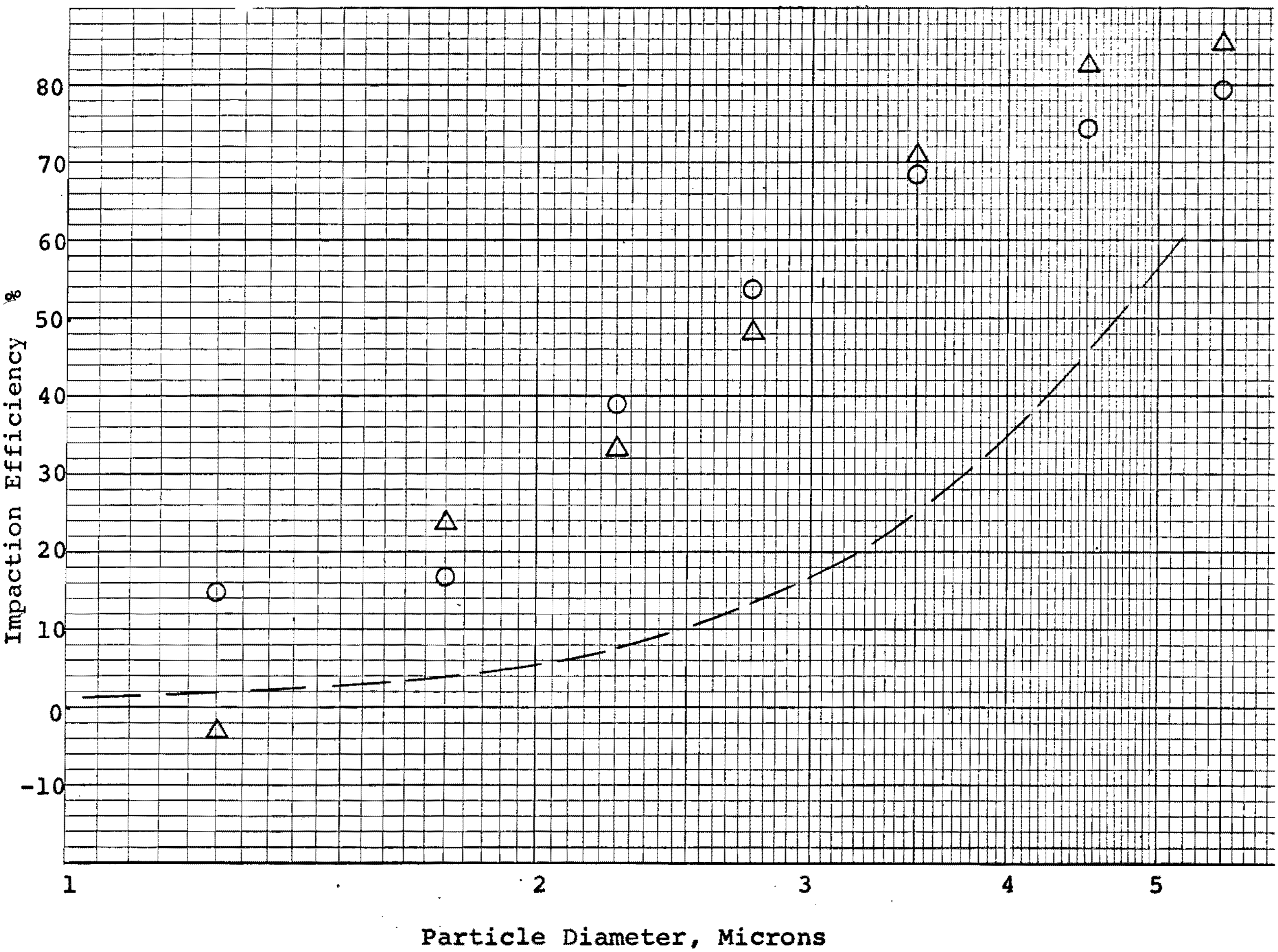

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FIGURE 11

IMPACTION EFFICIENCY VERSUS PARTICLE DIAMETER FOR
3/4 TO 1 1/2 INCH SHALE AT 2 FT/SEC SUPERFICIAL VELOCITY

Conditions

Superficial Velocity = 2.0 ft/sec
Bed Height = 1.5 ft
Nominal Shale Size = 3/4 to 1 1/2 Inch
APD = 0.54 Inch

