AGITATION REQUIREMENTS FOR COMPLETE DISPERSION OF EMULSIONS

By

Dun-Huang Tsai

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APPROVAL

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Agitation Requirements for Complete Dispersion of Emulsions

Name of Candidate: Dun-Huang Tsai

Thesis and Abstract Approved:

Dr. Piero M. Armenante Department of Chemical Enginerring	Date

Signatures of Other Members of the Thesis Committee:

Dr. Henry Shaw Department of Chemical Engineering	Date
Dr. Dana Knox Department of Chemical Engineering	Date

Vita

Name: Dun-Huang Tsai

Present address:

Permanent address:

Degree and date to be conferred: Master of Science, 1989

Date of birth:

Place of birth:

College institutions	Degree	Date of degree attended
Tam Kang U., Taiwan	B.S.	June, 1983
New Jersey Inst. of Tech.	M.S.	May, 1989

Major: Chemical Engineering

Abstract

Title of Thesis:

Agitation Requirements for Complete Dispersion of Emulsions

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Thesis directed by: Piero M. Armenante
Asistant Professor
Department of Chemical Engineering

An investigation on the minimum agitation speed required to achieve complete dispersion in liquid-liquid systems has been carried out. A model based on the momentum balance for a droplet and on Kolmogoroff's theory of isotropic turbulence was used for the prediction of the role of the most important variables on the minimum agitation speed. The equation so derived can be expressed in terms of a number of non-dimensional groups (such as Re, Ar, and Su). For geometrically similar systems the equation contains only one adjustable parameter (to be determined experimentally) in the form of the proportionality constant correlating Re with the other non-dimensional groups. The equation was tested against the experimental results previously reported in the literature by several investigators. The agreement between predicted and experimental values appears to be good. In addition, only one numerical value of the correlating parameter is required to explain all the different experimental results which were reported in previous investigations, and tested here. The overall correlation coefficient is equal to 0.98. Even better agreement is found if single sets of consistent data are considered. Experiments were also conducted to further test the validity of the equation, using five different impellers, four tank sizes, and three impeller sizes. In addition, the effect of impeller clearance off the dispersed phase, liquid height, phase volume ratio, and fluid properties were also investigated. These results were correlated using regression methods, but this introduced a second constant in the equation. A novel method to determine the minimum agitation speed for dispersing an organic phase in water was also used. A comparison between our data and the model appears favorable and is also provided.

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Finally, I want to thank all members of Mixing Group who gave me needed support, and suggestions during the research stage.

To my parents.

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Introduction

Mixing is one of the most common operations in a number of industrial processes. For the agitation of liquid-liquid systems, it should be known the minimum power required for emulsification. After agitation, energy will have been transferred to liquid-liquid system through the impellers so as to have produced as large as possible an interfacial area between the continuous and dispersed phase. For complete dispersion in liquid-liquid systems, the relation between the minimum mixing speed, the physical properties of the liquids, and the equipment geometry is considerably important.

There are many dynamic forces acting in the agitated vessel to break up one of the two liquids into small drops: (a) interfacial tension forces; (b) inertial forces; (c) buoyancy forces; and (d) viscous forces. The dynamic forces that bring about dispersion may be due to buoyance or to induced fluid flow creating viscous or inertial forces. By acting on different parts of the droplet surface, these forces may cause it to deform and eventually to break up.

Different locations,and types of impellers create different flow patterns in the vessel influencing the complete dispersion of a liquid-liquid system. In particular, the power consumption per unit mass and the macro circulation pattern of the continuous phase seem to be very important. The influence of the stirrer clearance also has an effect on the attainment of complete dispersion but a theoretical description of the problem is not easily carried out.

LITERATURE SURVEY

Minimum Stirrer Speed

The previous studies on the minimum impeller speed for complete dispersion began with Nagata (1) who used an unbaffled cylindrical vessel with centrally a mounted impeller and a four blade turbine impeller with T/D = 3 and blade width of 0.06 T . He obtained the following empirical equation:

$$N_{nim} = 6\ D^{-2/3}\ (n_c\ /\ p_c)^{1/9}\ (\Delta p/\ p_c)^{0.26} \tag{1}$$

Pavlushenko and Ianishevskii (2) carried out a study on liquid-liquid systems. Baffled and unbaffled glass vessel (two systems), five impellers were used to determine the uniform dispersion condition. Uniformity of phase distribution was checked by the sampling method. Samples of the emulsions were picked at three different points in the agitated vessels. For the baffled vessel the following correlations were obtained:

$$N_{m1n} = \frac{5.67\ \Delta p^{0.08}\ n_c^{0.06}\ n_d^{0.04}\ \sigma^{0.15}\ T^{0.92}}{p_c^{0.33}\ D^{1.87}} \tag{2}$$

for turbines, and:

$$N_{min} = \frac{5.67 \Delta p^{0.08} n_c^{0.06} n_d^{0.04} \sigma^{0.15} T^{1.25}}{p_c^{0.33} D^{2.2}} \qquad (3)$$

for propellers.

These authors also reported that the stirrer speed decreased with decreasing clearance and was independent of volume fraction of the dispersed phase.

Subsequently, Pavlushenko and Braginskii (3) derived an equation, based on the theory of local isotropy of turbulence, to analyze the relation between the critical stirrer speed, geometric and physiochemical characteristics of the system. They correlated the previous experimental data (1958), with the following expression:

$$Re_{min} = 2.2 \ (Re^2 / We)^{0.185} Ar^{0.315} (T / D)^{0.85} \qquad (4)$$

for turbines, and:

$$Re_{min} = 2.2 \ (Re^2 / We)^{0.185} Ar^{0.315} (T / D)^{1.25} \qquad (5)$$

for propellers

Esch, D'angelo, and Pike (4) presented dimensional analysis to obtain a correlation for the Reynolds Number , Re, in terms of the Suratman Number Su. They also estimated the Power Number for turbulent mixing. The data collected from their experiments were correlated by the following equation:

$$Re = 119\ Su^{0.39} \qquad (6)$$

These investigators mentioned that the critical impeller speed is weakly dependent on the relative volume fractions and very strongly dependent on the continuous phase properties.

Van Heuven and Beek (5) studied power input, drop size, and minimum stirrer speed to achieve complete dispersion in turblent liquid-liquid systems. From a combination of theory and experiments, they obtained the following equations:

$$\frac{d_{32}}{D} = 0.047 \left(\frac{N\ D^2}{v}\right)^{-6/5} \left(\frac{p\ v^2}{D\ \sigma}\right)^{-3/5} (1+2.5X_V) \qquad (7)$$

for the average drop size of the dispersed phase, and:

$$\frac{N^2\ D}{g} = 22 \left(\frac{N\ D_2}{v}\right)^{-3/5} \left(\frac{p\ v^2}{D\ \sigma}\right)^{-1/5} \left(\frac{\Delta p}{p}\right) (1+2.5X_V)^{7/3} \qquad (8)$$

for the minimum stirrer speed

They also mentioned that the volume fraction will be very important in those equations.

Skelland and Seksaria (6) predicted the minimum impeller speeds required to disperse two immiscible liquids of equal volume. Variables included size, location and form of impeller, and fluid properties were considered in the systems. An purely empirical correlation was found to be:

$$N_{min} = C\ D^{a}\ n_c^{1/9}\ n_d^{-1/9}\ \sigma^{0.3}\ \Delta p^{0.25} \qquad (9)$$

where a and C depend upon the type of impeller and its location. Dimensional analysis was used to correlate the same results. They found:

$$\left(\frac{D}{g}\right)^{1/2} N_{min} = C1 \left(\frac{T}{D}\right)^{a1} \left(\frac{n_c}{n_d}\right)^{1/9} \left(\frac{\Delta p}{p_c}\right)^{0.25} \left(\frac{\sigma}{D^2\ p_c\ g}\right)^{0.3} \qquad (10)$$

where C1 and a1 depend upon the type of impeller and its location.

Godfrey et al. (7) found the minimum condition for uniform dispersion in square-cross-section tanks to be expressed in terms of a number of dimensionless groups (such as Re, Ar, and Su). They showed that the holdup of the dispersed phase did not have an important effect on the minimum stirrer speed and the effect of holdup could be expressed by mean density and viscosity. They also noted no difference in minimum stirrer speed between batch and continuous flow operation. The expression correlating their data was found to be:

$$Re_{min} = K\ (\ Su\ )^{0.14}\ (\ Ar\ )^{0.33} \qquad (11)$$

where K is dependent on the type of impeller used.

Skelland and Ramsay (8) collected data from three different sources to obtain an empirical correlation of the minimum speed for complete liquid-liquid dispersion in baffled vessels. This work represents an extension of the earlier work by Skelland and Seksaria (6), because three new variables - H, T, and X_v - have been included in the experimental data. These results were empirically correlated by the following equation:

$$N_{min}=C\left(\frac{T}{D}\right)^{a} \frac{g^{0.42} \Delta p^{0.42} n_m^{0.08} \sigma^{0.04} X_v^{0.05}}{D^{0.71} \quad p_m^{0.54}} \qquad (12)$$

where c and a depend on the type of impeller and its location.

Power Consumption

Many types of impellers are used in agitation. To produce mixing it is necessary to supply energy and to transfer energy to the liquids through the rotation of an impeller. Rushton, Costich, and Everett (9) used dimensional analysis to obtain a correlation for the Power Number, Np, in terms of the Reynolds Number, Re.

$$Np = \frac{P}{p\ N^3\ D^5} = K\ (\ Re\ )^m \qquad (13)$$

For the Reynolds Number of the agitator, There are three zones to be distinguished:

$Re < 10$: laminar zone; the Power Number is inversely proportional to the Reynolds Number.

$10< Re <10^4$: transition zone; the Power Number is a function of the Reynolds Number.

$Re > 10^4$: turbulent zone; the Power number is independent of the Reynolds number.

Bates, Fondy, and Corpstein (10) established the generalized form for the effect of impeller and system geometry in agitated vessels. For impeller geometry, they considered the effect of the type of impeller, blade width and number of blades, impeller pitch, and shrouded impellers. As system geometry, they considered the effect of D/T, shape factors, and the clearance to tank bottom.

The Effect of Volume Fraction

Some previous work has showed that volume fraction is a very important factor for complete dispersion. With increasing volume fraction of the dispersed phase, the droplet size-distribution produces damping of the turbulence intensity by the dispersed droplets and increasing coalescence between the droplets in the regions of lower turblence in the agitated vessels.

Doulah (11) used Kolmogoroff's theory to show that the drop sizes in concentrated dispersions depend on dispersed phase viscosity because the dispersion viscosity depends on holdup and turbulent scales are affected. He derived the following relationship, which is based on theoretical considerations:

$$d_{32} = d_{32}^{0} \left(1 + 3 X_V \right) \tag{14}$$

Delichatsios and Probstein (12) showed that coalescence is the major cause of droplet size enlargement. The coalescence frequency resulting from binary drop collisions is assumed to be equal to an effective breakup frequency, yielding a semiempirical relation for the increase in drop size with holdup. They obtained the following expression for the holdup fraction:

$$f(X_V) = \left[\frac{\ln(C3 + C4\ X_V)}{\ln C3} \right]^{-3/5} \tag{15}$$

where C3=0.011, and C4 must be determined empirically. They also correlated the data from other papers to find C4 value.

The Effect of Clearance

The previous literature on liquid-liquid dispersion has failed to produce relationships between the impeller clearance off the tank bottom and the minimum agitator speed for complete dispersion. Therefore it is interesting to briefly review some of the literature on solid-liquid suspension including clearance effect on minimum agitator speed.

Zwietering (13) found that clearance had a negligible effect on the required stirrer speed for the suspension of solid particles. Nienow (14) showed that a reduction in clearance would reduce the impeller speed required for suspension. Baldi,Conti, and Alaria (15) pressent that the experimental results are interpreted on dimensionless group

$$Z = f\ (Re^{*}, T/D, C/D) \qquad (16)$$

They also showed that the influence of the Reynolds Number increases as C/D increases and that the influence of C on N is more complex.

Conti, Sicardi, and Specchia (16) concentrated on the effect of the clearance on the minimum stirrer speed for complete particle suspension. The following dimensionless correlation was reported

$$Z\ B^{0.134} = a\ (\ Re^{*}\ Np\ ) + b \qquad (17)$$

where for $C/T < 0.22$ $a = 2.08*10^{-5} - 6*10^{-5}\ (C/T)$

$b = 0.575 - 1.25\ (C/T)$

for $C/T > 0.22$ $a = 1.70*10^{-5} - 4.55*10^{-5}\ (C/T)$

$b = 0.21$

They also found that the Power Number is quite different in the two hydrodynamic regions which may be characterized by the C/T value.

Criteria of Complete Dispersion

For solid suspension in an agitated vessel, many investigators have reported that the minimum speed for complete suspension is taken as the speed at which no particles are visually served to remain at rest on the tank base for more than one or two seconds. Other authors have estimated the minimum speed by measuring the local solids concentration by withdrawing samples from the vessel.

When the dispersion of two immiscible liquids is being made, it has to be very careful about no complete dispersion until minimum stirrer speed reaching. Two main dispersion states can be defined : complete dispersion and homogeneous dispersion. A large majority of the previous works have concentrated on the criteria of dispersion.

" Homogeneous dispersion " means that the concentration of droplets is constant through the whole vessel. For Pavlushenko's uniformity of phase distribution, he picked up samples from three different points. Uniform dispersion would reach until getting same concentration from those points. For complete dispersion, there are many visual observations that were defined. Skelland (6) defined the minimum mixing speed as that speed which is just sufficient to completely disperse one liquid in the other, so that no clear liquid is observed either at the top or at the bottom of the mixing vessel. In a subsequent work, Skelland and Lee (19) devoted to minimum rotational speed for uniform dispersion and reported that minimum speed for uniform dispersion exceeds minimum speed for complete dispersion by an average of about 8 %. Van Haueven (5) defined that complete dispersion is used for a situation in which no large drops or agglomerates of droplets are found on the bottom of the vessel or at the liquid surface.

THEORY

Proposed Model for the Prediction of the Minimum Agitation Speed for Complete Dispersion

Kolmogoroff's theory of isotropic turbulence assumes that, in an agitated system, the turbulent flow produces primary eddies which have a wavelength or scale of similar magnitude to the dimensions of the main flow stream. The large primary eddies are unstable and disintegrate into smaller eddies until all their energy is dissipated by viscous flow. The Reynolds number of the main flow can be expressed in this form

$$Re_E = \frac{p\ v\ d}{n} \propto \frac{\text{inertial force}}{\text{viscous force}} \qquad (18)$$

We know that $Re_E >> 1$ for large eddies since the inertial forces are larger than viscous forces. Most of the kinetic energy is contained in the large eddies, but nearly all dissipation occurs in the smaller eddies. Kinetic energy is transferred from larger to smaller eddies, and because this transfer occurs in different directional deformation of the large eddies is gradually lost.

Kolmogoroff's theory was used in the derivation of the present model. In the derivation the following assumptions were also made: (1) the system is not coalescing, (2) the dispersed phase concentration is very small in comparison to the continuous phase, (3) the viscous stress of the dispersed phase is negligible in comparison to other stresses, and (4) the size of the responsible for droplet formation are of the same order of magnitude as the droplet diameter.

The outline of the derivation is as follows: in correspondence with the minimum agitation speed required to obtain a complete dispersion, a momentum balance can be written requiring that the force responsible for generating a new droplet be equal to the force which opposes this action.

Let's take a droplet larger than the smallest eddies. In order for the droplet to be dragged down by the eddies working near the surface it must be that inertial forces equal the surface tension forces, i.e.:

$$\tau d^2 = \sigma d \qquad (19)$$

Shinnar and Church (18) described the behavior of turbulent flow and drop size using the concepts of local isotropy. According to their conclusions, small-scale flow is determined by the local energy dissipation. For local isotropic turbulence the smallest eddies are responsible for most of the energy dissipation. By using Kolmogoroff's theory, it may be concluded that the shear stress due to turbulence is, for droplets larger than Kolmogoff's length scale, given by:

$$\tau \propto p_c \left(\frac{P}{V}\right)^{2/3} \left(\frac{d}{p_c}\right)^{2/3} \qquad (20)$$

substituting the value of τ in equation 19 gives

$$d \propto \frac{\sigma^{3/5}}{p_c^{1/5} \; (P/V)^{2/5}} \qquad (21)$$

which describes the mean drop size in dilute dispersions. At dilute dispersion, the mean drop size should be independent of holdup values. Although at high holdup values of the dispersed phase, the mean drop size should be a function of holdup values. Doulah (11) attributed the change in mean drop size with holdup to the damping of the turbulence. Delichatsios (12) described the relation between mean drop size and holdup, based on coalescence and breakup frequency of the dispersed phase. For this work, we use Delichatsios's expression:

$$f(X_V)^* = \{ -(1/4.5)* \ln (0.011 + 0.68 X_V) \}^{-3/5} \qquad (22)$$

to account for the hold-up effect on N.

