Hicks M.T., Myers K.J., Corpstein R.R., Bakker A., Fasano J.B. (1993). Cloud Height, Fillet Volume, and the Effect of Multiple Impellers in Solids Suspension. Presented at the MIXING XIV Conference, June 20-25, 1993, Santa Barbara, California. Oral presentation by Myers.

Cloud Height, Fillet Volume, and the Effect of Multiple Impellers in Solids Suspension

The focus of this work is the experimental determination of cloud height and fillet volume in an agitated slurry as functions of the agitation intensity, solid material, impeller type (pitched-blade or high efficiency), and system geometry. Cloud height and fillet volume refer to the level to which the solids are suspended in the slurry and the fraction of solid material that is not suspended, respectively. The cloud height is not strongly dependent on the impeller type or solid material, except for extremely rapidly settling particles. However, it is dependent on the impeller diameter to tank diameter ratio (D/T). The fillet volume does depend on solid type, but these differences are relatively small for agitation intensities greater than eighty percent of the just-suspended speed.

Multiple impellers do not exert a significant influence on the agitation level required to produce just-suspended conditions. The use of multiple impellers does, however, allow solids to be suspended to higher levels in tall batches. An intermediate impeller separation leads to optimal performance in terms of the power requirement to achieve a desired cloud height. Lower impeller separations do not yield significant performance improvements over a single impeller, while higher impeller separations lead to poor performance caused by "zoning" between the impellers.

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INTRODUCTION AND MOTIVATION

The vast majority of studies concerned with liquid-solid agitation have focused on the just-suspended condition, while in industrial agitation installations there is a need to understand the complete range of suspension levels. Two important design parameters in this instance are the fillet volume and the cloud height. These parameters characterize the portion of the solid that remains unsuspended on the tank base and the level to which the particles are suspended in the slurry, respectively. Collectively, they represent a qualitative measure of suspension performance. A more quantitative measure of suspension performance would be the complete distribution of solids throughout the system; however, this task is beyond the scope of this preliminary study.

A second area of importance to industry is the use of multiple impellers for liquid-solid agitation. The effect of dual impellers on the just-suspended speed and the influence of impeller separation on the suspension quality will be the primary areas of focus in this investigation.

EXPERIMENTAL APPARATUS AND PROCEDURE

For the most part, the experimental apparatus consisted of a 11.4 inch (0.29 m) diameter, cylindrical, flat-bottomed tank, and either 45° pitched-blade (P-4) turbines or Chemineer high-efficiency (HE-3) impellers. An illustration of these impellers can been seen in Figure 1. The primary solid studied was an acrylic plastic. Its physical characteristics and those of the other solids studied are summarized in the following table.

SOLID PHYSICAL PROPERTIES

Material	Shape	Size (μm)	Density (g/ml)	Settling Velocity (ft/min (m/s))
Ion Exchange Resin	Spheres	780	1.053	2.59 (0.039)
Acrylic Plastic	Rectangular Cylinders	2950	1.18	15.1 (0.23)
Sand	Granules	600	2.59	17.8 (0.27)
Coarse Sand	Granules	1850	2.59	35.1 (0.53)

The typical solid loading studied was 10 weight percent. In many instances in which square batch geometry was not used ($Z/T \neq 1$), the solids loading was 10 weight percent based upon square batch geometry ($Z/T = 1$). For all but one experiment the solid was suspended in water. To study an extremely slowly settling material, the acrylic plastic was studied in salt water with a density of 1.16 g/ml. Under these conditions, the solid settled with a velocity of 0.92 ft/min (0.014 m/s).

The typical system geometry was as follows: the off-bottom clearance of the lowest impeller or of a single impeller was twenty-five percent of the tank diameter ($C/T = 0.25$), the impeller diameter to tank diameter ratio was either thirty-five or forty-eight percent ($D/T = 0.35$ or 0.48), and the liquid level to tank diameter ratio (Z/T) was equal to 1.0 or 1.75. This system geometry was constant for all experiments except when it was desired to determine the effects that a parameter had on the suspension performance. For these experiments, the new system geometry will be specified as needed.

For some experiments, it was necessary to determine the power draw. In these cases, the power number of the impeller system was determined, and this data can be found in the appendix. The quantities to be determined, the just-suspended speed (N_{js}), cloud height (CH), and fillet volume, were measured by visual inspection (often by agreement of multiple observers) and was repeated to ensure reliability and repeatability of the results.

RESULTS AND DISCUSSION

Effect of Liquid Level on the Just-Suspended Speed of Single Impellers

Introduction

Mechanical agitation allows the suspension of solids in a liquid phase resulting in a slurry. Many such industrial installations exist where the liquid level (Z) is significantly different than the tank diameter (T); that is, the Z/T ratio is not unity. These systems have not been previously well studied, and it was desired to determine what effect various Z/T ratios would have on the just-suspended speed.

Experimental Apparatus and Procedure

Two experiments were performed for this study. The first experiment operated at a constant solids mass of 2.26 lbs. (5 weight percent in $Z/T = 1$) in Z/T ratios from 0.5 to 1.75. The second experiment operated at a constant solids loading (expressed in weight percent) for Z/T ratios ranging from 0.5 to 2.0. For both experiments the Chemineer high efficiency impeller and a pitched blade turbine were used.

Conclusions

The experimental results from the first experiment (constant mass) can be seen in Figure 2, and they indicate that under these conditions the just-suspended speed (N_{js}) is not dependent on the liquid level (Z) for both impeller types.

The experimental results from the second experiment (constant solids loading) indicate that the just-suspended speed is dependent on liquid level for both impeller types. To analyze the results of this experiment, the solids loading was adjusted to a normalized weight percent based on a system geometry with a square batch ($Z/T = 1$). Using the normalized weight percent and a correlation between the just-suspended speed and the solids loading developed by Myers[1], the experimental data is plotted with the correlation in Figure 3. The experimental data is in good agreement with the correlation, and it is recommended that this is a possible procedure for predicting the just-suspended speed in non-square geometries ($Z/T \neq 1$).