Test 146 = ○ Eo = 46.8%
Test 147 = △ Eo = 46.2%

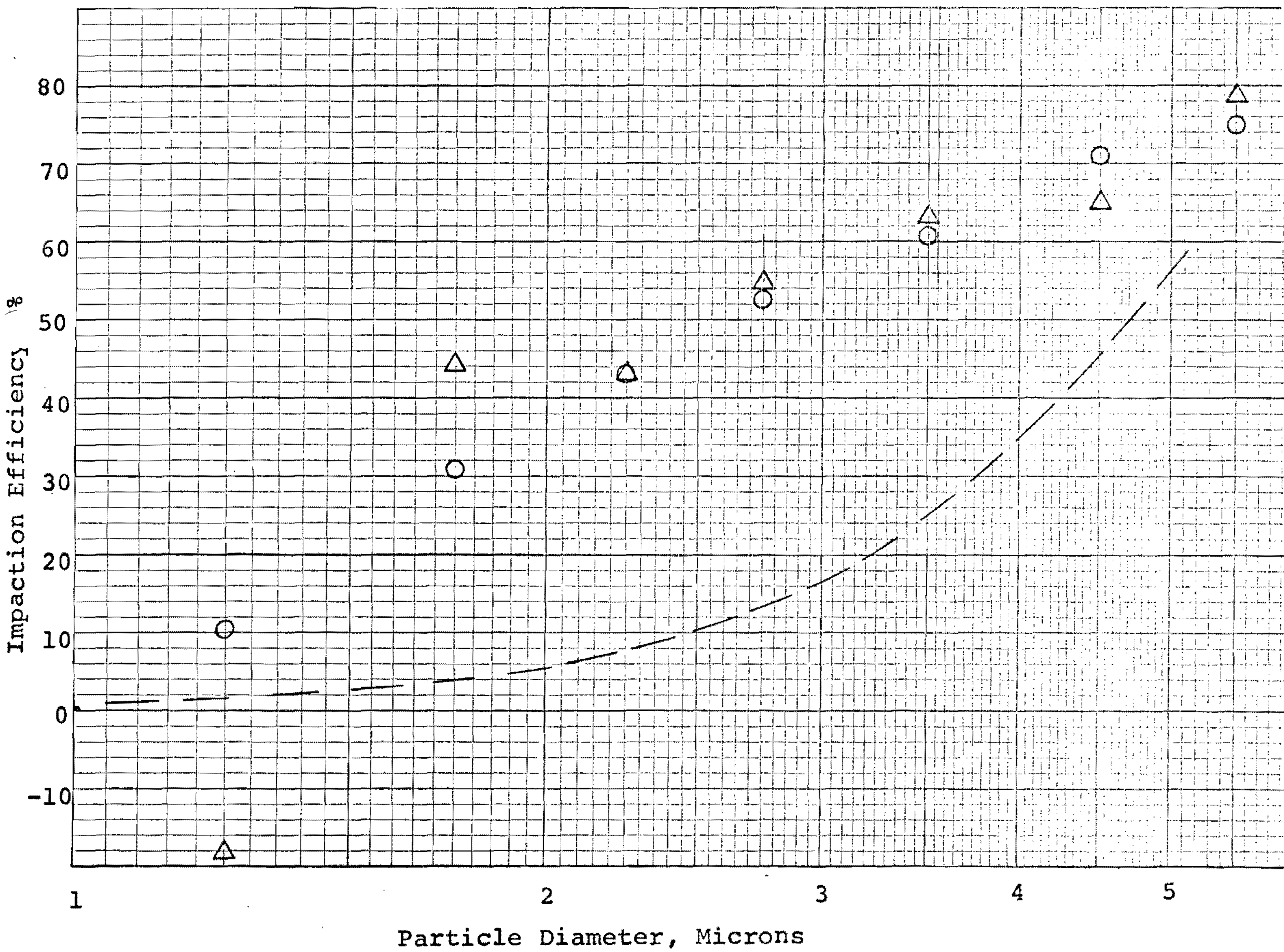

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FIGURE 12

IMPACTION EFFICIENCY VERSUS PARTICLE DIAMETER FOR
1 1/2 TO 3 INCH SHALE AT 3 FT/SEC SUPERFICIAL VELOCITY

Conditions

Superficial Velocity = 3.0 ft/sec
Bed Height = 1 ft
Nominal Shale Size = 1 1/2 to 3 Inch
APD = 0.922 Inch