In addition, the inertial forces must be able to counterbalance the buoyancy forces that would, otherwise, break the emulsion by lifting the droplets, thus reforming the immiscible phase originally present in the tank. Therefore it must be that:

$$p_c\, d^2 \left(\frac{P}{V}\right)^{2/3} \left(\frac{d}{p_c}\right)^{2/3} \propto \Delta p\, g\, d^3 \tag{23}$$

i.e.:

$$d \propto p_c \left(\frac{P}{V}\right)^2 \frac{1}{(\Delta pg)^3} \tag{24}$$

Eliminating d from equation 24 and 21 leads to

$$\frac{\sigma^{3/5}}{p_c^{1/5}\, (P/V)^{2/5}} \propto p_c \left(\frac{P}{V}\right)^2 \frac{1}{(\Delta pg)^3} \tag{25}$$

For fully turbulent flow in agitated tank, the power consumption can be expressed as follows:

$$\frac{P}{V} \propto \frac{Np\, p_c\, N^3\, D^5}{T^2\, H} \tag{26}$$

Equation 26 ,22, and 25 yield the proposed expression for the minimum agitation speed required for complete dispersion:

$$N \propto \frac{(\Delta pg)^{5/12}\, \sigma^{1/12}\, f(X_v)}{p_c^{1/2}\, Np^{1/3}\, D^{2/3}} \left(\frac{T}{D}\right)^{2/3} \left(\frac{H}{D}\right)^{1/3} \tag{27}$$

where

$$f(Xv) = ((-1/4.5)\ \ln(0.011+0.68Xv))^{-1/2}$$

is the term accounting for the hold-up effects.

We can be rearranged equation 27 using dimensionless groups to relate the Reynold Number to the Suratman Number and the Archimedes Number:

$$Re \propto Su^{1/12}\ Ar^{5/12}\ Np^{-1/3}\ \left(\frac{T}{D}\right)^{2/3}\ \left(\frac{H}{D}\right)^{1/3}\ f(X_v) \qquad (28)$$

where

$$Re = \frac{p_c\ N\ D^2}{n_c}$$

$$Su = \frac{p_c\ \sigma\ D}{{n_c}^2}$$

$$Ar = \frac{g\ p_c \Delta\ p\ D^3}{{n_c}^2}$$

Equation (27) and (28) will be compared with the experimental results obtained in this work and with the data reported in the literature.

EXPERIMENTAL METHODS

The objective of the experimental work was to further test the validity of the equation for complete dispersion presented above (eqn 27 & 28), considering impeller type, tank size, liquid height, fluid properties, dispersed phase volume fraction, and the effect of impeller clearance off the top or bottom of the agitation tank which is different from the solid-liquid system.

Three immiscible systems were used in this work, Heptane - water, Dibromomethane - water, and Methyl isobutyl ketone - water. Fluid properties, such as density, and interfacial tension, were measured at ambient laboratory temperature, which remained consistently between 70° and 80° F. The range of dispersed phase volume ratio was performed from 0.05 to 0.26. The physical properties of liquids are shown in Table 1. All of the experimental results are listed in the Appendix.

Interfacial tension was measured using surface tensiometer. The force necessary to pull a platinum-iridium du Nuoy ring through the liquid-liquid interface was measured and converted into interfacial tension. The density was measured using an analytical density balance. The viscosity was obtained from the literature(20,21).

Four cylindrical flat-bottomed tanks equipped with four radial baffles at 90^{o} intervals were employed. Standard 6-disc turbines, 6-flat turbines, 6-curved turbines, 6-pitched turbines, and square pitch propellers, centrally located on a vertical shaft, were driven by a 1/8 HP variable speed (G. K. Heller Co.) moter. The accuracy of the speed control dial was checked with a stroboscope. Torque measurement was performed by the caculation of Power number. A diagram of the equipment is shown in Fig.1. Apparatus dimensions are reported in Table 2.

The minimum speed for complete dispersion was defined as the speed at which the dispersed phase just disappears in the agitated vessel. It was determined in this work by observing and by withdrawing a sample from same location with the impeller. The estimate of this speed by withdrawing a sample from the vessel was very close to the estimate obtained by observation. In order to maintain consistency throughout this work, both the methods will be used at the same time. The dispersed phase concentrations in the withdrawn samples are plotted versus impeller speed in Figure 2.

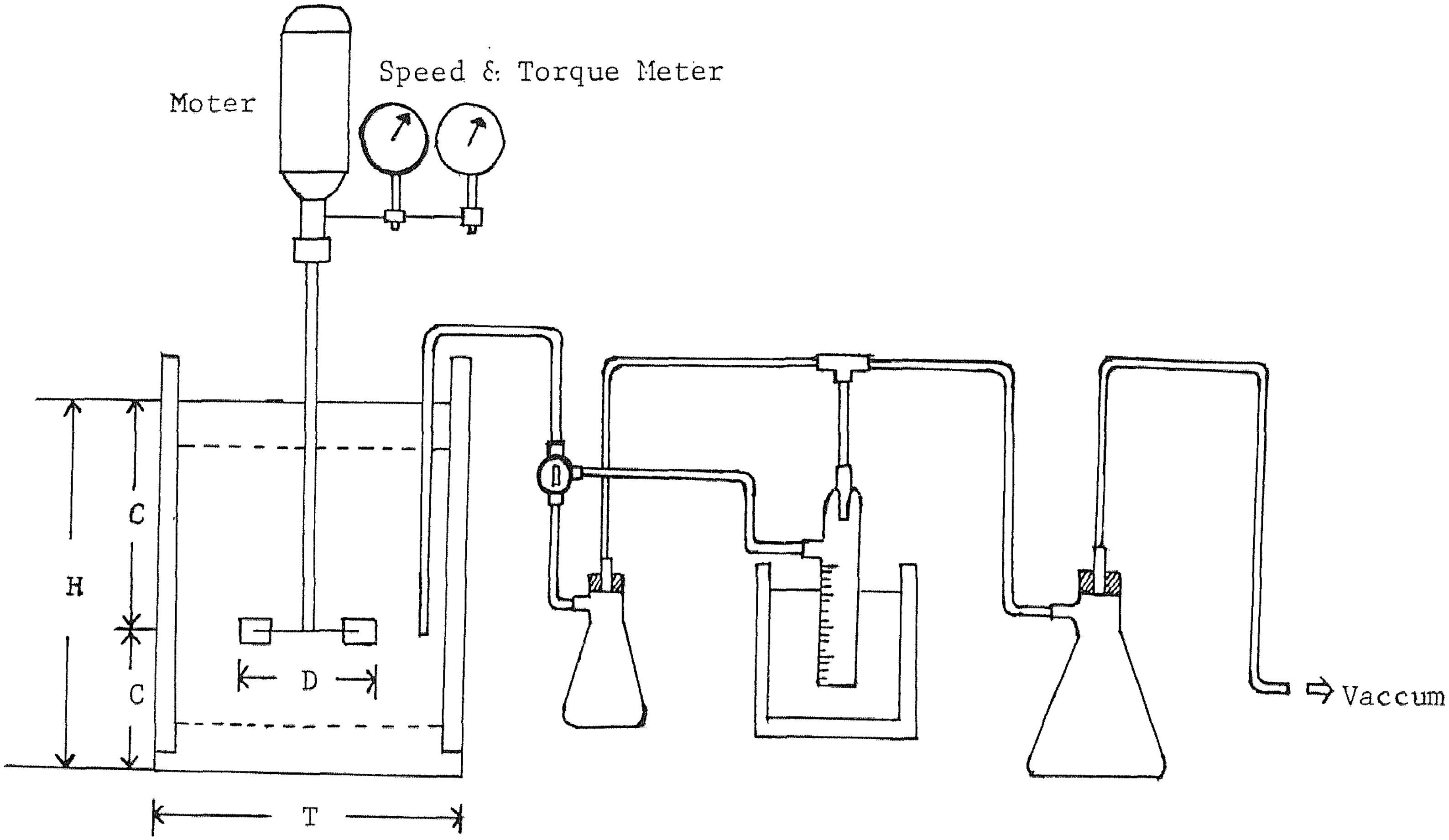
Table 1 Physical Properties of Liquids

Fluid	Density (kg/m^3)	Viscosity (mpa.s)	Interfacial tension with water (mN/m)
Heptane	679	0.39	50.0
Dibromomethane	2482	0.99	36.8
Methylisobutyl ketone	815	0.60	9.8
Water	998	0.94	____

Table 2 Apparatus Dimensions

Tank Diameter (cm)	Baffle width (cm)	Liquid heigh (cm)	Impeller diameter (cm)
19.0	1.6	19.0-21.0	6.4, 7.7
24.7	2.1	15.3-32.2	6.4, 7.7, 10.2
28.6	2.1	22.0-29.0	6.4, 7.7, 10.2
34.5	2.1	34.5	7.7

Fig. 1 Diagram of Experimental Apparatus



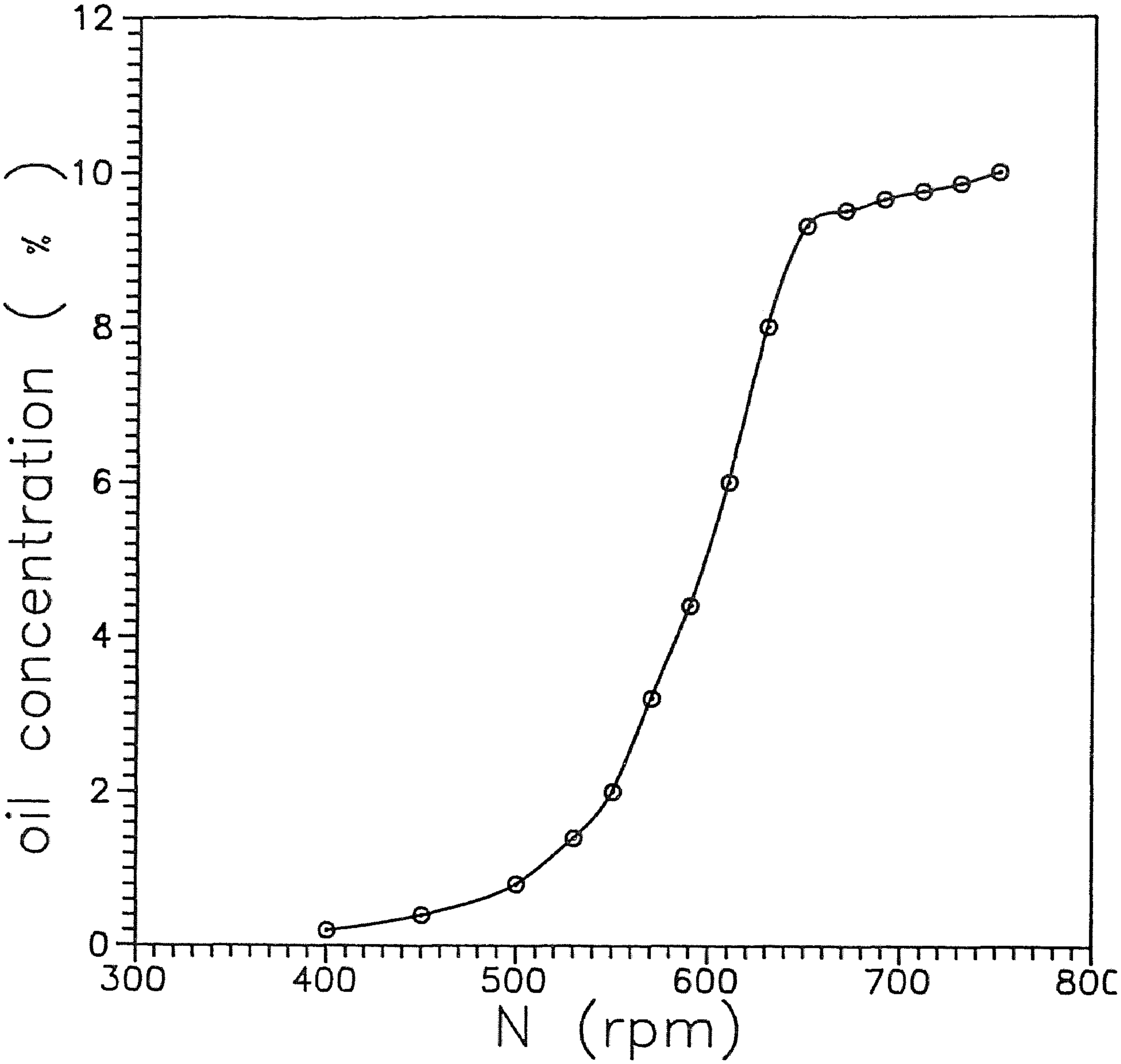


Fig 2 Local oil concentration vs. impeller speed

RESULTS & DISCUSION

The 568 experimental data points obtained in this and previous work are presented in tabular form in Appendices A and B. The experimental values of N, the minimum agitation speed for complete dispersion, and of the independent veriables which were kept constant during each run are reported in those tables, as are the corresponding values of Re, Su, and Ar. The experimental relationship between N and each of the other variables considered separatelly (such as liquid properties, impeller diameter and type) is presented below and compared with the dependence predicted by the proposed model (equation 28). In addition, a comparison between the dependence (both theoretical and experimental) obtained in this work and the experimental dependence among variables, as reported by previous investigators, is also presented.

Liquid Properties

Effect of Continuous Phase Density

Fig 3 presents the dependence of N on p_C. Three different liquid-liquid system were examined. Only two points for each system could be obtained. This was accomplished by reversing the volume ratio of the two phases so that the organic phase was continuous in one experiment and discontinuous in the

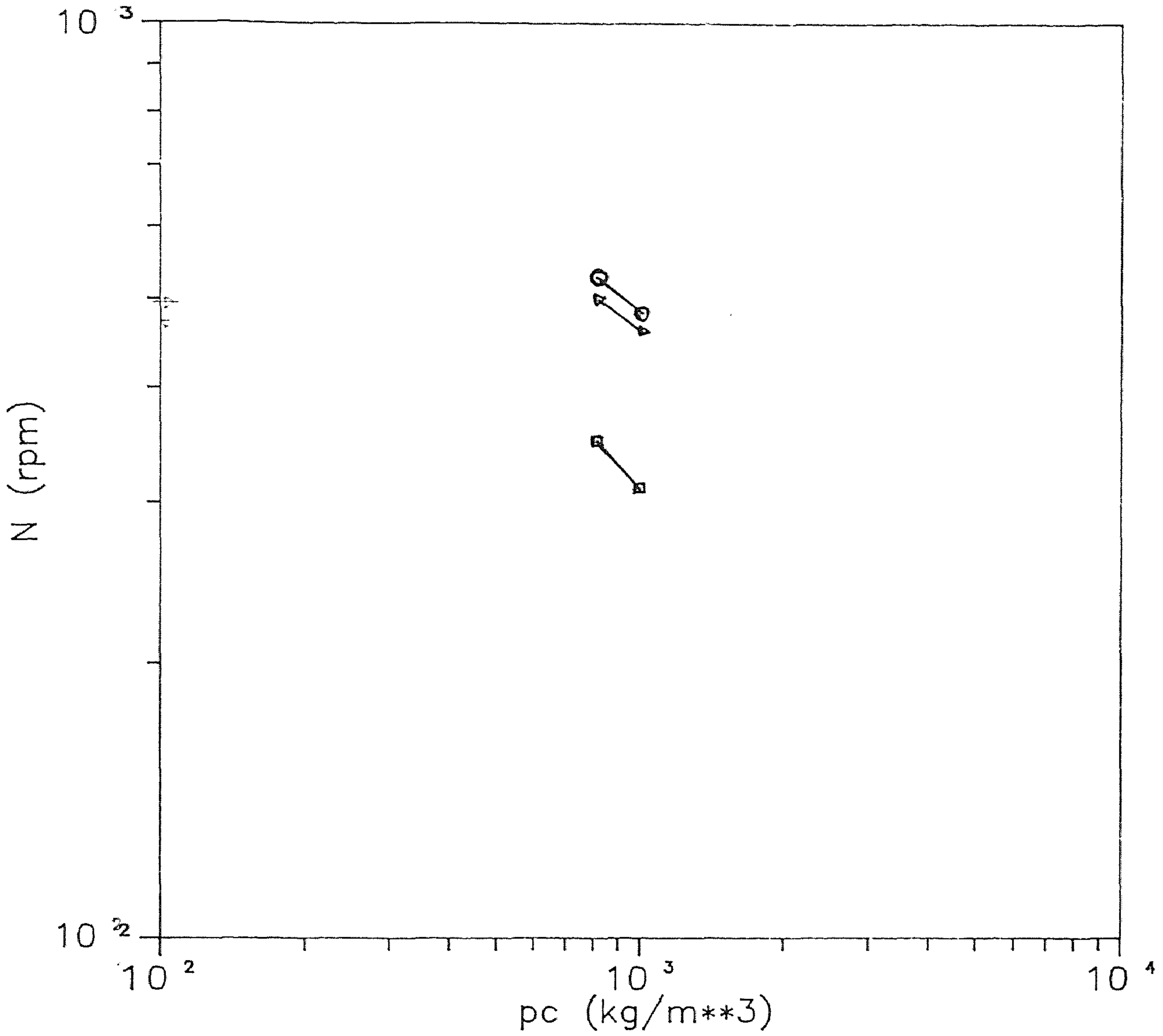


Fig3 Effect of continuous phase density on N;
D=7.7; C=12.5; T=H=24–24.7; Xv=0.1–0.15;
Methylisobutyl Ketone–Water; pc=815–998;
□ DT; ▷ FT; ○ CT.

other. In this way all the other system and liquid properties except p_c could be kept constant. From equation 27 the relationship between N and p_c is expected to be :

$$N \propto p_c^{B1}$$

Table 3 compares the predicted and experimentally found dependence. In spite of the potentially large error introduced by the use of only two points at a time the agreement is significant.