Previous work in this area has been conducted by Oldshue[2], who correlated the just-suspended at any liquid level as the product of the just-suspended speed in a square batch ($N_{js}(Z/T=1)$) and a correction factor, f. Mathematically this is represented by the following equation.

$$N_{js}(Z/T) = f^{*}N_{js}(Z/T=1)$$

However, Oldshue's procedure varied from that of the present study in that he held the impeller clearance to liquid level constant ($C/Z = 0.25$), whereas in the present experiments the impeller clearance to tank diameter is kept constant ($C/T = 0.25$). Following Oldshue's procedure, experiments were performed to determine the correction factor f as a function of liquid level (Z/T). The results are plotted with Oldshue's recommended correction factor in Figure 4, and can be seen to agree well.

Effect of Impeller Diameter on Cloud Height of Single Impellers at Just-Suspended Conditions

Introduction

The vast majority of studies in liquid-solid agitation are concerned with the just-suspended speed of the slurry; however this parameter does not completely describe the quality of the suspension. It only guarantees, by definition, that no solid is forming fillets or remaining stationary on the base of the tank. Considering the cloud height to liquid level ratio (CH/Z) at just-suspended conditions gives a more complete picture of the quality of the suspension by indicating the level to which the particles are being suspended.

Experimental Apparatus and Procedure

First, the just-suspended speed for each impeller was determined. Then the cloud height to liquid level ratio was measured at this speed for various impeller diameter to tank diameter ratios (D/T) for both the pitched blade turbine and the Chemineer high efficiency impeller.

Conclusions

The results of these experiments can be seen in Figure 5. The figure clearly shows that the just-suspended speed does not completely describe the quality of the suspension. At the just-suspended speed, the suspension levei is dependent on the impeller diameter to tank diameter ratio (D/T); increasing the impeller diameter to tank diameter ratio results in a higher suspension level at just-suspended conditions.

Dependence of Cloud Height on Agitation Level with Single Impellers

Introduction

As the previous experimental results indicate, the quality of the suspension of a slurry is not described solely by the just-suspended speed. Thus, it is desired to determine the suspension level (cloud height to liquid level ratio, CH/Z) across the spectrum of agitation intensities (expressed by the relative speed, N/N_{js}).

Experimental Apparatus and Procedure

Five cases, covering a range of industrially-important physical properties, were used in this experiment. The solids were an ion exchange resin, acrylic plastic in both water and saltwater, and two sizes of coarse sand. Solid physical properties are listed in the Experimental Apparatus and Procedure section. For this experiment, the starting impeller speed was the lowest speed that resulted in minimal agitation of the slurry. The speed was then incremented by approximately 20 rpm until the cloud height to liquid level ratio was no longer appreciably changing.

Four experiments were performed in this area. First, a Chemineer high-efficiency impeller was used to suspend the various solids. Second, the pitched-blade impeller was used to suspend the acrylic solid, and these results were then compared to those of the high-efficiency impeller. Third, experiments were performed for both impeller types using the acrylic solid in a tall batch (Z/T=1.75), but keeping the solids loading at 10 weight percent based on a square batch geometry (Z/T=1.0). Last, impeller diameter to tank diameter ratio (D/T) effects were considered for the Chemineer high efficiency impeller using the acrylic solid.

Conclusions

Figure 6 illustrates the solid effects on the HE-3 suspension performance. It shows that the cloud height to liquid level ratio (CH/Z) is relatively independent of the solid material when the level of agitation is normalized relative to the just-suspended speed. Only in the case of the coarser sand with an extremely high settling velocity is the cloud height dependence on agitation intensity significantly different than that of the other solids. In this case it is very difficult to suspend the solid to the upper regions of the tank. Further, the cloud height fluctuates substantially with this solid.

Figure 7 indicates that the performance of the high-efficiency impeller and the pitched-blade turbine are essentially identical at the same relative levels of agitation.

Figure 8 demonstrates the effect of increasing the liquid level on the suspension quality of the high efficiency impeller. The data clearly shows that it is extremely difficult to disperse solids throughout a tall batch with a single impeller. The highest cloud height observed was approximately twenty five percent greater than the tank diameter (CH=1.25T). Similarly, Figure 9 demonstrates this effect for the pitched-blade turbine. Note that the absolute cloud height (CH, rather than the normalized suspension level CH/Z) of the suspended particles is approximately equal when comparing the Z/T=1 and Z/T=1.75 results. This was found to hold for both impellers.

Figure 10 shows the effects of the impeller diameter to tank diameter ratio (D/T) on the quality of the suspension for a Chemineer high-efficiency impeller. The results show that the cloud height to liquid level ratio is dependent on this parameter when the level of agitation is normalized relative to the just-suspended speed.

Figure 11 is the same data except the cloud height to liquid level ratio is plotted as a function of power input. The power has been normalized relative to the just-suspended power consumption of an impeller with an impeller diameter to tank diameter ratio of 0.352. The figure indicates that the optimum suspension performance occurs at an impeller diameter to tank diameter ratio of forty-four percent (D/T=0.44) for any power input level; that is, for any fixed power input, this impeller diameter to tank diameter ratio yields the highest relative suspension level (CH/Z). However, the other large impeller diameter to tank diameter ratios studied (D/T=0.352 and 0.527) yield similar results at higher levels of agitation (relative power inputs greater than approximately 1.5).

Dependence of Fillet Volume on Agitation Level with Single Impellers

Introduction

Sometimes it is necessary to operate at reduced agitation levels. This maybe be a result of an improperly designed system or the just-suspended speed may vary over time because the properties of the slurry vary over time. If this is the case, it is desirable to be able to estimate the amount of stagnant particles in the system. In order to do this, the relative fillet size (the fraction of stationary particles) must be known as a function of the level of agitation.

Experimental Apparatus and Procedure

Three solids, possessing industrially-relevant physical properties, were used in this experiment. The solids are the ion exchange resin, acrylic plastic, and (less coarse) sand discussed previously. For this experiment, the starting impeller speed was the lowest speed that resulted in minimal agitation of the slurry. The speed was then incremented by approximately 20 rpm until the just-suspended state was achieved.

Two experiments were performed in this area. First, a Chemineer high-efficiency impeller was used to suspend the various solids. Second, the pitched-blade turbine was used to suspend the acrylic solid, and was then compared to the high-efficiency impeller.