Test 104 = ○ Eo = 12.9%
Test 105 = △ Eo = 15.1%

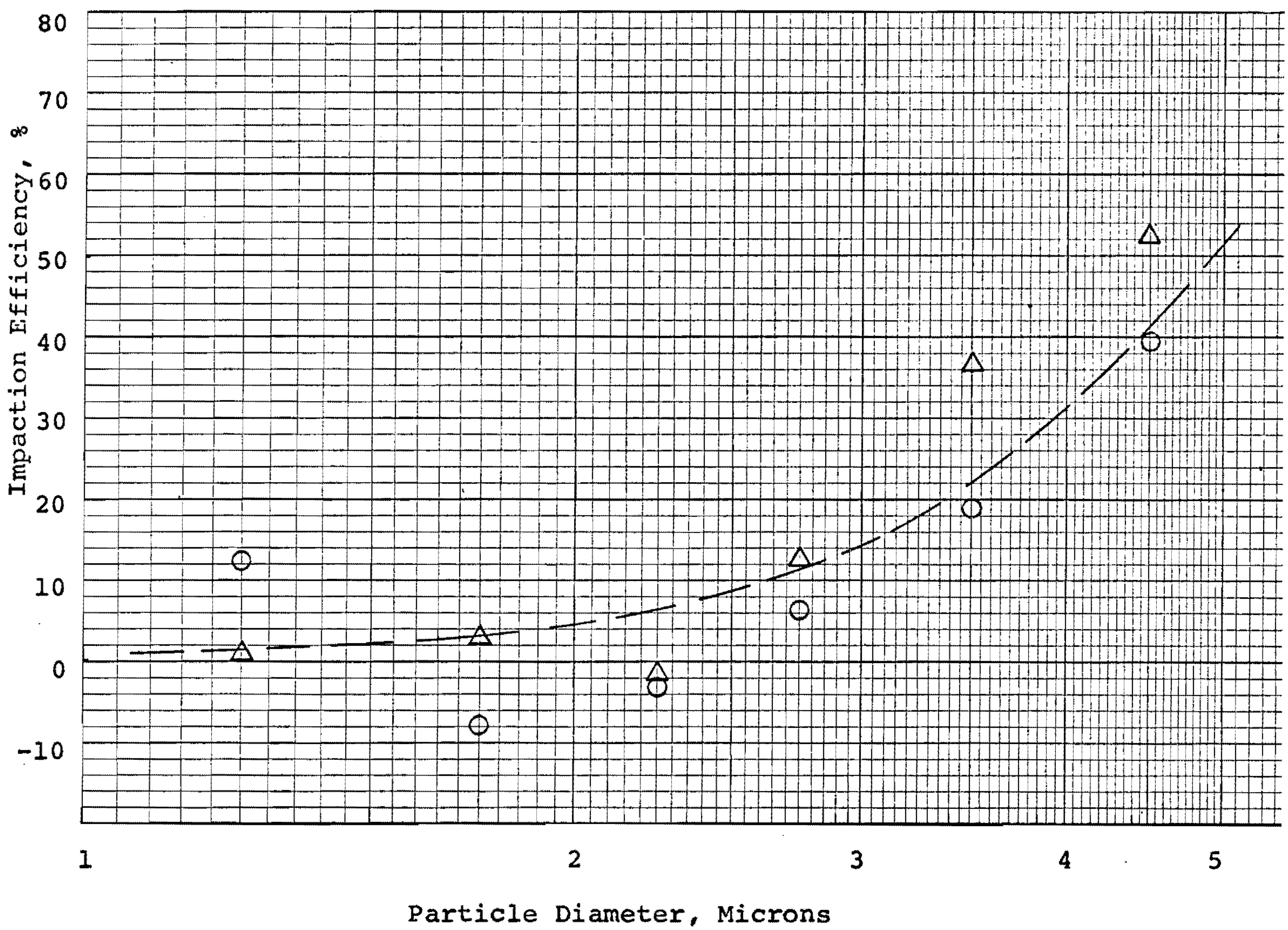

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FIGURE 13

IMPACTION EFFICIENCY VERSUS PARTICLE DIAMETER FOR
1/4 TO 3 INCH SHALE AT 2 FT/SEC SUPERFICIAL VELOCITY

Conditions

Superficial Velocity = 2.0 ft/sec
Bed Height = 1 ft
Nominal Shale Size = 1/4 to 3 Inch
APD = 0.64 Inch