Effect of Surface Tension and Density Difference

Fig 4 shows the effect of the group ($\sigma^{1/12} \Delta p^{5/12}$) on N This group was obtained from equation 27 which predicts that :

$$N \propto \sigma^{1/12} \Delta p^{5/12}$$

The surface tension and density difference effects were considered simultaneously since it was impossible to keep one of the two constant while varying the other in our systems. Table 4 shows the comparison between theory and experiments, assuming that :

$$N \propto (\sigma^{1/12} \Delta p^{5/12})^{B2}$$

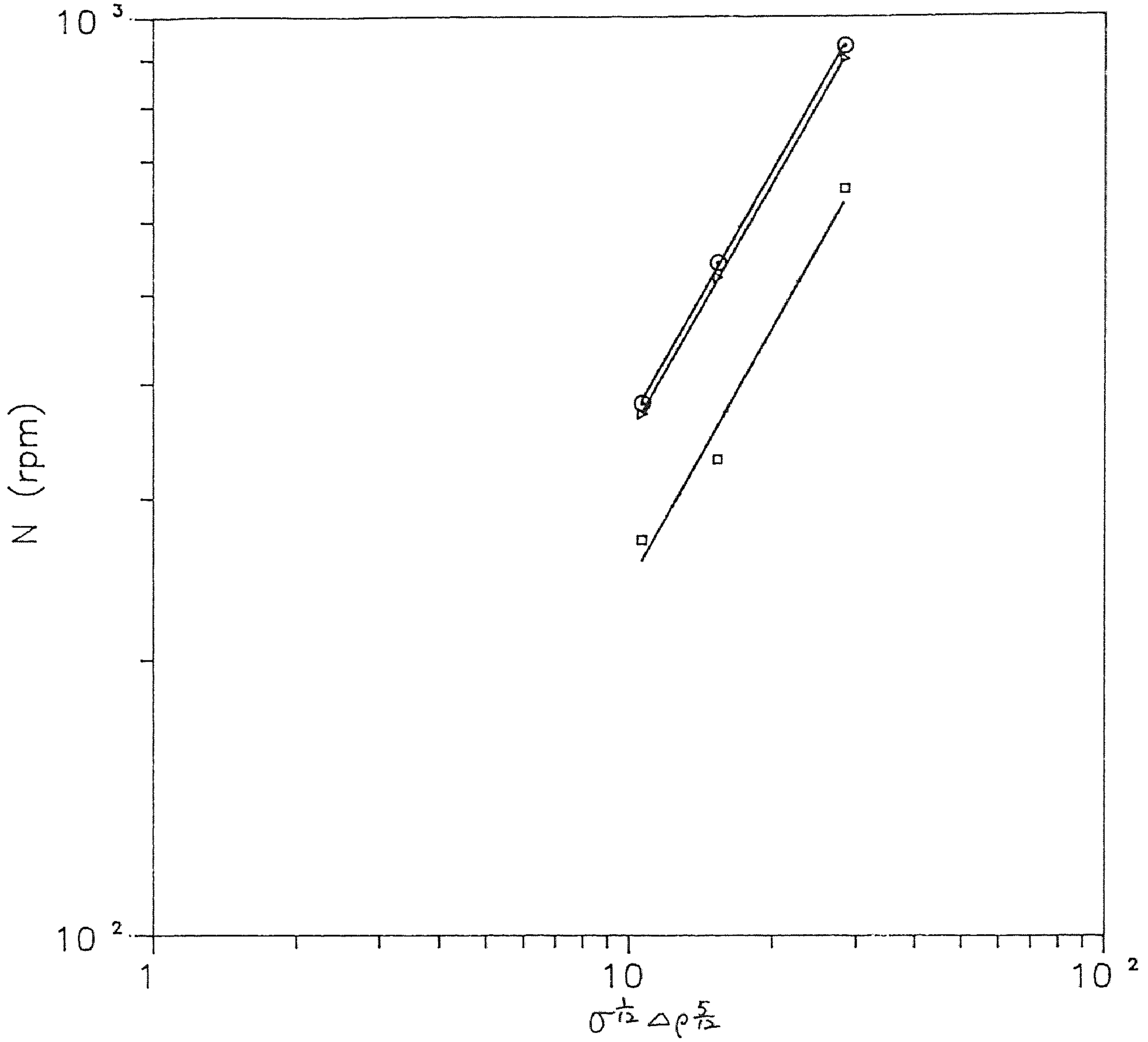


Fig4 Effect of fluid properties on N;
C/D=1; H/D=T/D=3; pc=998; Xv=0.15–0.18;
□ DT; ▷ FT; ⊙ CT;

Table 3 Comparison of B1 with N vs. p_c from Fig.3

Impeller	B1 experiment	B1 theory
Disc	-0.599	-0.5
Flat	-0.411	-0.5
Curved	-0.489	-0.5

Table 4 Comparison of B2 with N vs. $\sigma^{1/12} \Delta p^{5/12}$ from Fig.4

Impeller	B2 experiment	B2 theory
Disc	0.92	1
Flat	0.91	1
Curved	0.91	1

System Properties

Effect of Power Number

Several previous investigators have pointed out that the type of impeller has a significent effect on the value of N. Here it was found that this dependence can be expressed quantitatively as :

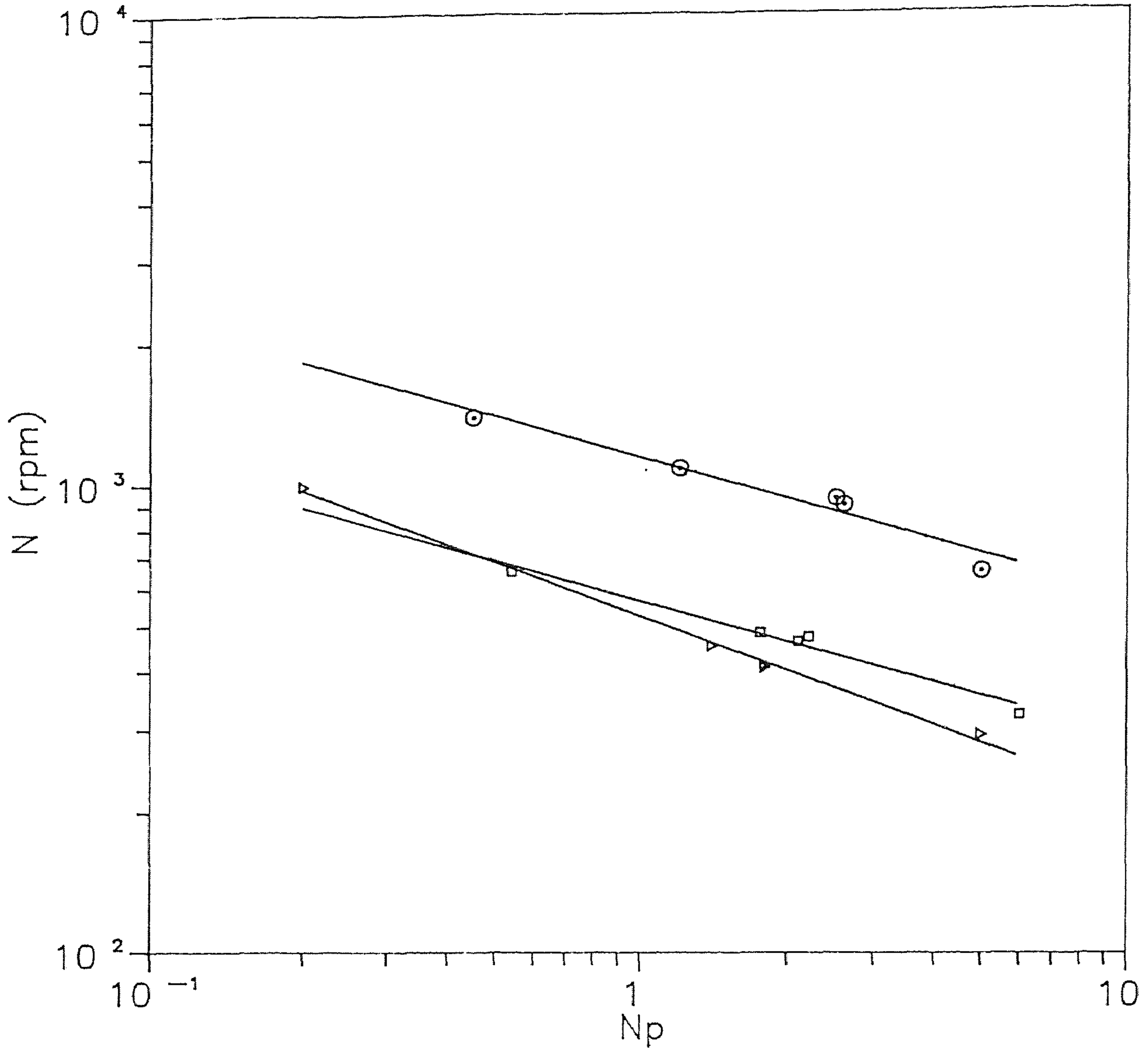


Fig5 Effect of Power number on N;
□ Methylisobutyl Ketone–Water
▷ Heptane–Water
⊙ Dibromomethane–Water

$$N \propto Np^{-1/3}$$

Fig 5 and Table 5 show the experimentally found dependence and the comparison with theory, assuming that :

$$N \propto Np^{B3}$$

In this case, also, the agreement is satisfactory.

Table 5 Comparison of B3 with N vs. Np from Fig.5

Liquid	B3 experiment	B3 theory
Methylisobutyl ketone	-0.29	-0.33
Heptane	-0.38	-0.33
Dibromomethane	-0.29	-0.33

Effect of Impeller Diameter

To vary the impeller diameter without changing some other geomtric characteristic of the system is not possible. Therefore, Fig 7 shows a plot of N vs. D assuming constant clearance off the tank bottom or top, C. This type of plot has also been used by several previous investigators (such as Godfrey et al., and Skelland and Seksaria) The plot shows the exponent of D in:

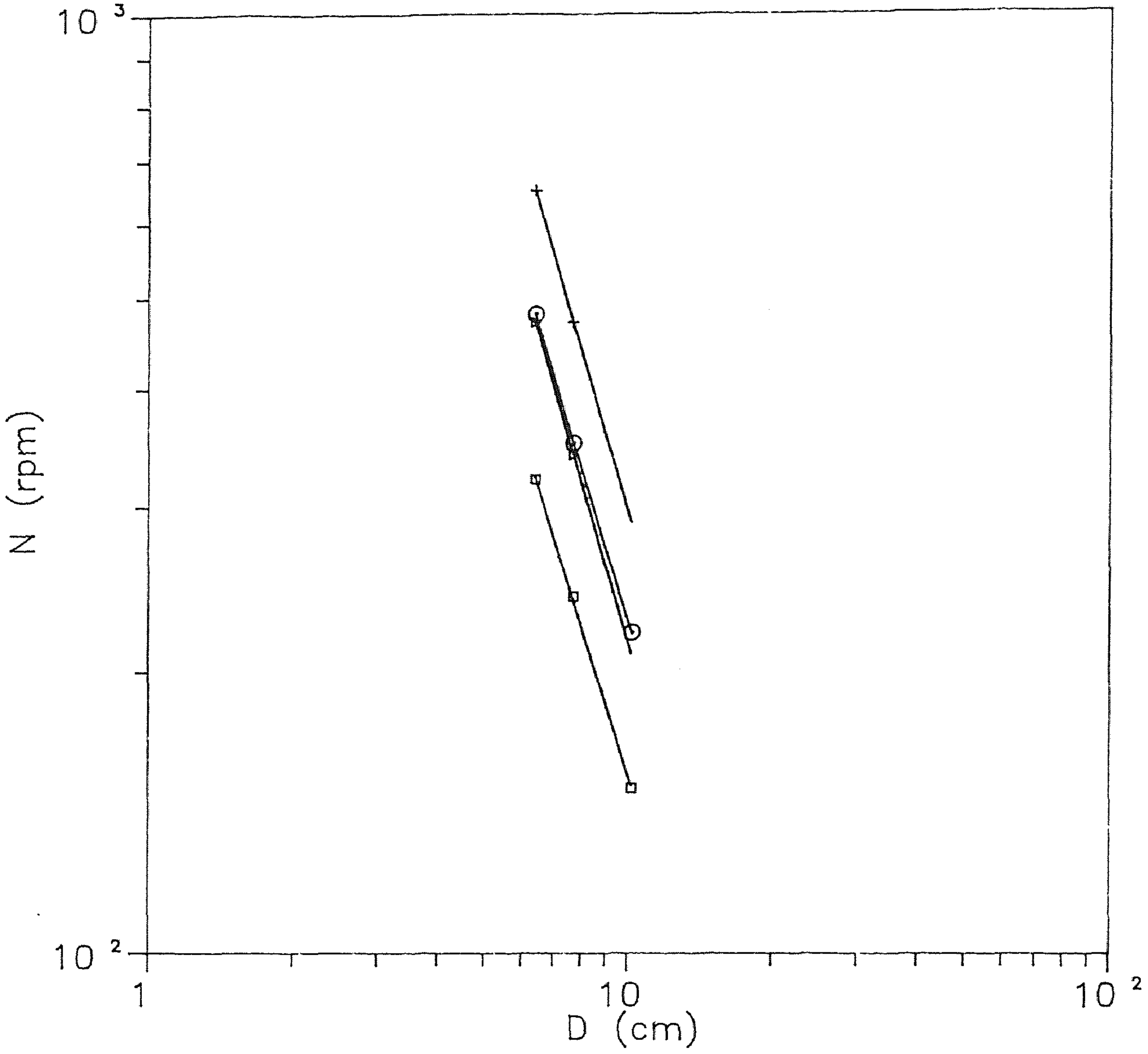


Fig6 Effect of impeller size on N (constant C/D)
C/D=1; H=T=24.7cm; Methylisobutyl Ketone–Water; Xv=0.15;
□ DT; ▷ FT; ○ PT; + Propeller.