Conclusions

Figure 12 illustrates the solid effects on the high-efficiency relative fillet size. The data indicates that the relative fillet size is the largest for the easiest to suspend material when the level of agitation is normalized relative to the just-suspended speed. However, for agitation speeds of practical interest (above about eighty percent of the just-suspended speed), there is less variation between the behavior of the various solids. Figure 13 indicates that the performance of the high efficiency impeller and the pitched blade turbine are essentially identical at the same relative levels of agitation.

Effect of Dual Impellers on Just-Suspended Speed

Introduction

Industrial applications are routinely designed with dual impellers. However, the benefits of additional impellers have not been well quantified previously. If achievement of just-suspended conditions is the sole design criterion, then the dual impeller just-suspended speed must be significantly lower than that of a single impeller system to justify its use., This is due to the fact that, at the same speed, the dual impeller system will draw more power and operate at a higher torque level than a single impeller system.

Experimental Apparatus and Procedure

For this experiment, the just-suspended speed for a single impeller was determined. Then a second impeller was added at various separations to determine its effects on the just-suspended speed. The lower impeller off-bottom clearance was held constant (C1/T=0.25), and the impeller separation is defined as:

$$S=(C2-C1)/D$$

where: S - Impeller Separation
C2 - Clearance of Upper Impeller
C1 - Clearance of Lower Impeller
D - Impeller Diameter

The experiment was performed for both high-efficiency impellers and pitched-blade turbines operating in a Z/T=1.5 batch with a solids loading of 5 weight percent based on Z/T=1.

Conclusions

Figure 14 shows the results of using multiple impellers on the just-suspended speed of the high-efficiency impeller. The data indicates that the addition of a second impeller has no effect on the just-suspended speed. The deviation for all impeller spacings was less than five percent of the single impeller just-suspended speed.

Figure 15 shows the results of the effects of multiple impellers on the just-suspended speed of the pitched-blade turbine. The data indicates that the addition of a second impeller has a minor effect on the just-suspended speed. This is believed to be the result of the pumping characteristics of the impeller. At low separation the two impellers act as one, thus lowering the just-suspended speed slightly. However, at higher separations the two impellers interfere with each other, thus increasing the just-suspended speed.

Effect of Dual Impellers on Cloud Height

Introduction

As previously stated, the quality of suspension is not completely described by the just-suspended speed; the cloud height to liquid level ratio is also an appropriate measure of this quantity. If the performance of dual-impeller systems offers significant improvements over its single-impeller counterparts, then this would be just reason for designing systems with dual impellers.

Experimental Apparatus and Procedure

For these experiments the liquid level to tank diameter ratio (Z/T) was 1.75 in order to accommodate large impeller separations. The solids loading was set at 10 weight percent based on square batch geometry (Z/T=1.0). The impeller separation procedure is the same as described in the previous section. The starting impeller speed was the lowest speed that resulted in minimal agitation of the slurry. The speed was then incremented by approximately 20 rpm until the cloud height to liquid level ratio was no longer appreciably changing.

The experiments were performed with Chemineer high efficiency impellers and pitched blade turbines. The experiments were performed at two impeller diameter to tank diameter ratios (D/T=0.35 and 0.48) for both impellers.

Conclusions

Figure 16 demonstrates the effect of dual impeller separation on the high-efficiency impeller suspension performance for the lower impeller diameter to tank diameter ratio (D/T=0.35). The data indicates that from slightly below the just-suspended speed, the suspension performance is best for an impeller separation equal to three (S=3). Although not shown in the figure, data taken at an impeller separation of three and one-half (S=3.5) indicates that "zoning" occurs. Under these conditions there is a distinct decrease in solids concentration above the lower impeller. At an impeller separation of four (S=4) the upper impeller exerts almost no influence on the cloud height. Under these conditions very few solid particles are lifted higher than they would be if only a single impeller was used.

Figure 17 is the same data except that the cloud height to liquid level ratio is plotted as a function of power input. The power has been normalized relative to the power consumption of the single impeller at the just-suspended speed. The figure indicates that the optimum suspension performance occurs at S=3 for any power; that is, for the same power consumption the cloud height to liquid level ratio is the highest.

Figure 18 illustrates the effect of dual impeller separation on the pitched-blade turbine suspension performance for D/T=0.35. The data indicates that for the most part, an impeller separation of two offers the best performance. The impeller separation of three does outperform the others, but this is not until $N/N_{js}=2$. Figure 19 is the same data except the suspension performance is plotted as a function of normalized power as defined previously. From this plot, the failure of the high impeller spacing (S=3.0) at low power consumptions is even more evident. It is not until the relative power is equal to approximately 10 that it outperforms the other configurations.

Figure 20 demonstrates the effect of dual impeller separation on the high-efficiency impeller suspension performance for the larger impeller diameter to tank diameter ratio (D/T=0.48). The failure of the high impeller separation (S=2.5) is now evident at low speeds as it was for the pitched-blade turbine. The data indicates that for the most part the suspension performance is best for an impeller separation equal to two (S=2). Figure 21 is the same data except the cloud height to liquid level ratio is plotted as a function of normalized power as previously defined. This figure indicates that the optimum suspension performance occurs at S=2 for any power consumption.

Figure 22 illustrates the effect of dual impeller separation on the pitched-blade turbine suspension performance for D/T=0.48. The failure of the high impeller separation (S=2.5) is evident for all speeds. The data indicates that for the most part, an impeller separation of two offers the best performance. Note that S=1 is optimal at low power inputs. Figure 23 is the same data except the suspension performance is plotted as a function of the normalized power as defined previously. From this plot, the failure of the high impeller spacing (S=2.5) at all power consumptions is even more evident.

SUMMARY

The suspension performance of the Chemineer high-efficiency impeller and of the pitched-blade turbine has been quantified in terms of solid properties, impeller diameter to tank diameter ratio (D/T), liquid level to tank diameter ratio (Z/T), and dual impeller effects. Although this covers a broad range of industrial applications, it is not complete. Two areas that still need to be investigated are solids loading and scale effects. At this time, it is uncertain what effect these parameters will have on the suspension performance of the impellers; and it is recommended that additional experiments be performed to examine these effects.

Another description of the suspension performance is the solids distribution in the slurry. Comparison of quantitative solids distribution data with the qualitative data of this study would add further insight into solids suspension agitation.