Test 110 = ○ Eo = 12.5%
Test 114 = △ Eo = 29.4%
Test 119 = + Eo = 30.0%

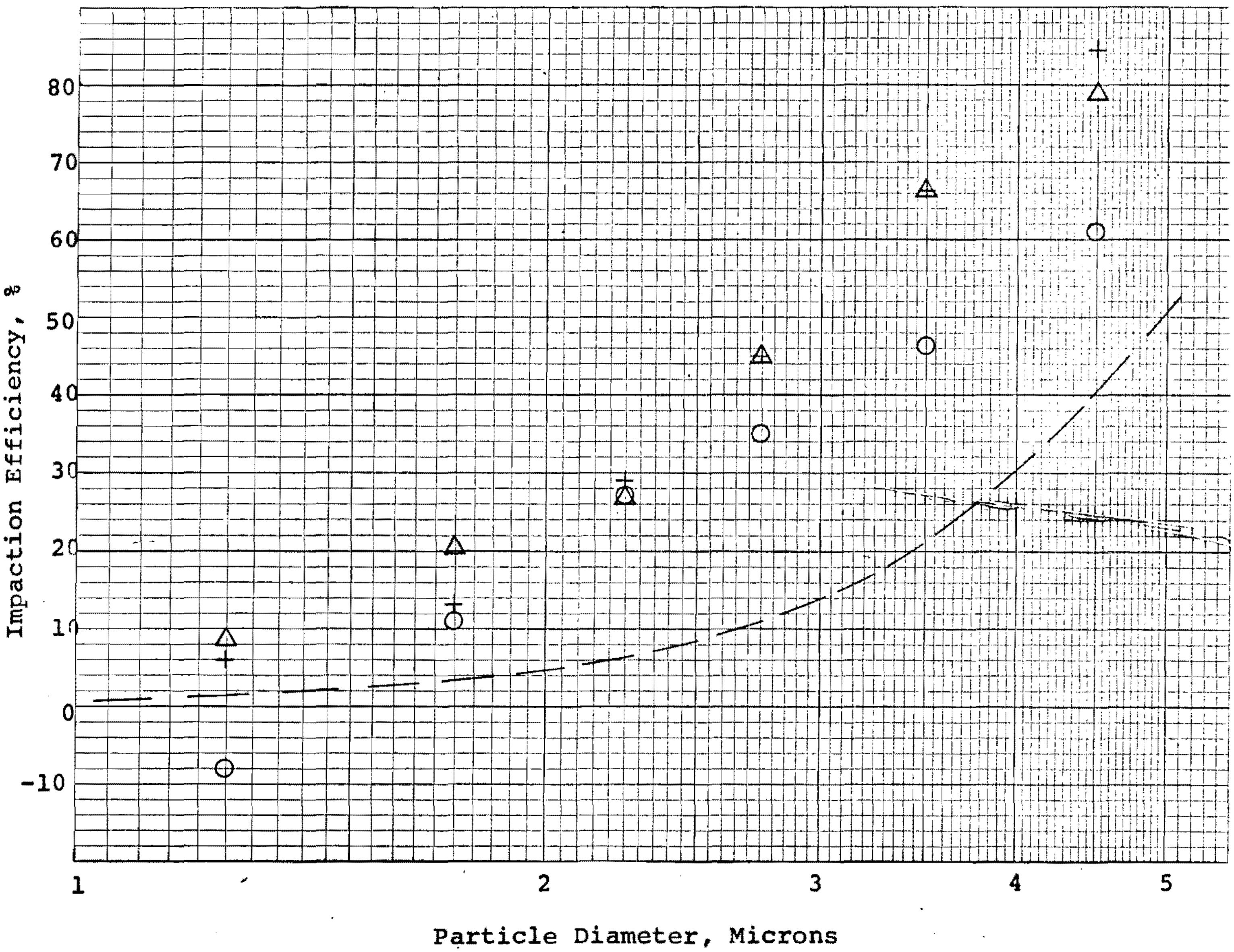

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FIGURE 14

IMPACTION EFFICIENCY VERSUS PARTICLE DIAMETER FOR RETORTING ZONE TYPE SHALE AT 0.5 FT/SEC SUPERFICIAL VELOCITY

Conditions

Superficial Velocity - 0.5 ft/sec
Bed Height = 1 ft
Nominal Shale Size = Retorting Zone
APD = 0.033 Inch