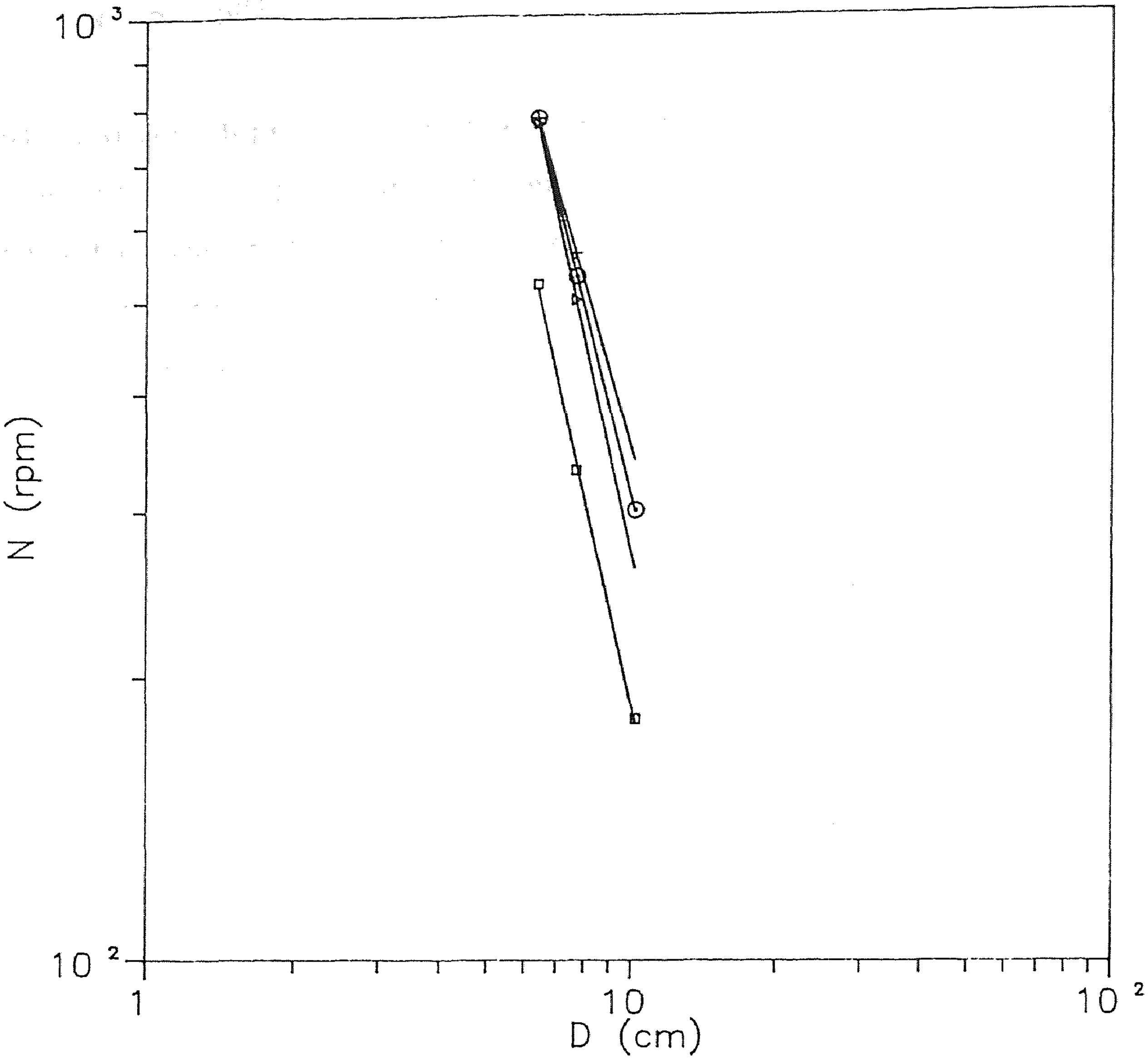


Fig7 Effect of impeller size on N (constant C)
C=14 ; H=T=24.7 ; Xv=0.15;
Methylisobutyl Ketone–Water;
□ DT; ▷ FT; ○ PT; + Propeller.

$$N \propto D^{B4}$$

B4 changes depending on the type of impeller used. Table 7 presents a comparison between experimental and theoretical results. The model in this case does not seem to accuretelly predict the experimental data since B4 is not constant. However, equation 27, which predicts that

$$N \propto D^{-1.67}$$

assuming that the ratio C/D is constant. Therefore, this kind of plot is presented in Fig 6. The slopes in this figure are very similar to each other, in spite of the different types of impeller used. Table 6 shows that the theoretically predicted value of -1.67 for B4 is closely approximated by all impellers, as expected.

Table 6 Comparison of B4 with N vs. D for C/D=constant;(Fig.6)

Impeller	B4 experiment	B4 theory
Disc	-1.63	-1.67
Flat	-1.75	-1.67
Pitched(downward)	-1.67	-1.67
Propeller(downward)	-1.75	-1.67

Table 7 Comparison of B4 with N vs. D for C=constant;(Fig.7)

Impeller	B4 experiment	B4 theory
Disc	-2.27	________
Flat	-2.33	________
Pitched(downward)	-2.04	________
Propeller(downward)	-1.79	________

Effect of Impeller Clearance

We define the impeller clearance as the distance between the impeller and either the tank bottom or the air-liquid interface, depending on whether the dispersed phase is heavier or lighter then the continuous phase, respectively. For the case of lquid dispersions, the influence of the stirrer clearance, C,on the minimum stirrer speed for complete dispersion is rarely fully considered. On the other hand, many papers on solid suspension mention that the clearance is a very important factor for the attainment of the complete dispersed state but that is not easy to mathematically model the role of this variable. According to our experimental data, the influence of C on N is very complex. Approximately, we can use power function to express the effect of the stirrer clearance, although no theory can be invoked to justify the results obtained.

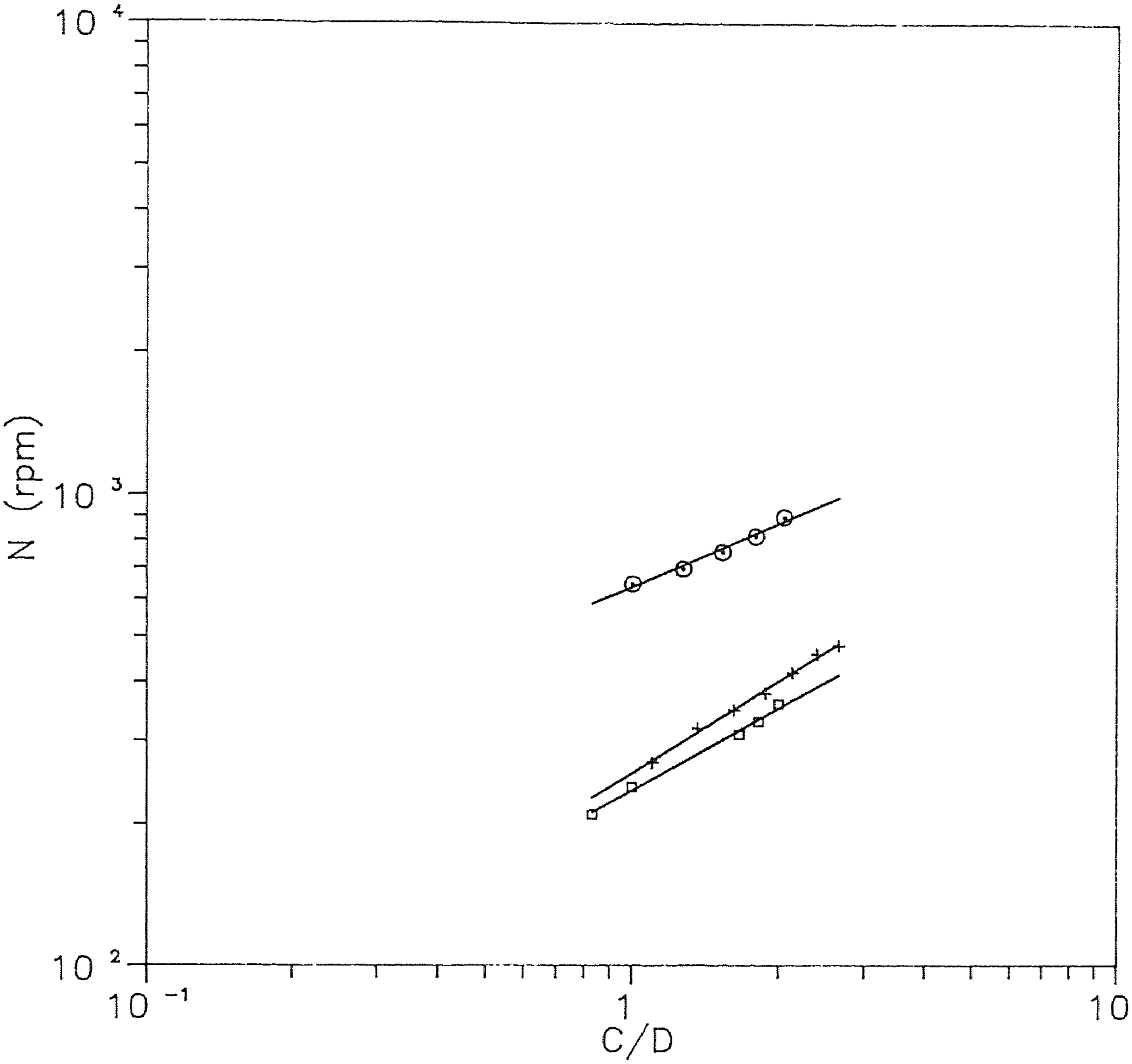


Fig8 Effect of C/D on N (Disc turbine)
☐ Methylisobutyl Ketone—Water pc=815;
○ Dibromomethane—Water pc=998;
+ Methylisobutyl Ketone—Water pc=998;

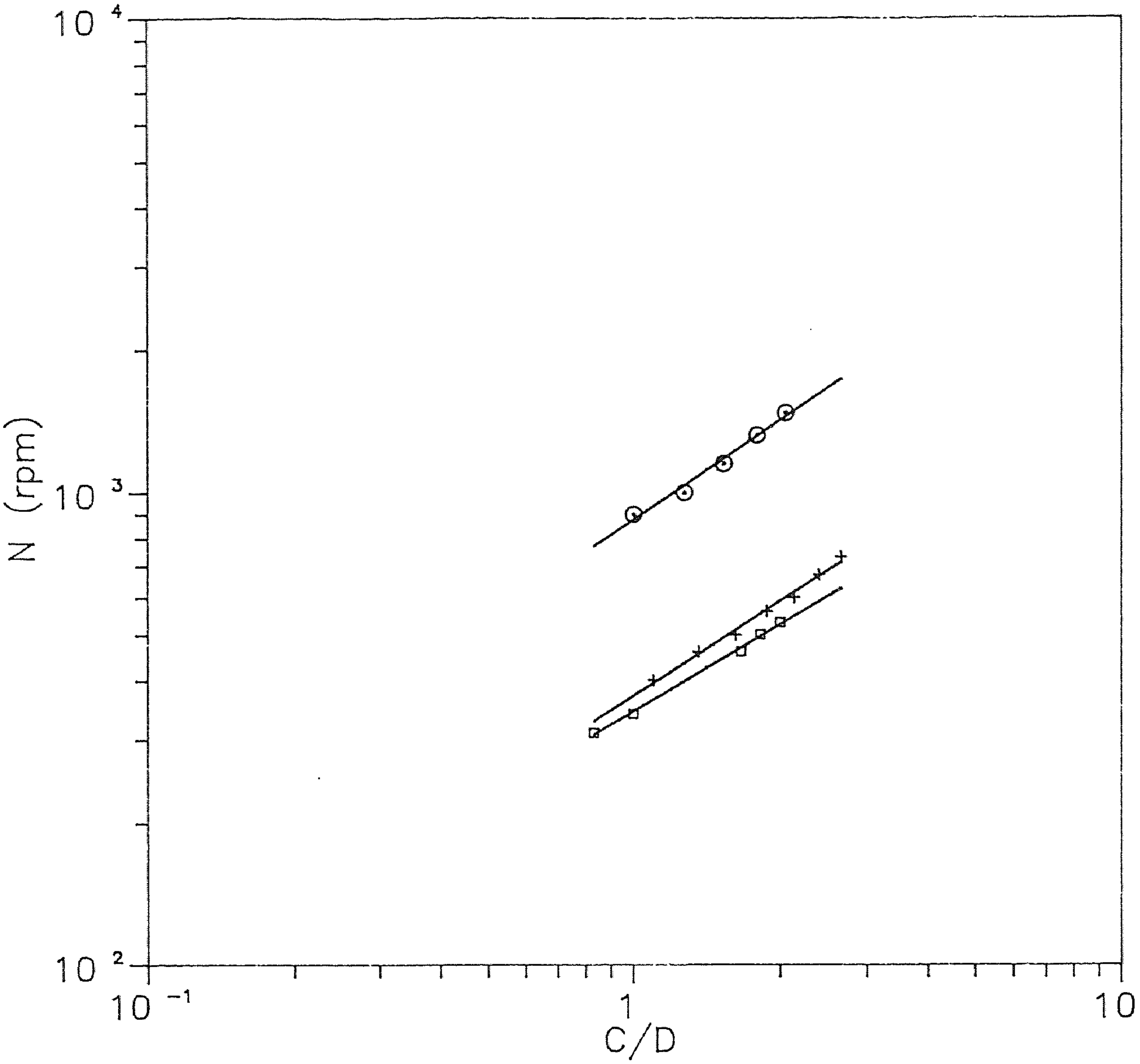


Fig9 Effect of C/D on N (Flat turbine)
□ Methylisobutyl Ketone–Water pc=815;
○ Dibromomethane–Water pc=998;
+ Methylisobutyl Ketone–Water pc=998;

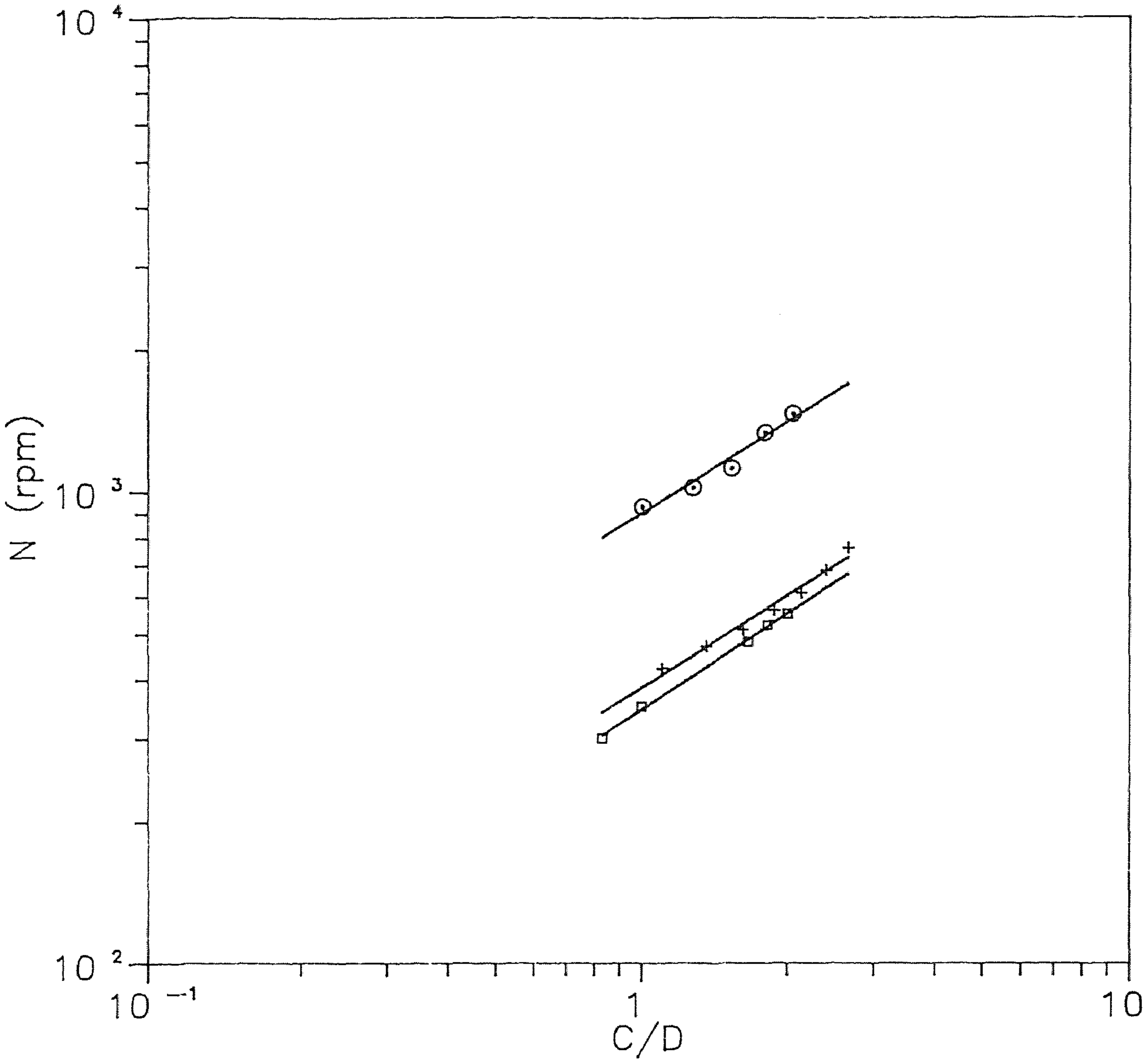


Fig10 Effect of C/D on N (Curved turbine)
□ Methylisobutyl Ketone–Water pc=815;
○ Dibromomethane–Water pc=998;
+ Methylisobutyl Ketone–Water pc=998;