REFERENCES

1. Myers, K.J., Personal Communications, Chemineer Inc., Dayton OH, 1992-1993.

2. Oldshue, James Y., Fluid Mixing Technology, Figure 5-27, page 117, McGraw-Hill, New York, N.Y., 1983.

3. Armenante, P. M., Y.-T. Huang, and T. Li, "Determination of the Minimum Agitation Speed to Attain the Just-Dispersed State in Solid-Liquid and Liquid-Liquid Reactors Provided with Multiple Impellers", Chemical Engineering Science, Volume 47, Numbers 9-11, pages 2865-2870 (1992).

APPENDIX: IMPELLER POWER NUMBERS

The power number of an impeller is defined in the following manner.

$$N_p = \frac{P}{\rho N^3 D^5}$$

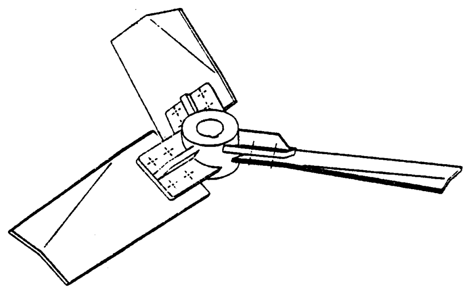
The following power number data was taken as part of this study to interpret speed data in terms of power draw.

Type	Single/Dual	Z/T	D/T	N_p
HE-3	Single	1.0	0.154	0.353
HE-3	Single	1.0	0.242	0.317
HE-3	Single	1.0	0.352	0.281
HE-3	Single	1.0	0.440	0.258
HE-3	Single	1.0	0.527	0.241
HE-3	Single	1.75	0.352	0.326
HE-3	Dual, S=1	1.75	0.352	0.532
HE-3	Dual, S=2	1.75	0.352	0.598
HE-3	Dual, S=3	1.75	0.352	0.638
HE-3	Single	1.75	0.484	0.281
HE-3	Dual, S=1	1.75	0.484	0.536
HE-3	Dual, S=2	1.75	0.484	0.588
HE-3	Dual, S=2.5	1.75	0.484	0.631
P-4	Single	1.75	0.352	1.38
P-4	Dual, S=1	1.75	0.352	2.23
P-4	Dual, S=2	1.75	0.352	2.35
P-4	Dual, S=3	1.75	0.352	2.54
P-4	Single	1.75	0.484	1.20
P-4	Dual, S=1	1.75	0.484	2.15
P-4	Dual, S=2	1.75	0.484	2.57
P-4	Dual, S=2.5	1.75	0.484	2.45

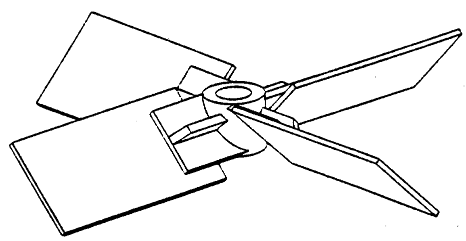
NOMENCLATURE

C	Impeller Clearance from Tank Bottom
CH	Cloud Height
CH/Z	Suspension Level (Cloud Height to Liquid Level Ratio)
C/T	Impeller Clearance to Tank Diameter Ratio
D	Impeller Diameter
D/T	Impeller Diameter to Tank Diameter Ratio
HE-3	Chemineer High-Efficiency Impeller
N	Impeller Speed
N_{js}	Just-suspended Speed
N/N_{js}	Relative Speed Level
N_p	Impeller Power Number
P	Power
P-4	45° Pitched-Blade Impeller
S	Impeller Separation ((C2-C1)/D)
T	Tank Diameter
X	Weight Percent of Solid ((weight solid/weight slurry) * 100)
Z	Liquid Level
Z/T	Liquid Level to Tank Diameter Ratio
ρ	Density

IMPELLER ILLUSTRATIONS



Chemineer High-Efficiency



45° Pitched-Blade

FIGURE 1

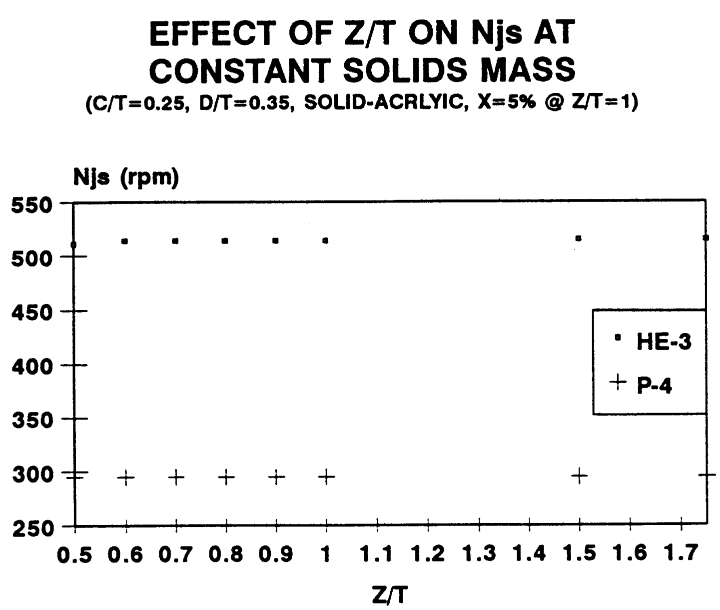
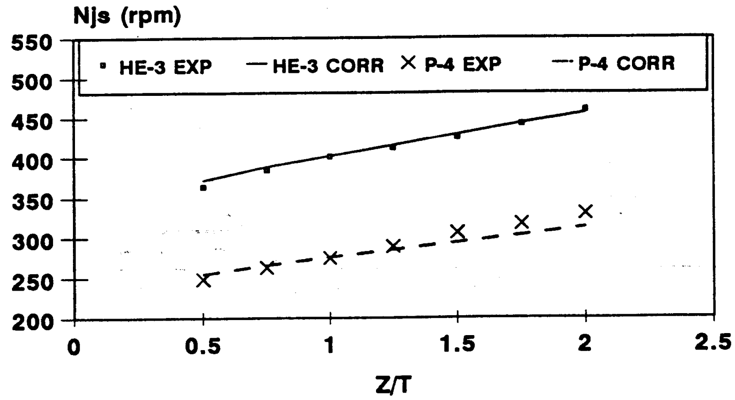