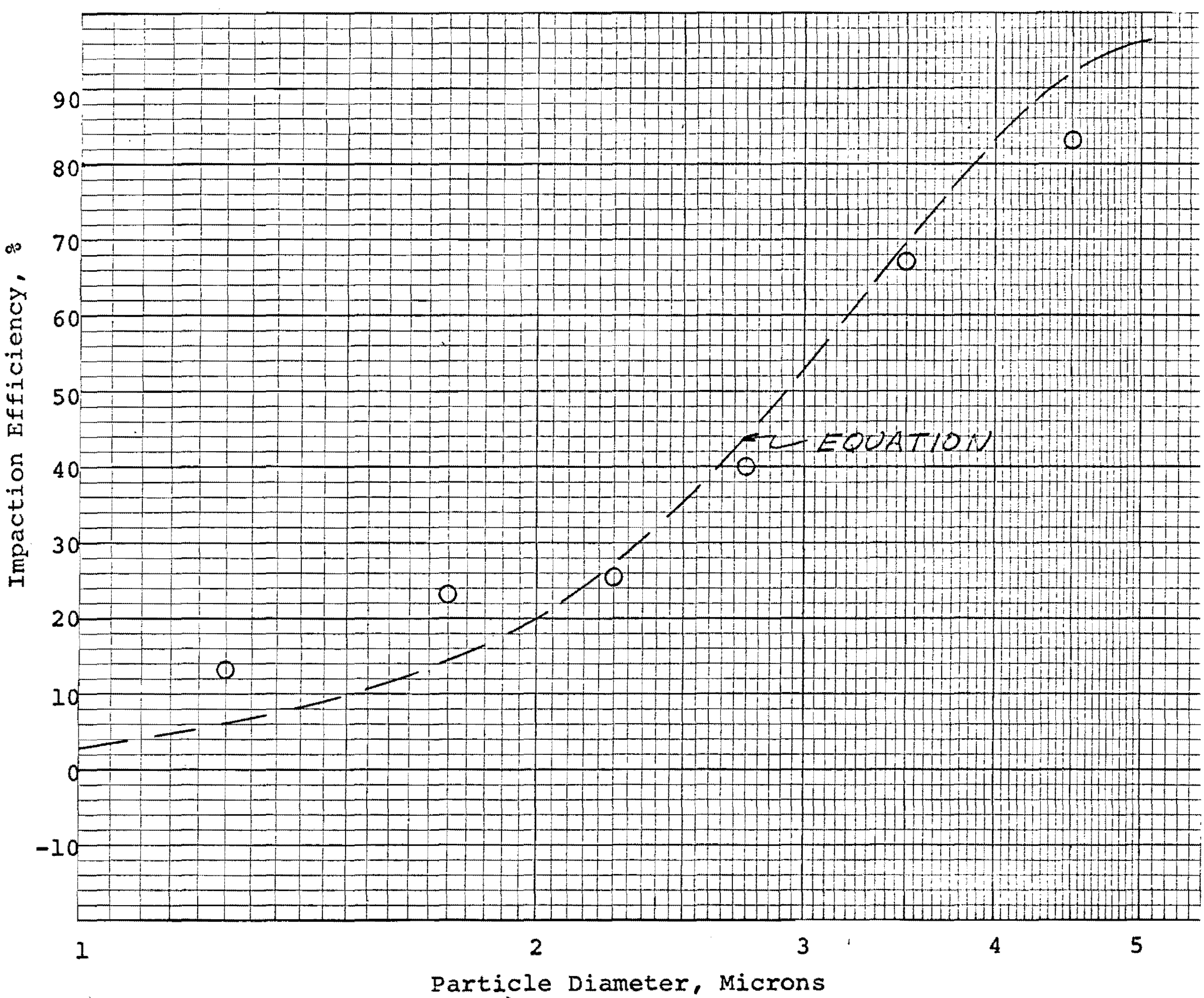

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FIGURE 15

VERTICAL MIST PROFILE PARTICLE SIZE DISTRIBUTIONS