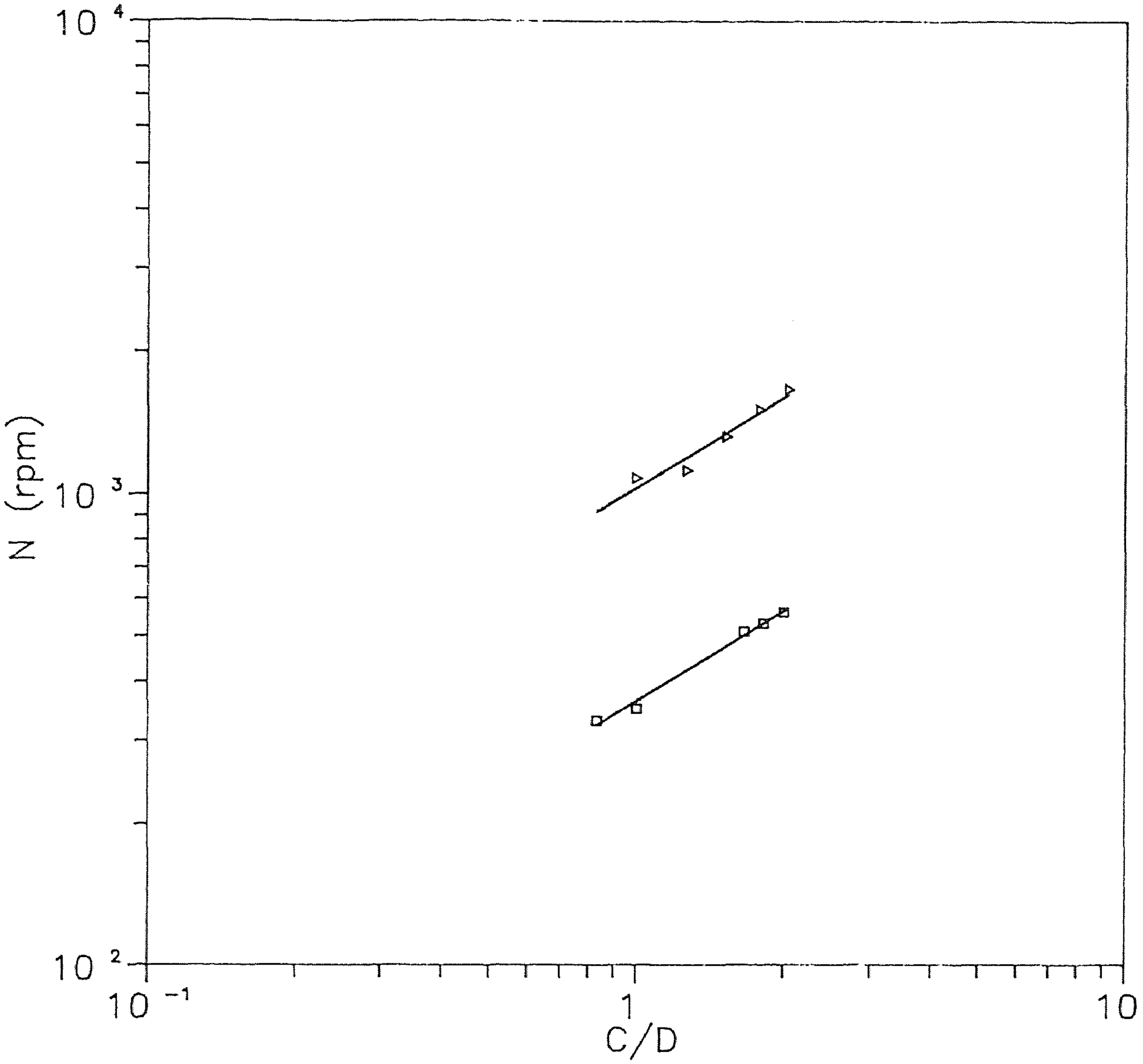


Fig11 Effect of C/D on N (pitched turbine)
downward; dispersed phase on bottom;
▷ Dibromomethane–Water pc=998;
□ Methylisobutyl Ketone–Water pc=815;

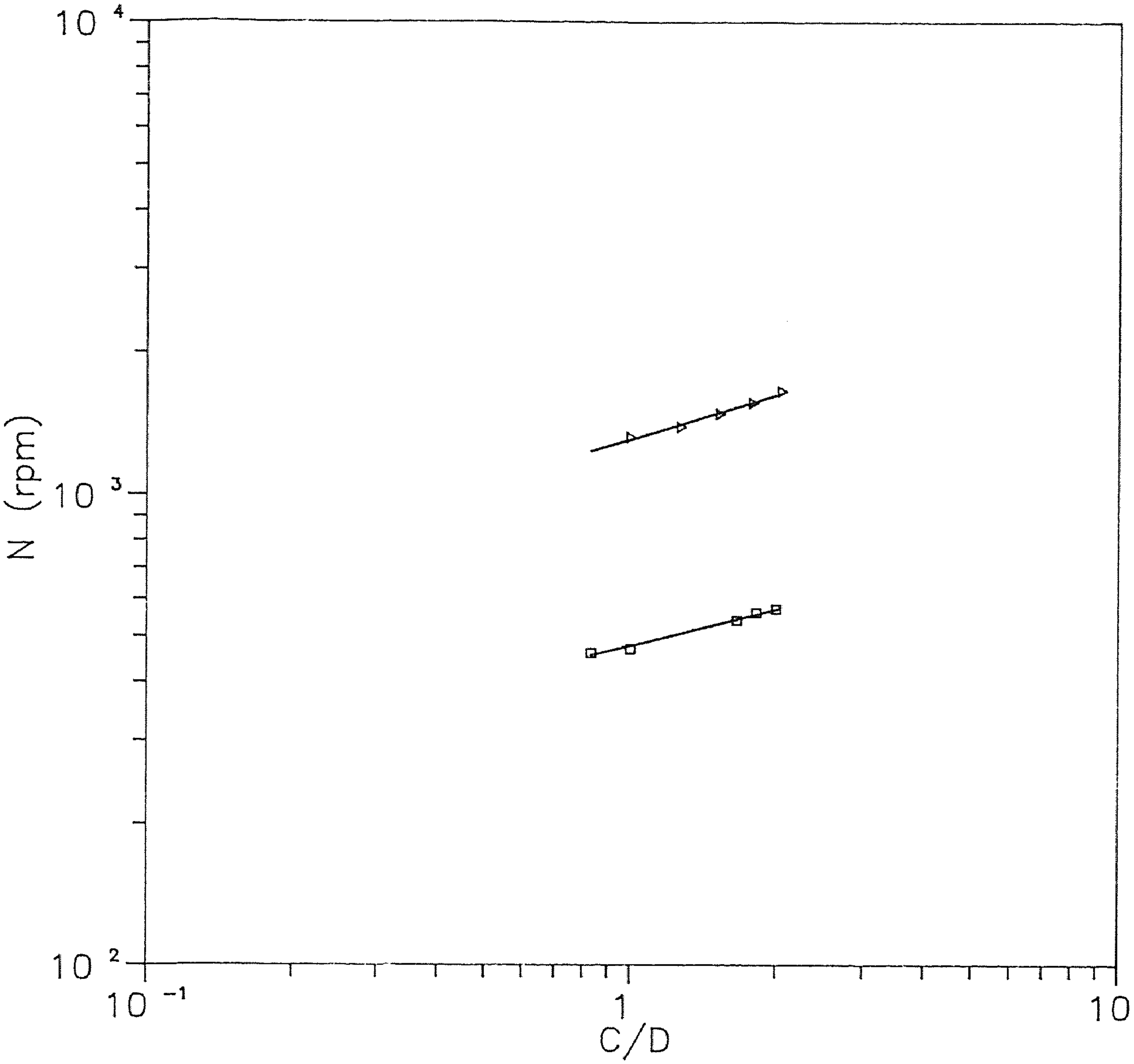


Fig12 Effect of C/D on N (Propeller)
downward; dispersed phase on bottom;
▷ Dibromomethane−Water pc=998;
□ Methylisobutyl Ketone−Water pc=815;

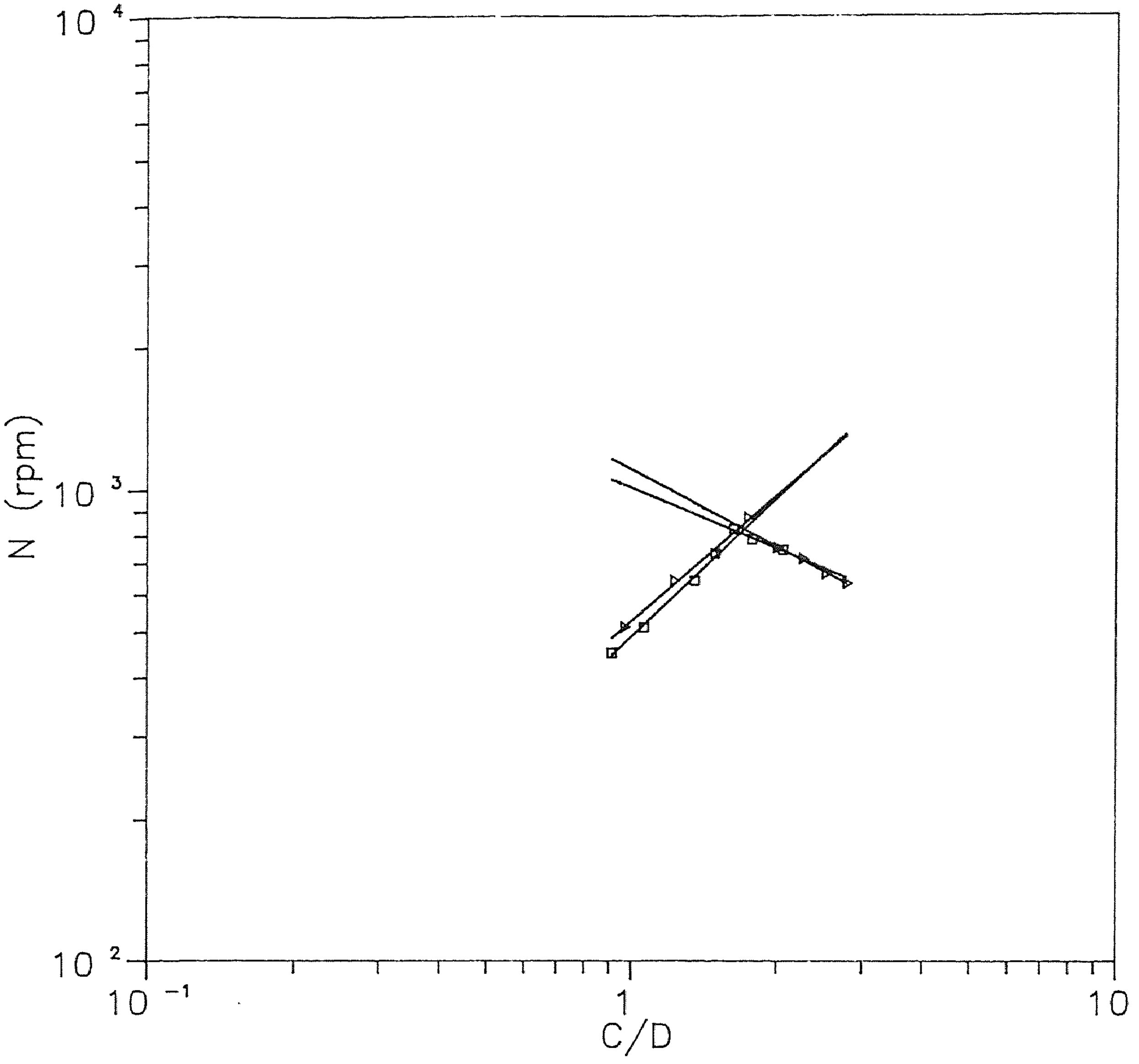


Fig13 Effect of C/D on N (Pitched turbine);
downward; dispersed phase on top;
□ Heptane–Water pc=998;
▷ Methylisobutyl Ketone–Water pc=998;

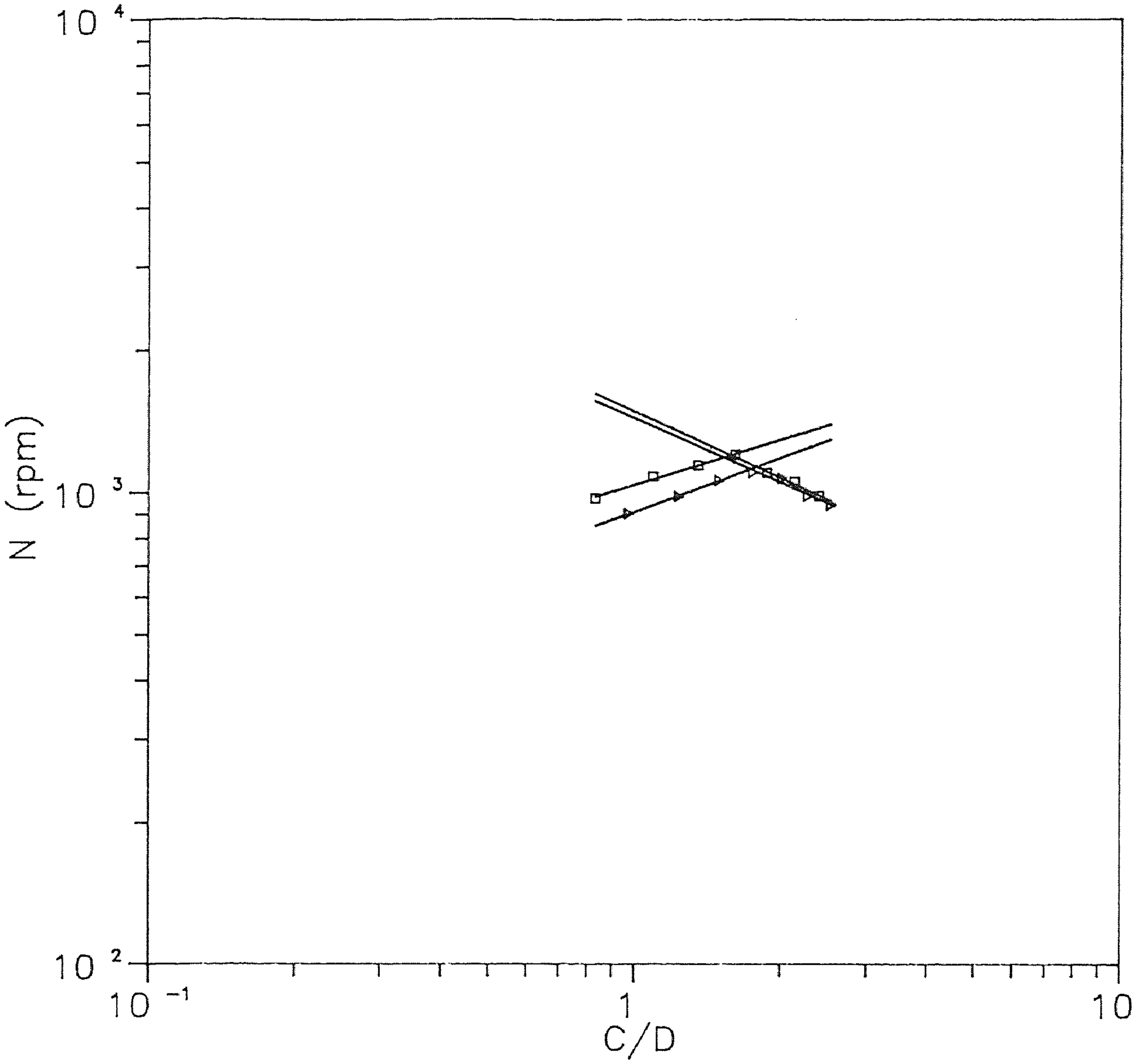


Fig14 Effect of C/D on N (Propeller)
downward; dispersion phase on top;
□ Heptane—Water pc=998;
▷ Methylisobutyl Ketone—Water pc=998;

Analysis of our data for five types of impeller is shown in Fig. 8-Fig. 14 and in Table 8-Table 14. The relationship between N and C/D is expressed as :

$$N \propto (C/D)^{B5}$$

Table 8 Comparsion of B5 with N vs. C/D for DT;(Fig.8)

Liquid	B5 experiment
Methylisobutyl ketone p_C=815	0.58
Dibromomethane p_C=998	0.57
Methylisobutyl ketone p_C=998	0.65

Table 9 Comparsion of B5 with N vs. C/D for FT;(Fig.9)

Liquid	B5 experiment
Methylisobutyl ketone p_C=815	0.61
Dibromomethane p_C=998	0.69
Methylisobutyl ketone p_C=998	0.66

Table 10 Comparsion of B5 with N vs. C/D for CT;(Fig.10)

Liquid	B5 experiment
Methylisobutyl ketone p_c=815	0.67
Dibromomethane p_c=998	0.64
Methylisobutyl ketone p_c=998	0.65

Table 11 Comparison of B5 with N vs. C/D for PT;
(downward; dispersed phase on bottom)(Fig 11)

Liquid	B5 experiment
Dibromomethane p_c=998	0.53
Methylisobutyl ketone p_c=815	0.53

Table 12 Comparison of B5 with N vs. C/D for Propeller;
(downward; dispersed phase on bottom)(Fig.12)

Liquid	B5 experiment
Dibromomethane p_c=998	0.21
Methylisobutyl ketone p_c=815	0.16

Table 13 Comparison of B5 with N vs. C/D for PT;
(downward; dispersed phase on top)(Fig.13)

Liquid	B5(C/D <1.7) experiment	B5(C/D >1.7) experiment
Heptane p_C=998	0.96	-0.43
Methylisobutyl ketone p_C=998	0.88	-0.54

Table 14 Comparison of B5 with N vs. C/D for Propeller;
(downward; dispersed phase on top)(Fig.14)

Liquid	B5(C/D <1.7) experiment	B5(C/D >1.7) experiment
Heptane p_C=998	0.37	-0.46
Methylisobutyl ketone p_C=998	0.38	-0.45

The data presented in Fig. 13 & 14 for pitched-blade turbines and propellers differ from the corresponding figures for radial-flow impellers. Referring to Fig. 13 & 14, the line for the Pitched and Propeller show a break which corresponds with a change in the flow pattern. The similar effect was reported by Zwietering (13) for solid suspension.