FIGURE 2

EFFECT OF Z/T ON Njs AT CONSTANT SOLIDS LOADING

(C/T=0.25, D/T=0.35, SOLID-ACRYLIC, X=5% @ Z/T=1)



WEIGHT PERCENT NORMALIZED TO Z/T = 1
FOR CORRELATED VALUES
FIGURE 3

Njs FACTOR RELATED TO Z/T

(C/Z=0.25, D/T=0.35, SOLID-ACRYLIC, X=5% @ Z/T=1)

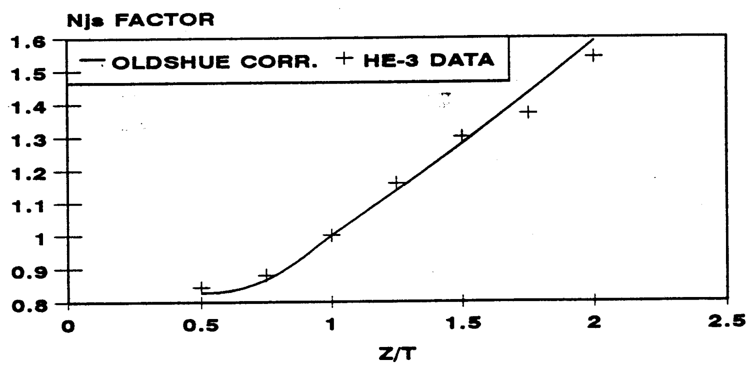
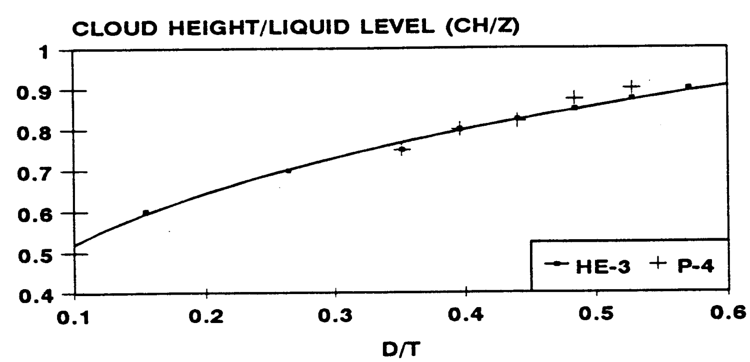


FIGURE 4

SUSPENSION LEVEL AS A FUNCTION OF IMPELLER TO TANK DIAMETER RATIO AT JUST-SUSPENDED CONDITIONS



C/T=0.25, SOLID-ACRYLIC, X=10%, Z/T=1
FIGURE 5

SOLID EFFECTS ON HE-3 SUSPENSION PERFORMANCE
(C/T=0.25, D/T=0.35, Z/T=1.0, X=10%)

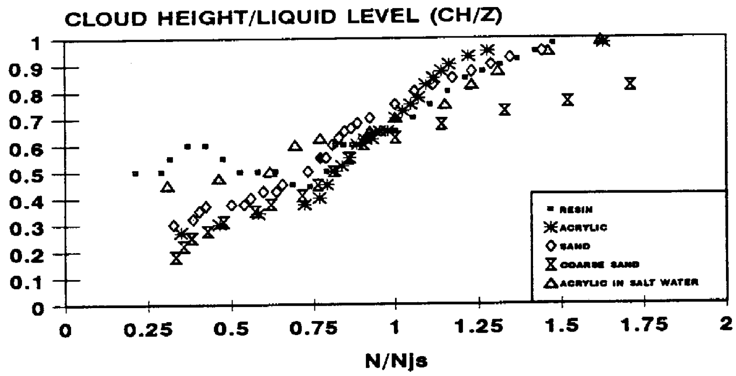


FIGURE 6

IMPELLER EFFECTS ON SUSPENSION PERFORMANCE: COMPARISON OF HE-3 AND P-4 IMPELLERS
(C/T=0.25, D/T=0.35, Z/T=1.0, SOLID-ACRYLIC, X=10%)

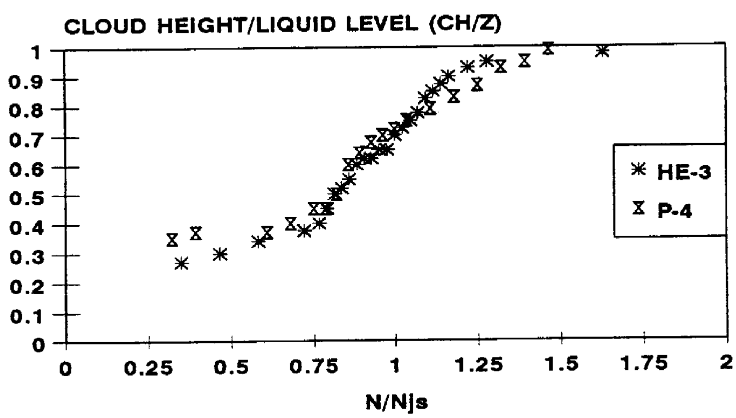


FIGURE 7

Z/T EFFECTS ON HE-3 SUSPENSION PERFORMANCE
(C/T=0.25, D/T=0.35, SOLID-ACRYLIC, X=10% @ Z/T=1)

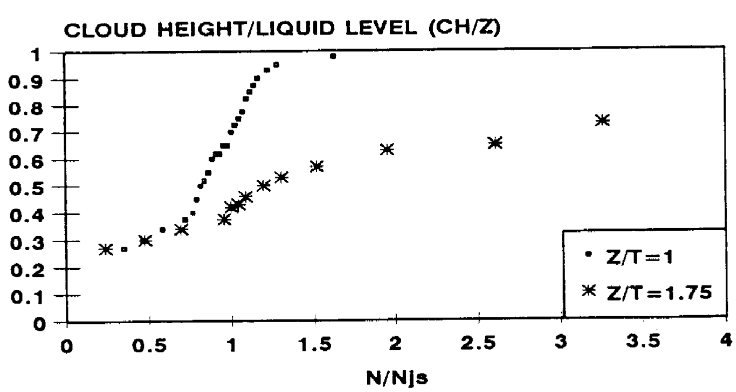


FIGURE 8

Z/T EFFECTS ON P-4 SUSPENSION PERFORMANCE

(C/T=0.25, D/T=0.35, SOLID-ACRYLIC, X=10% @ Z/T=1)