Loading = 8.3 lbs/MSCF Top of Bed
Loading = 9.2 lbs/MSCF 5 Feet Above Top of Bed

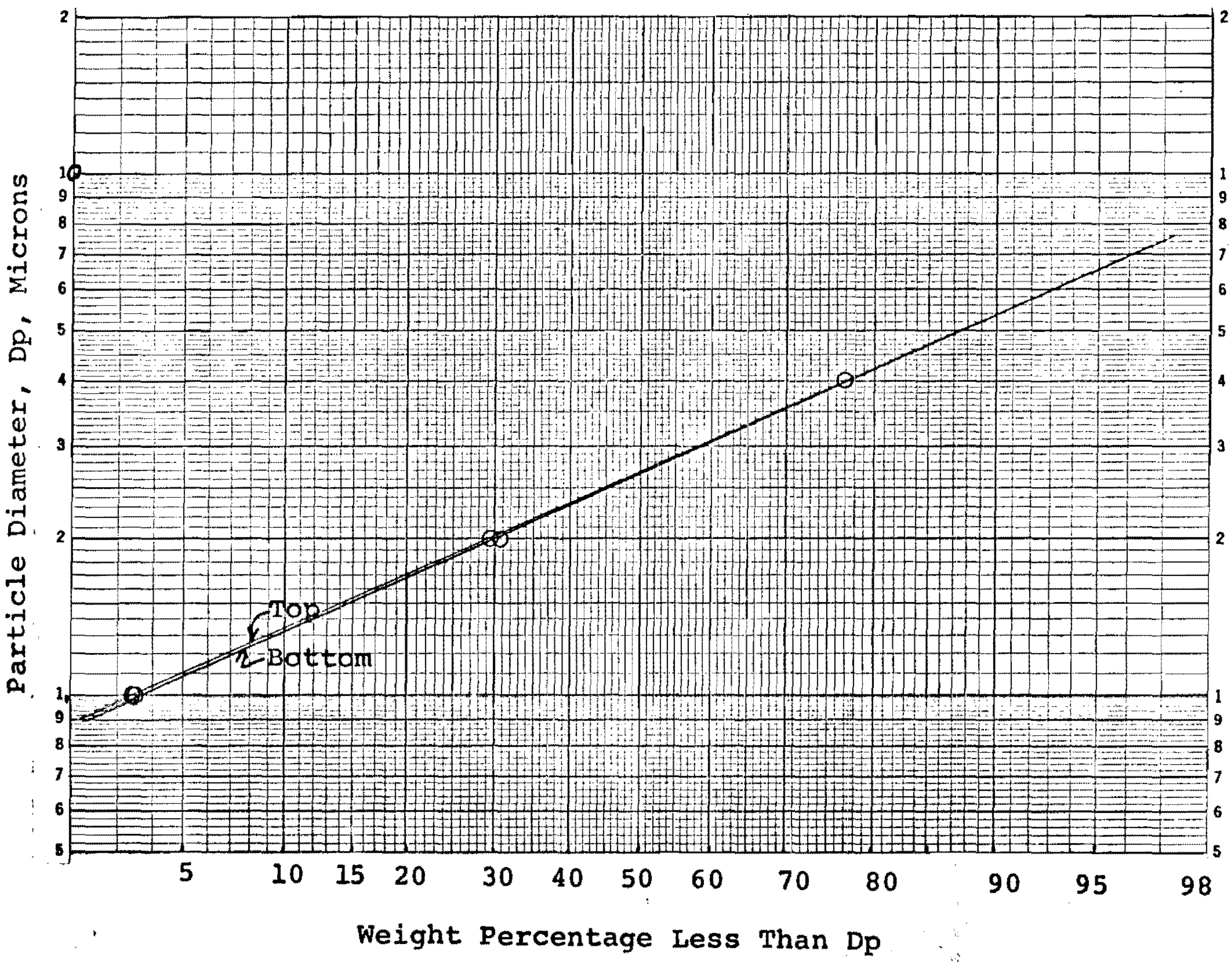

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