In order to get a better expression for the effect of clearance, we use all data to get a correlation for each type of impeller.

$$\frac{N \ \rho_c^{1/2} \ Np^{1/3} \ D^{2/3}}{(\Delta \rho g)^{5/12} \ \sigma^{1/12} \ f(Xv)} (T/D)^{2/3} (H/D)^{1/3} \propto (C/D)^{B6}$$

The exponent, B6, for different types of impeller is shown in Table 15.

Table 15 Correlation of B6 for the effect of clearance

Impeller	B6	B6 (C/D <1.7)	B6 (C/D >1.7)
Disc	0.67		
Flat	0.72		
Curved	0.76		
Pitched(downward) (dispersed phase on bottom)	0.57		
Propeller(downward) (dispersed phase on bottom)	0.16		
Pitched(downward) (dispersed phase on top)		0.96	-0.48
Propeller(downward) (dispersed phase on top)		0.38	-0.45

Effect of Scale-Up

In this section, the effects of other geometric variables, which are important for scale-up purposes, are considered.

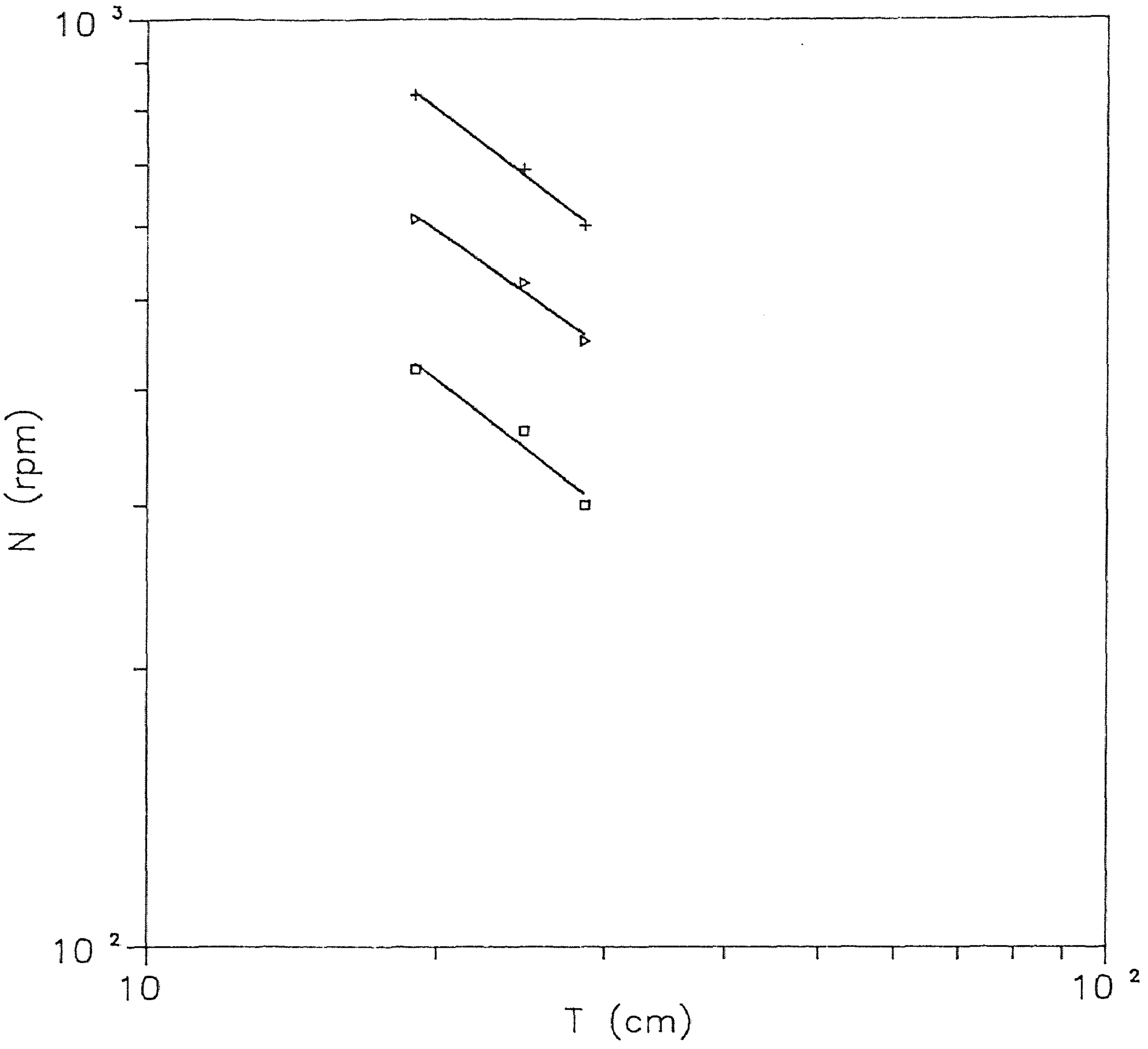


Fig15 Effect of tank size on N ;
C/D=2; H/D=T/D=3; Heptane–Water Xv=0.1;
□ DT; ▷ FT; + PT.

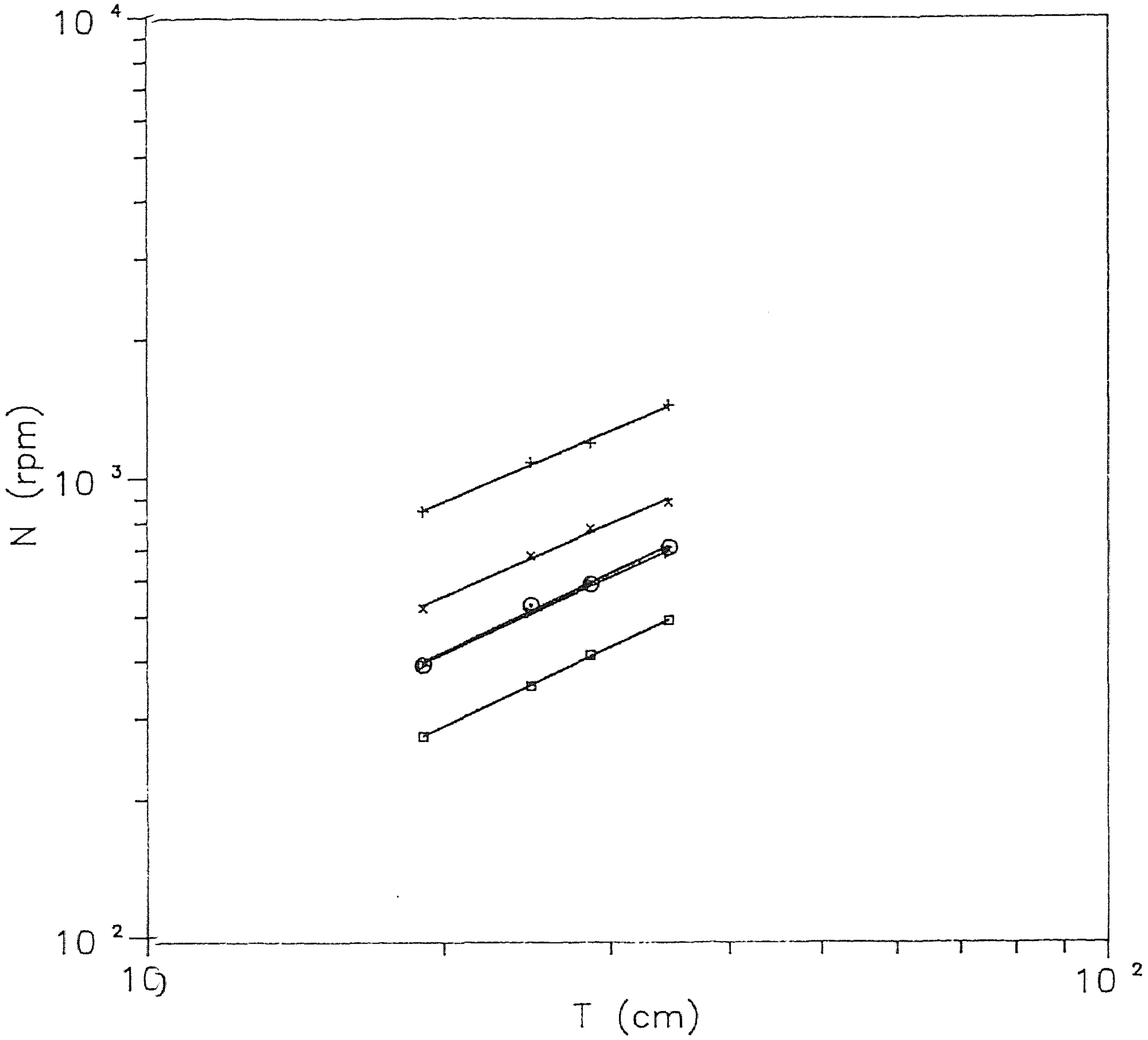


Fig16 Effect of tank size on N ;
C=14.4; H=T; D=7.7; Heptane–Water Xv=0.1;
□ DT; ▷ FT; ○ CT;
× PT; + Propeller;

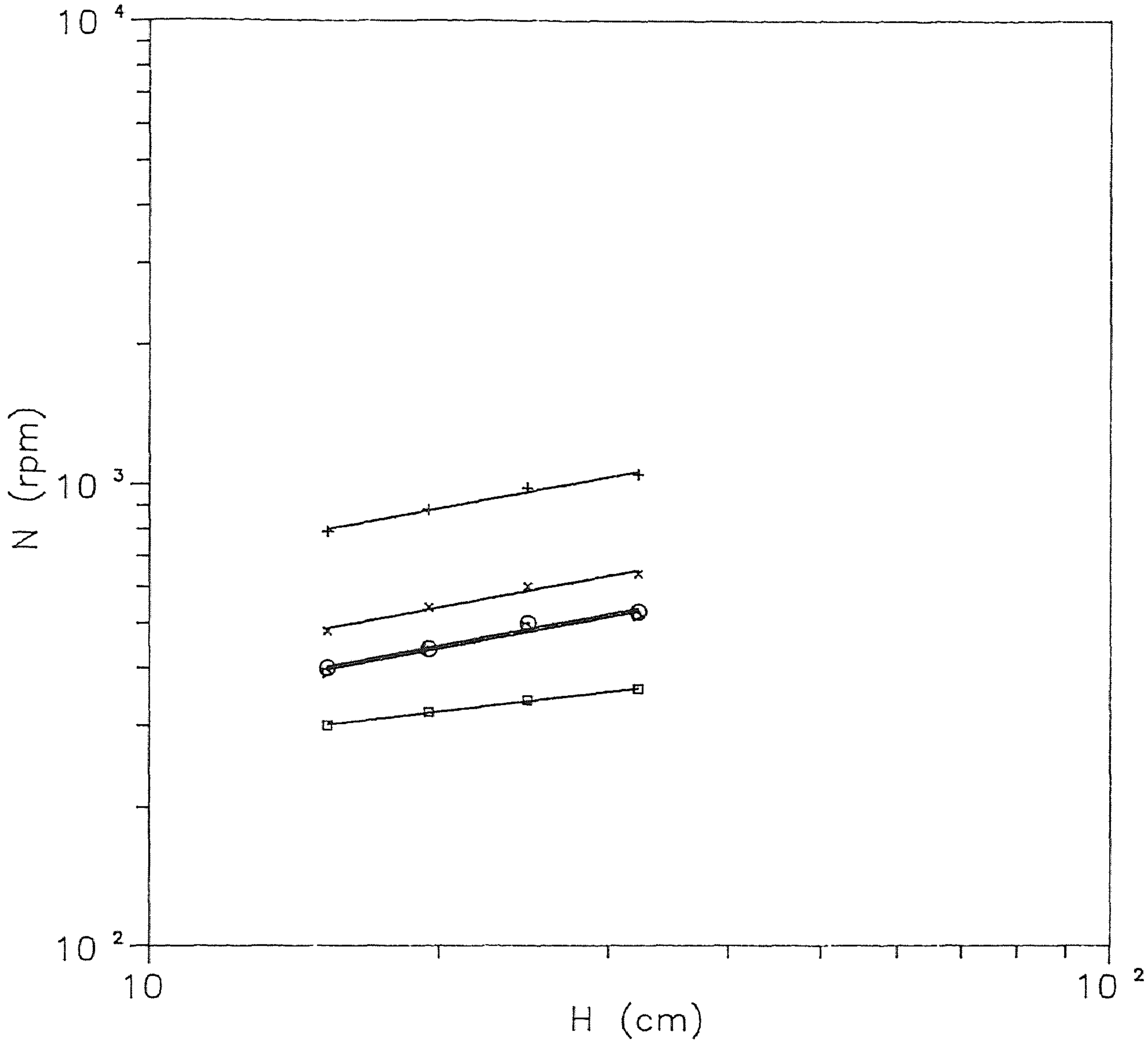


Fig17 Effect of liquid heigh on N;
C=12; T=24.7; D=7.7; Heptane–Water Xv=0.1;
□ DT; ▷ FT; ○ CT;
X PT; + Propeller;

Three cases are considered here : (1) C/D=constant, T/D=H/D=constant, N $\propto$ $D^{-0.67}$ $\propto$ $H^{-0.67}$ reported in Fig. 15 & table 16; (2) C=constant, D=constant, H=T, N $\propto$ T shown in Fig.16 & Table 17; (3) C=constant, D=constant, T/D=constant, N $\propto$ $H^{0.33}$ presented in Fig.17 & Table 18. The relationships for scale-up are obtained in Fig.15- 17 & Table 16-18, and expressed as:

(1) N $\propto$ T^{B7} for case 1

(2) N $\propto$ T^{B8} for case 2

(3) N $\propto$ H^{B9} for case 3

Table 16 Comparison of B7 for scale-up effect(Case 1 ; Fig.15)

Impeller	B7 experiment	B7 theory
Disc	-0.79	-0.67
Flat	-0.72	-0.67
Pitched	-0.78	-0.67

Table 17 Comparison of B8 for sacle-up effect (Case 2; Fig.16)

Impeller	B8 experiment	B8 theory
Disc	0.97	1
Flat	0.94	1
Curved	0.97	1
Pitched	0.89	1
Propeller	0.87	1

Table 18 Comparison of B9 for scale-up effect (Case 3; Fig.17)

Impeller	B9 experiment	B9 theory
Disc	0.26	0.33
Flat	0.39	0.33
Curved	0.39	0.33
Pitched	0.39	0.33
Propeller	0.38	0.33

Correlation of the Data of This and Previous Work

From the previous paper of liquid dispersion, they got several equations to describe the complete dispersion and used several different constant and exponential coefficient to explain different conditions of liquid dispersion, such as type of impeller and impeller location. But for this work, we try to correlate all data to a general equation to describe liquid dispersion.