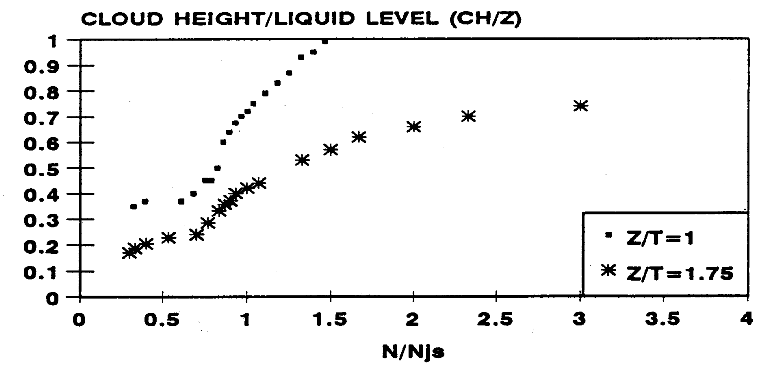


FIGURE 9

D/T EFFECTS ON HE-3 SUSPENSION PERFORMANCE

(C/T=.25, Z/T=1, SOLID-ACRYLIC, X=10%)

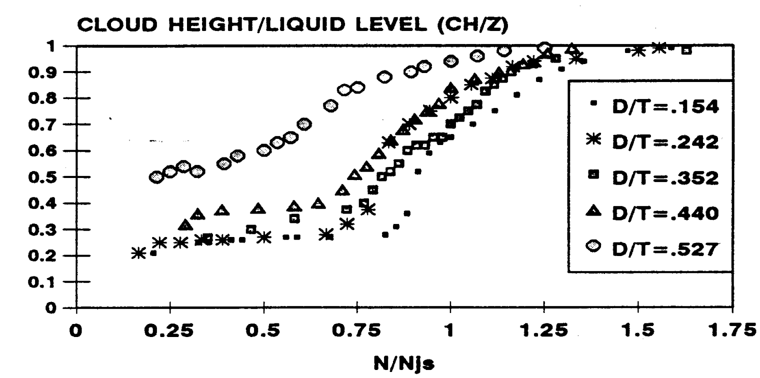
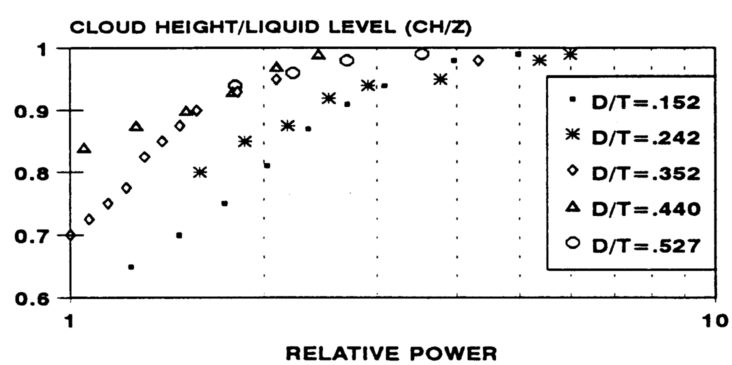


FIGURE 10

D/T EFFECTS ON HE-3 SUSPENSION PERFORMANCE: POWER INPUT RELATIONSHIP

(C/T=0.25, Z/T=1.0, SOLID-ACRYLIC, X=10%)



POWER NORMALIZED RELATIVE TO Njs AT D/T=0.352
FIGURE 11

SOLID EFFECTS ON HE-3 RELATIVE FILLET SIZE
(C/T=0.25, D/T=0.35, Z/T=1.0, X=10%)

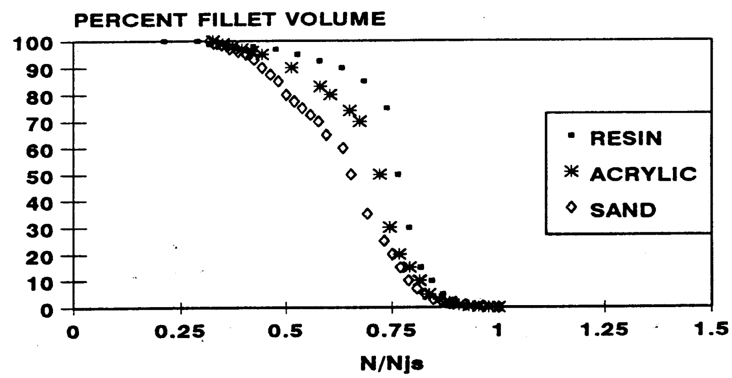


FIGURE 12

IMPELLER EFFECTS ON RELATIVE FILLET SIZE: COMPARISON OF HE-3 AND P-4 IMPELLERS
(C/T=0.25, D/T=0.35, Z/T=1, SOLID-ACRYLIC, X=10%)

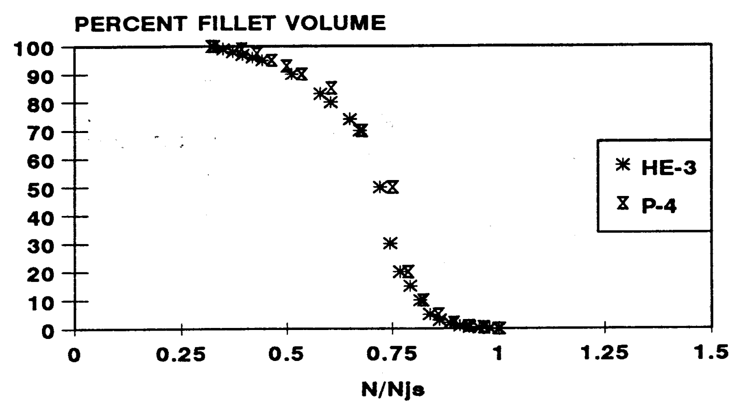
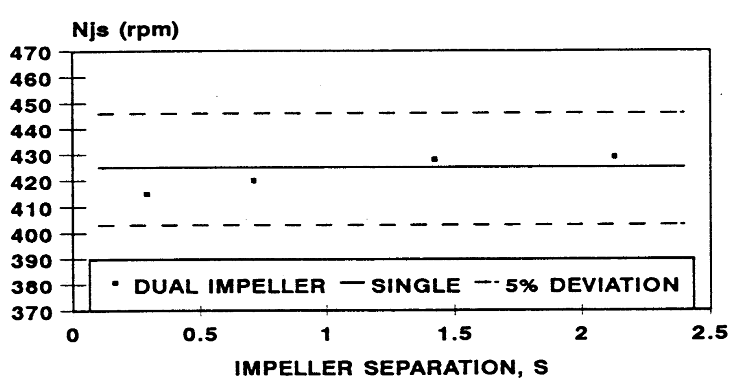