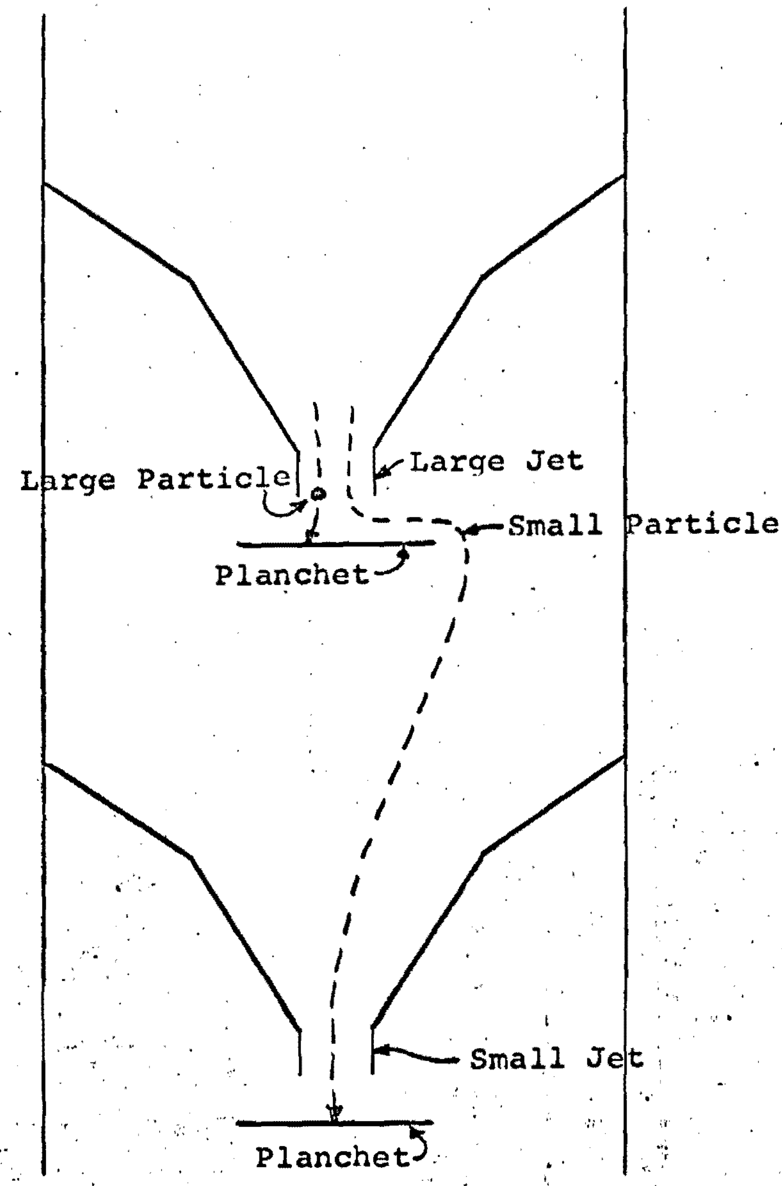
FIGURE 16

SCHEMATIC DIAGRAM OF CASCADE JET IMPACTOR



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