We Develop Eqn 28 to express the general equation.

$$Re \propto g(C/D)\,f(Xv)\,(Su^{1/12})\,(Ar^{5/12})\,(Np^{-1/3})\,(T/D)^{2/3}\,(H/D)^{1/3} \quad (29)$$

where

$$Re = \frac{p_c\ N\ D^2}{n_c}$$

$$Su = \frac{p_c\ \sigma\ D}{n_c^2}$$

$$Ar = \frac{g\ p_c \Delta p\ D^3}{n_c^2}$$

$$f(Xv) = ((-1/4.5)\ \ln(0.011+0.68\ Xv))^{-1/2}$$

$$g(C/D) = (C/D)^B$$ (B:from Table 15 of different impeller)

Because Godfrey used square tank, we time 0.75 for Power Number. so that Np for each source are expressed

Godfrey,	Propeller	; Np=0.26
GOdfrey,	Disc turbine;	Np=3.8
Esch,	Disc turbine;	Np=5
Van Heuvan,	Disc turbine;	Np=5

and also we make some file to store data from different sources

G1 : Godfrey data for Disc, D=5.1cm; Fig.18
G2 : Godfrey data for Disc, D=10cm; FIg.18
G5 : GOdfrey data for Propeller, D=5.1cm; Fig.19
G6 : Godfrey data for Propeller, D=10cm; Fig.19
G7 : G1 + G2 for all Disc of Godfrey; Fig.20
G8 : G5 + G6 for all Propeller of Godfrey; Fig.21
G9 : G7 + G8 for all data of Godfrey; Fig.22 & 23
Es : Esch data; Fig.24
Van : Van Heuvan data; Fig25
GEV : G9 + Es + Van; Fig. 26 & 27
D2 : Data for Disc turbine of this work
F2 : Data for Flat turbine of this work
C2 : Data for Curved turbine of this work
Pi2 : Data for Pitched(dispersed on bottom) of this work
Pr2 : Data for Propeller(dispersed on bottom) of this work
DFC : D2 + F2 + C2 ; Fig. 28 & 29
IR : Pi2 + Pr2 ; Fig. 30 & 31
DFCIR: DFC + IR ; Fig. 32
GEVA : GEV + DFCIR ; Fig. 33 & 34

we use least square method to fix Eqn 29, then we obtain the following expression

$$Re=a\{g(C/D)f(Xv)(Su^{1/12})(Ar^{5/12})(Np^{-1/3})(T/D)^{2/3}(H/D)^{1/3}\}^{b} \quad (30)$$

and we can force b to equal 1

$$Re=A\{g(C/D)f(Xv)(Su^{1/12})(Ar^{5/12})(Np^{-1/3})(T/D)^{2/3}(H/D)^{1/3}\} \quad (31)$$

The regression results for each data file are presented in Table 19, and all give virtually the same value of A. Fig.35-44 show plots of N(obs) vs. N(pred) for the data files.

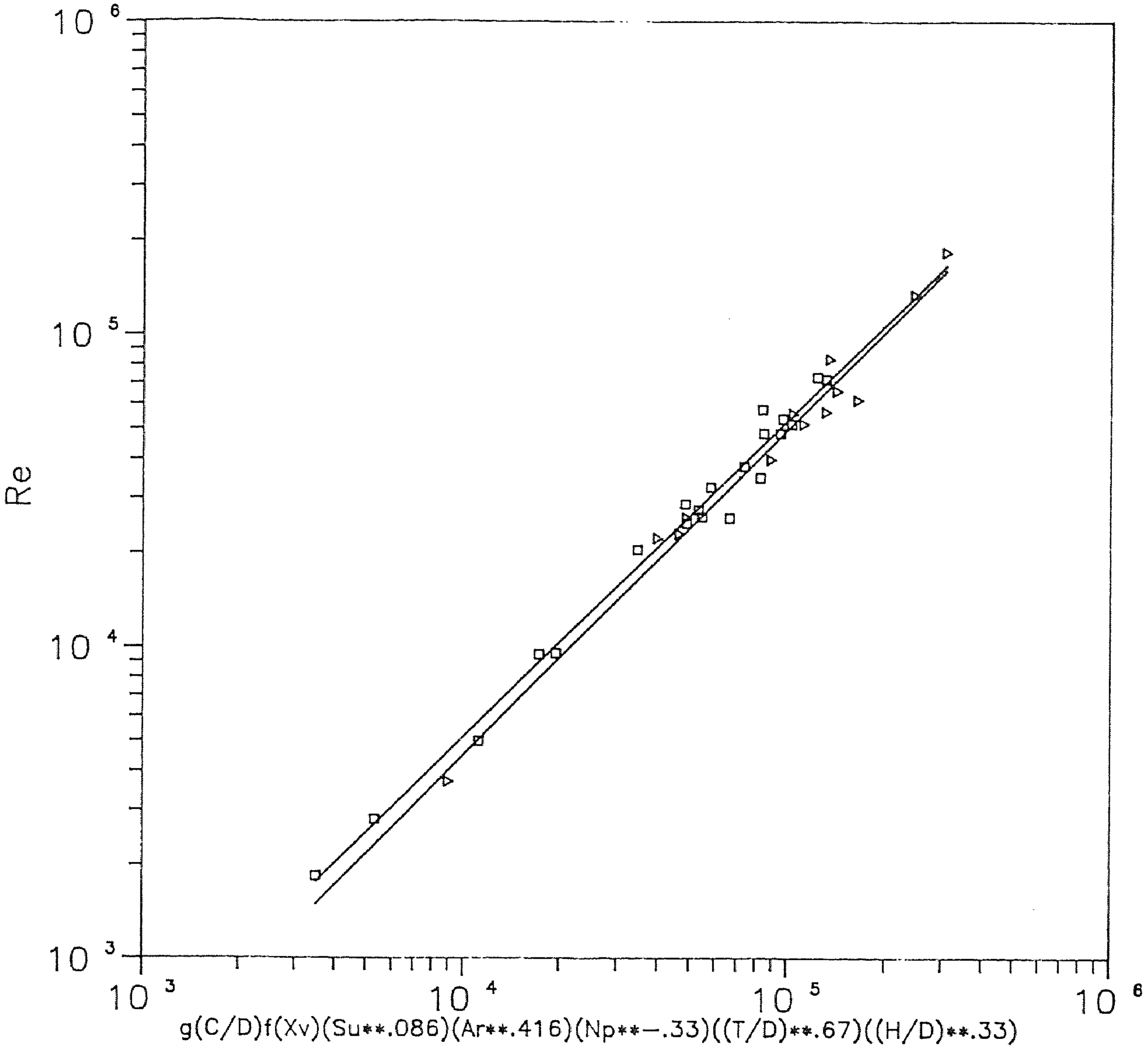


Fig18 Application of eqn 29;the data of Godfrey & Reeve (1984)
seperated turbine data of different impeller diameter
□ DT, D=5.1cm; ▷ DT, D=10cm;

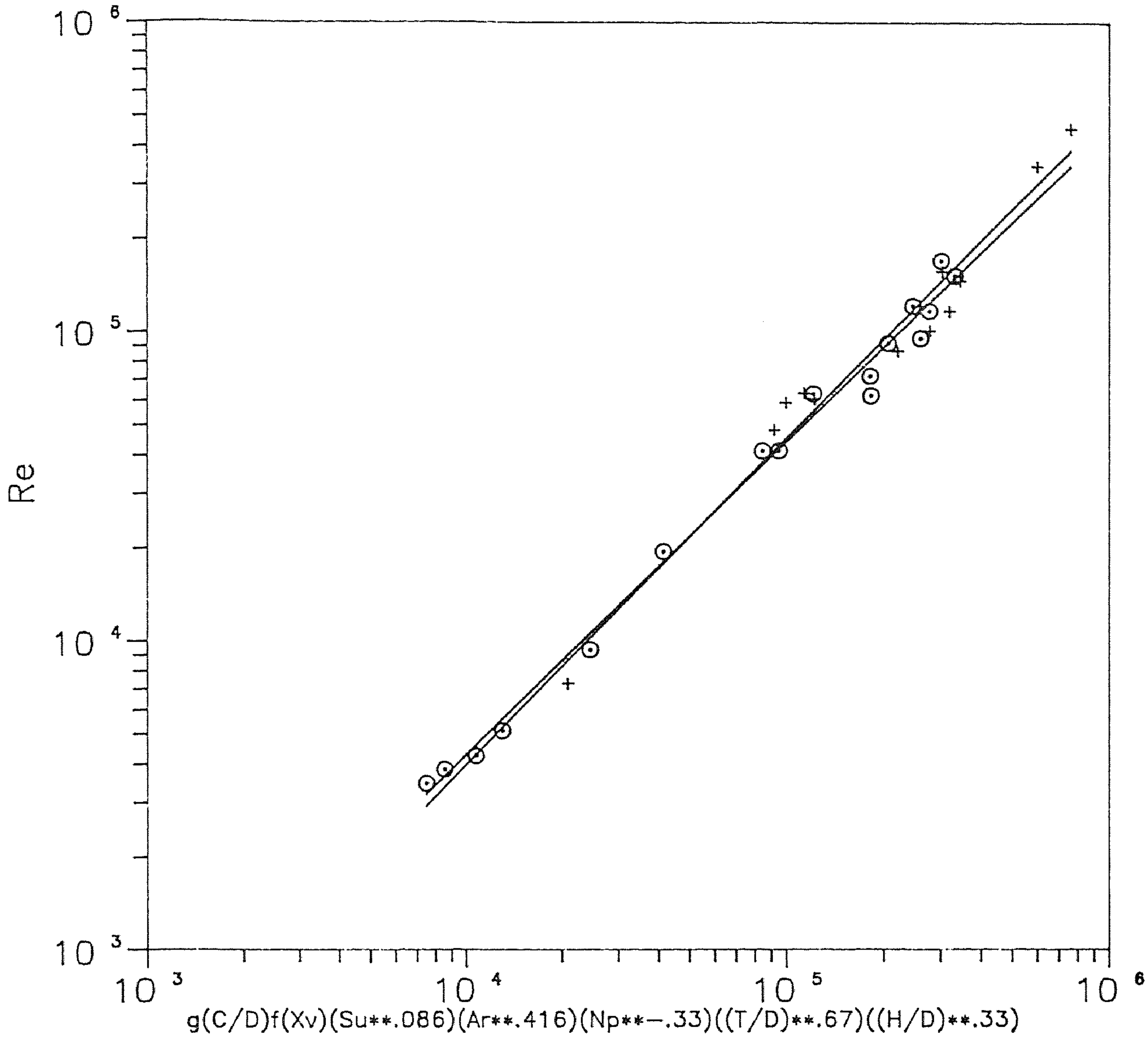


Fig19 Application of eqn 29;the data of Godfrey & Reeve (1984)
seperated propeller data of different impeller diameter
○ Propeller D=5.1cm; + Propeller D=10cm;

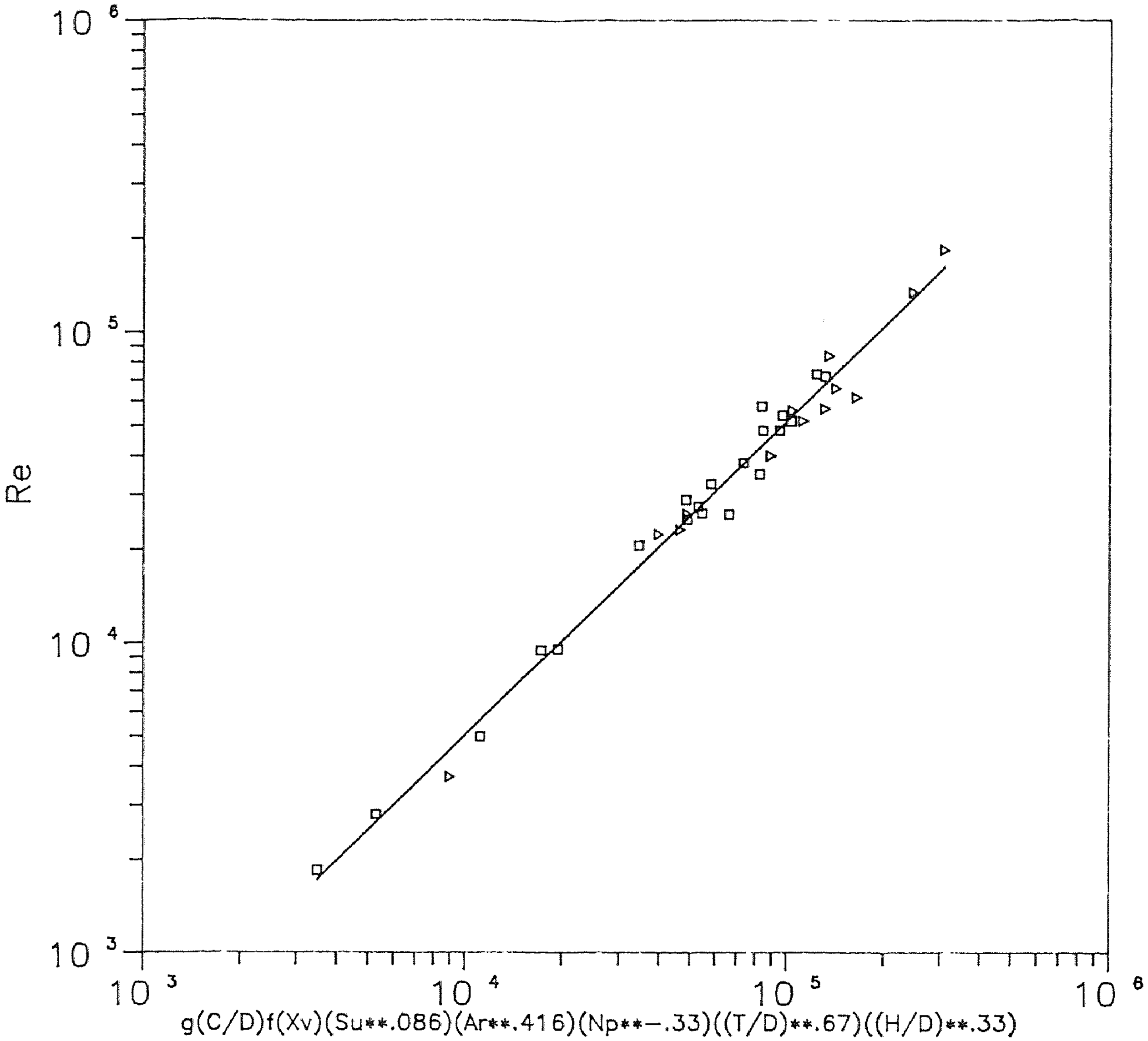


Fig20 Application of eqn 29 ; the data of Godfrey & Reeve (1984)
combined turbine data of different impeller diameter
□ DT D=5.1cm; ▷ DT D=10cm;

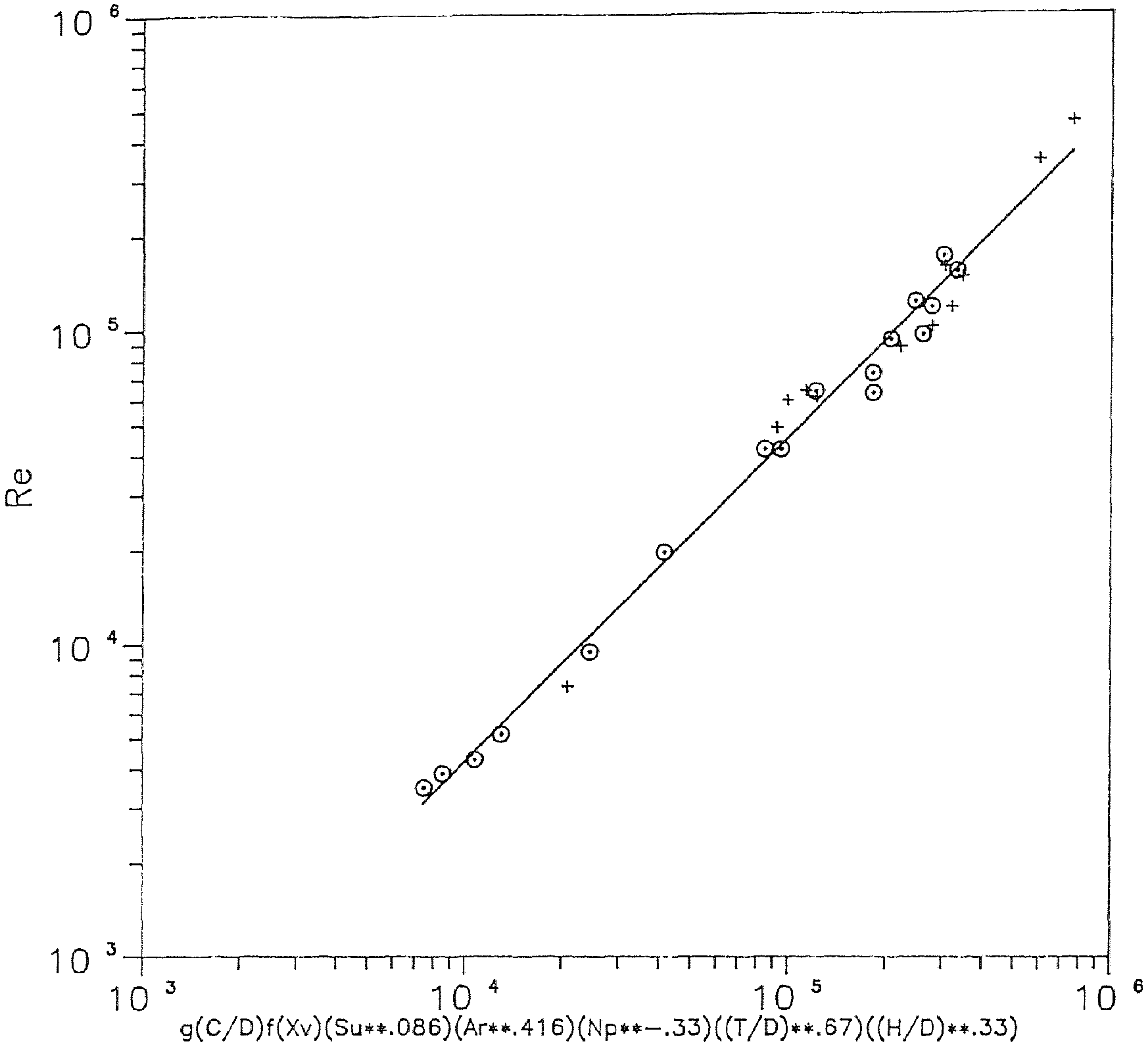


Fig21 Application of eqn 29;the data of Godfrey & Reeve (1984)
combined propeller data of different impeller diameter
○ Propeller D=5.1cm; + Propeller D=10cm;