FIGURE 13

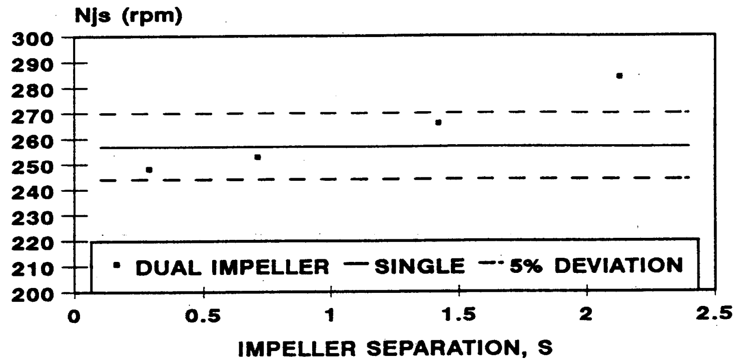
DUAL HE-3 IMPELLER EFFECTS ON Njs DEPENDENCE ON IMPELLER SEPARATION
(C1/T=0.25, D/T=0.35, Z/T=1.5, SOLID-ACRYLIC, X=5% @ Z/T=1)



S=(C2-C1)/D
FIGURE 14

DUAL P-4 IMPELLER EFFECTS ON Njs DEPENDENCE ON IMPELLER SEPARATION

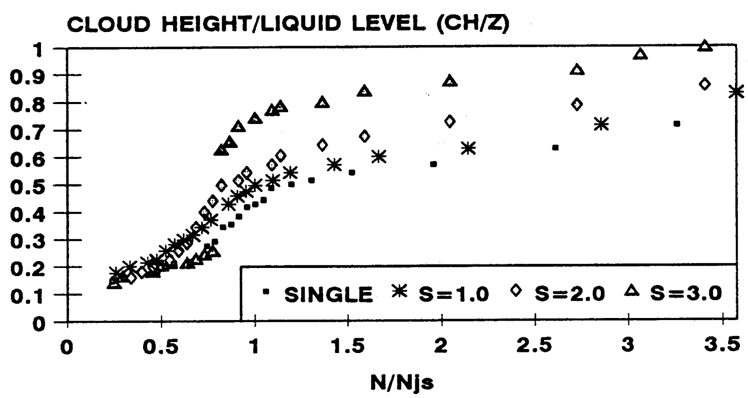
(C1/T=0.25, D/T=0.35, Z/T=1.5, SOLID-ARCYLIC, X=5% @ Z/T=1)



S=(C2-C1)/D
FIGURE 15

EFFECT OF DUAL IMPELLER SEPARATION ON HE-3 SUSPENSION PERFORMANCE

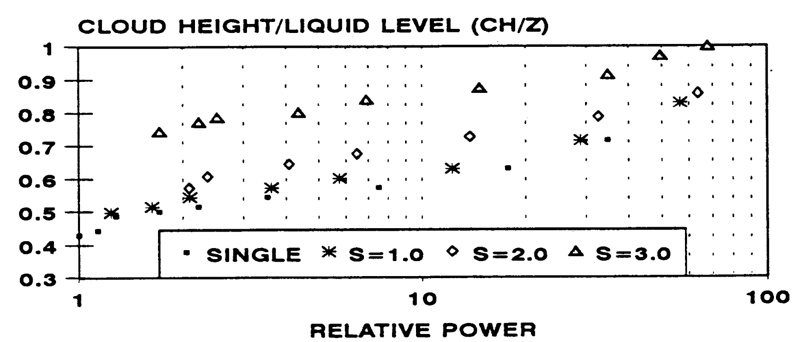
(C1/T=0.25, D/T=0.35, Z/T=1.75, SOLID-ACRYLIC, X=10% @ Z/T=1)



S=(C2-C1)/D
FIGURE 16

IMPELLER SEPARATION EFFECTS ON HE-3 SUSPENSION PERFORMANCE: POWER INPUT RELATIONSHIP

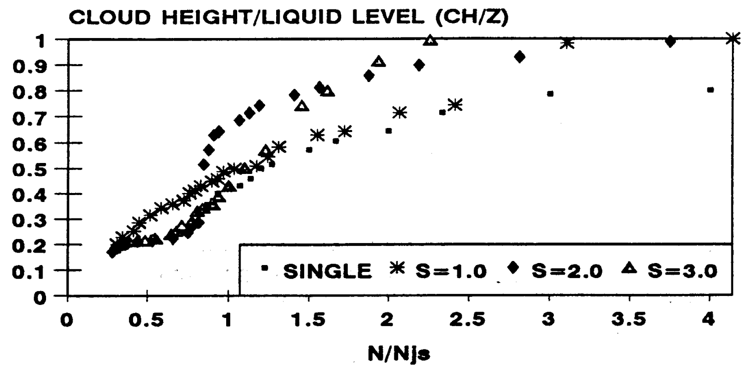
(C1/T=0.25, D/T=0.35, Z/T=1.75, SOLID-ACRYLIC, X=10% @ Z/T=1)



S=(C2-C1)/D
POWER NORMALIZED RELATIVE TO Njs OF SINGLE IMPELLER
FIGURE 17

EFFECT OF DUAL IMPELLER SEPARATION ON P-4 SUSPENSION PERFORMANCE

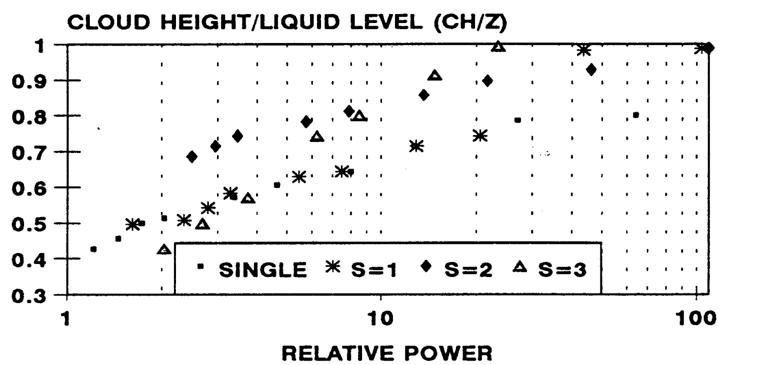
(C1/T=0.25, D/T=0.35, Z/T=1.75, SOLID-ACRYLIC, X=10% @ Z/T=1)



S=(C2-C1)/D
FIGURE 18

IMPELLER SEPARATION EFFECTS ON P-4 SUSPENSION PERFORMANCE: POWER INPUT RELATIONSHIP

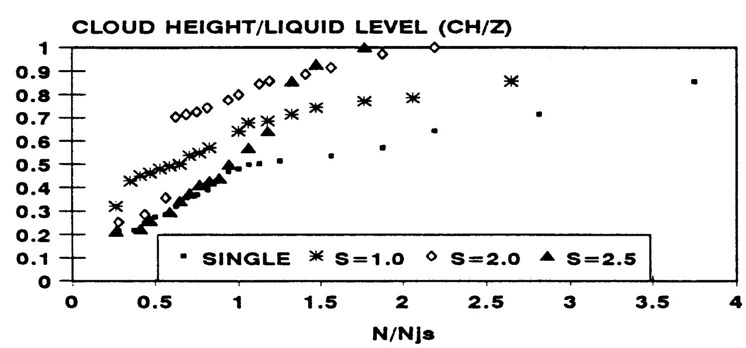
(C1/T=0.25, D/T=0.35, Z/T=1.75, SOLID-ACRYLIC, X=10% @ Z/T=1)



S=(C2-C1)/D
POWER NORMALIZED RELATIVE TO Njs OF SINGLE IMPELLER
FIGURE 19

EFFECT OF DUAL IMPELLER SEPARATION ON HE-3 SUSPENSION PERFORMANCE

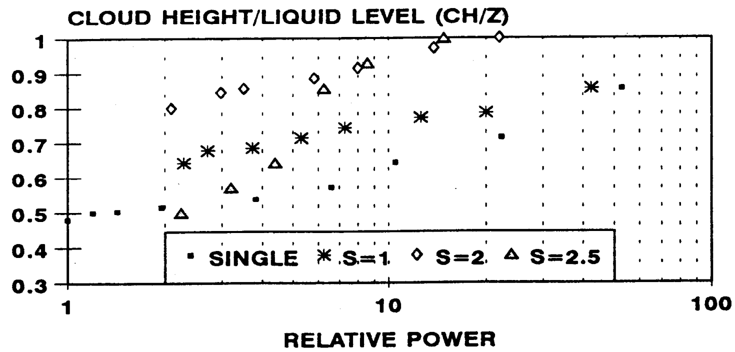
(C1/T=0.25, D/T=0.48, Z/T=1.75, SOLID-ACRYLIC, X=10% @ Z/T=1)



S=(C2-C1)/D
FIGURE 20

IMPELLER SEPARATION EFFECTS ON HE-3 SUSPENSION PERFORMANCE: POWER INPUT RELATIONSHIP

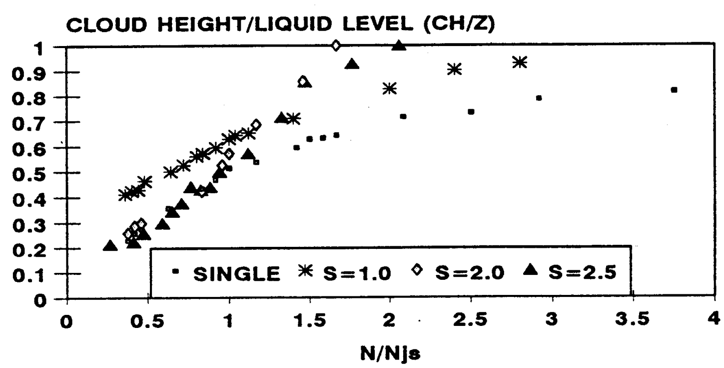
(C1/T=0.25, D/T=0.48, Z/T=1.75, SOLID-ACRYLIC, X=10% @ Z/T=1)



S=(C2-C1)/D
POWER NORMALIZED RELATIVE TO Njs OF SINGLE IMPELLER
FIGURE 21

EFFECT OF DUAL IMPELLER SEPARATION ON P-4 SUSPENSION PERFORMANCE

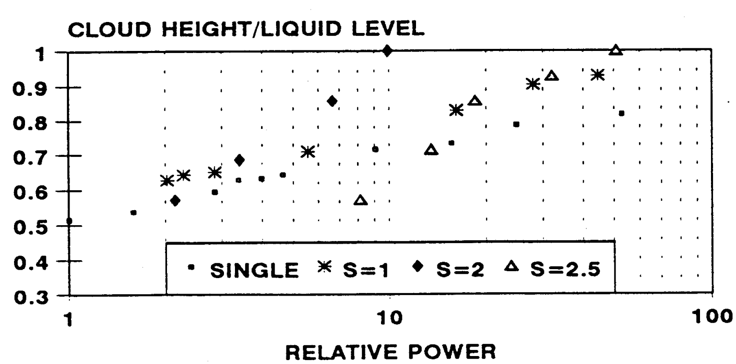
(C1/T=0.25, D/T=0.48, Z/T=1.75, SOLID-ACRYLIC, X=10% @ Z/T=1)



S=(C2-C1)/D
FIGURE 22

IMPELLER SEPARATION ON P-4 SUSPENSION PERFORMANCE: POWER INPUT RELATIONSHIP

(C1/T=0.25, D/T=0.48, Z/T=1.75, SOLID-ACRYLIC, X=10% @ Z/T=1)



S=(C2-C1)/D
POWER NORMALIZED RELATIVE TO Njs OF SINGLE IMPELLER
FIGURE 23