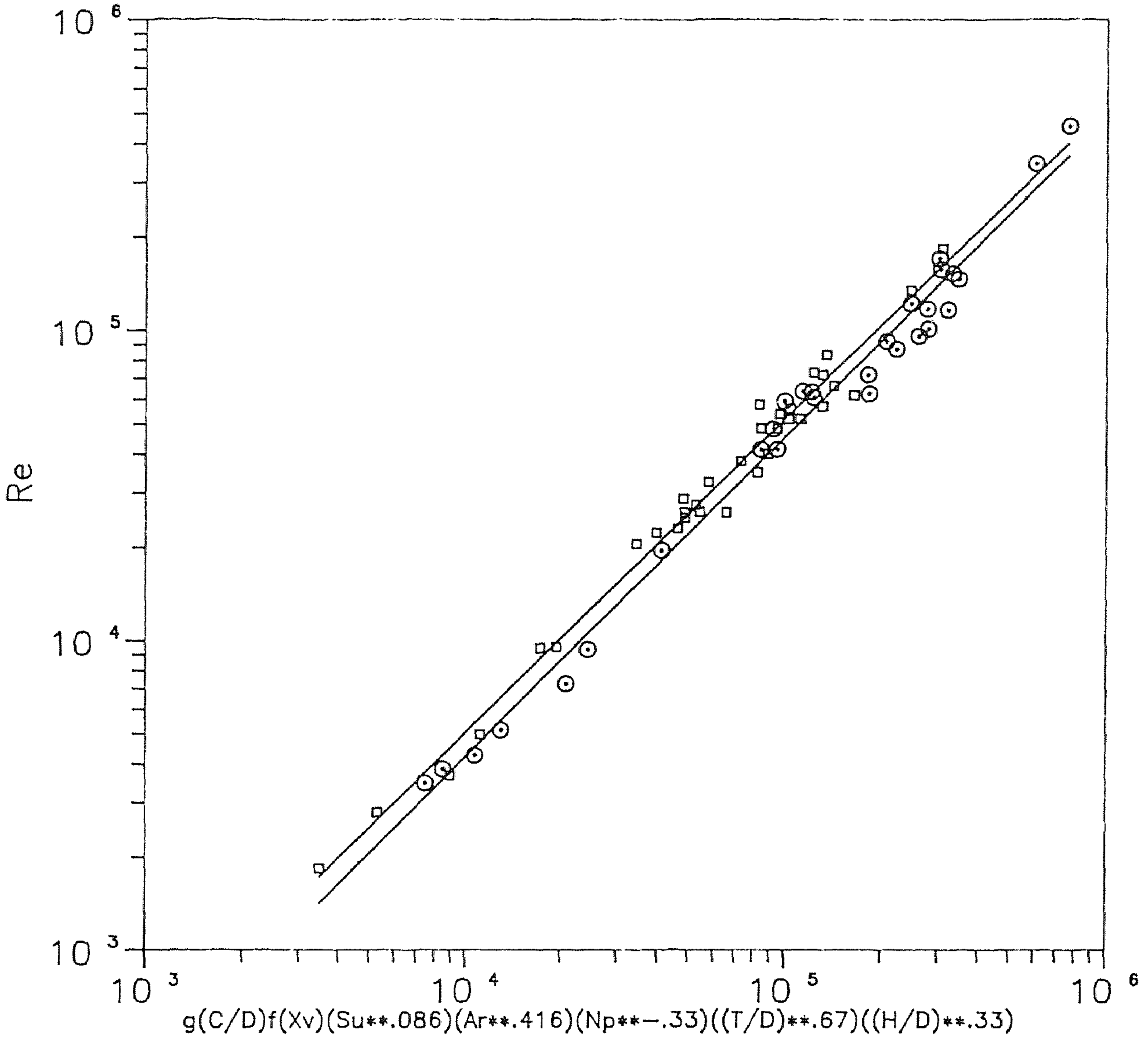


Fig22 Application of eqn 29;the data of Godfrey & Reeve (1984)
seperated the data of different impeller type
□ DT; ○ Propeller;

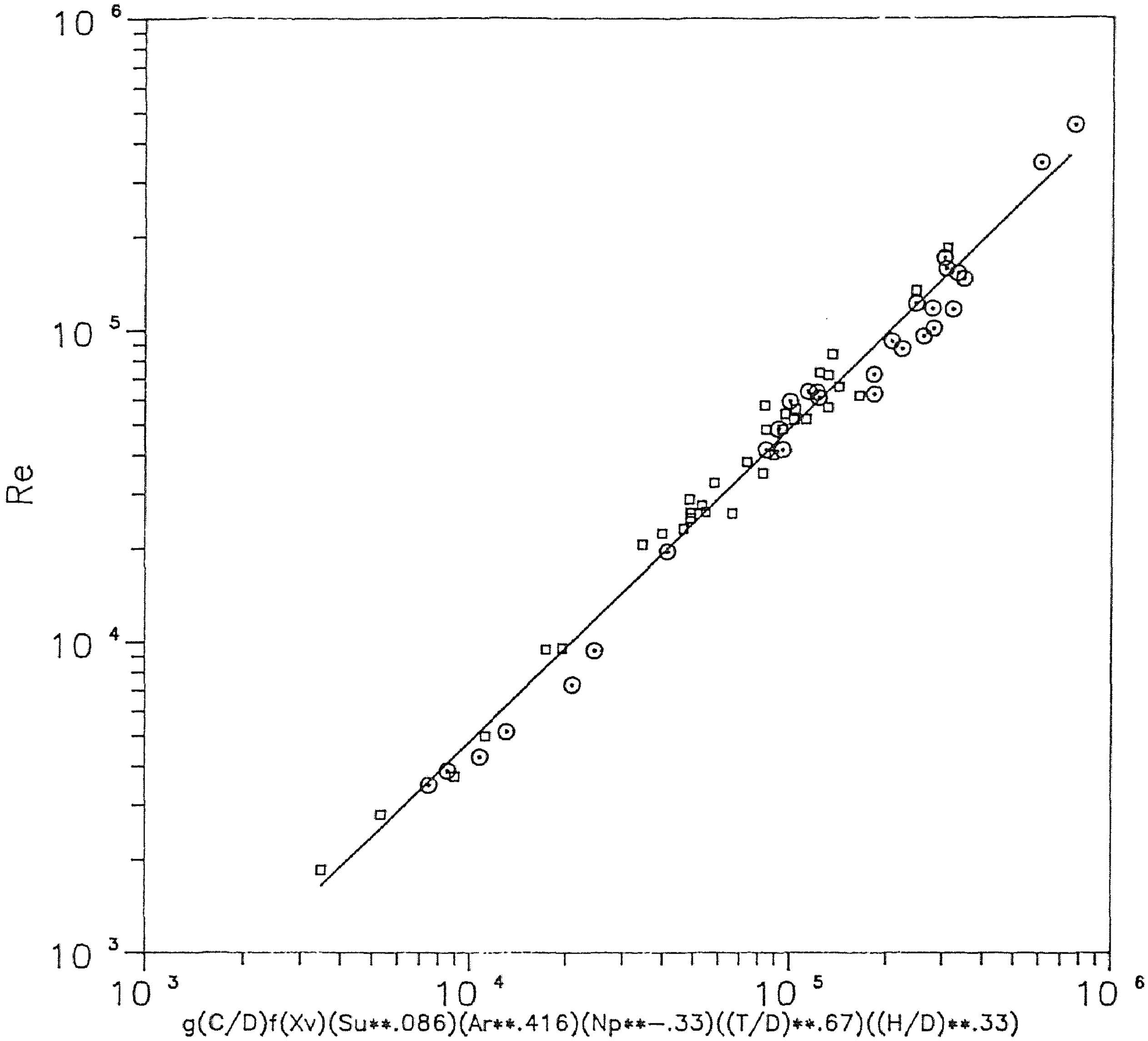


Fig23 Application of eqn 23;the data of Godfrey & Reeve (1984)
combined the data of different impeller type
□ DT; ○ Propeller; .

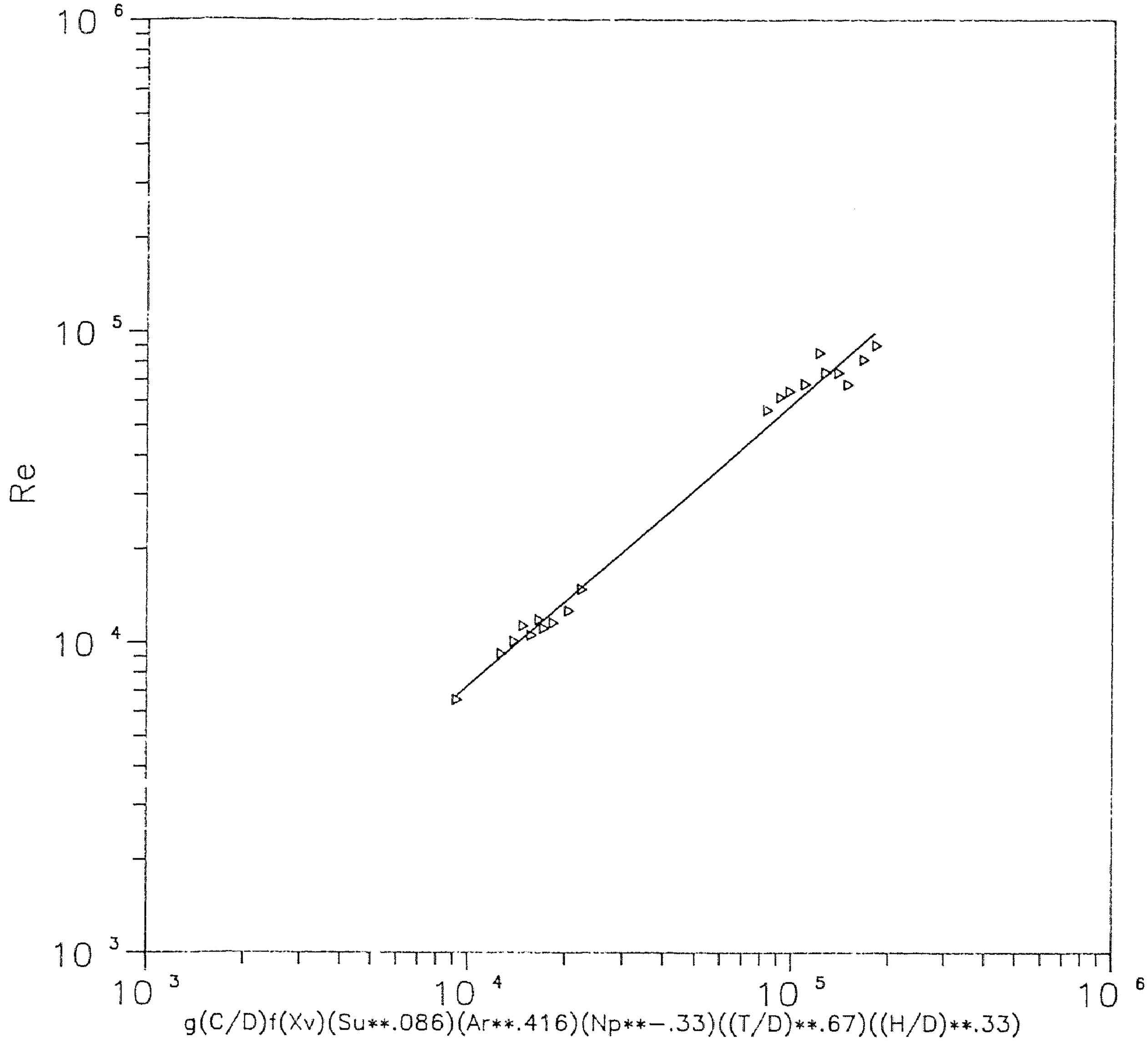


Fig24 Application of eqn 29;the data of Esch et al.(1971)

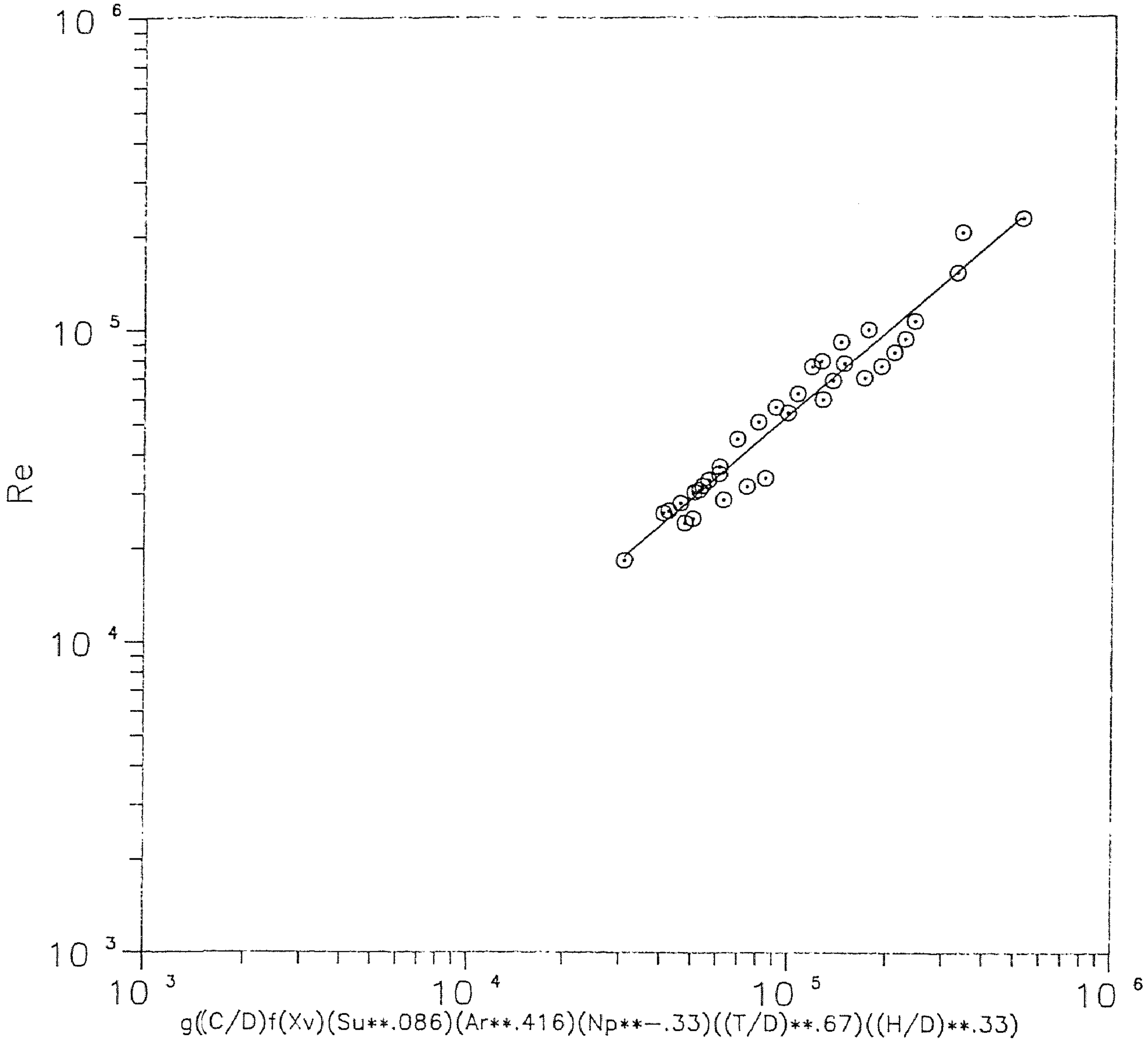


Fig25 Application of eqn 29;the data of Van Heuven & Beek (1971)

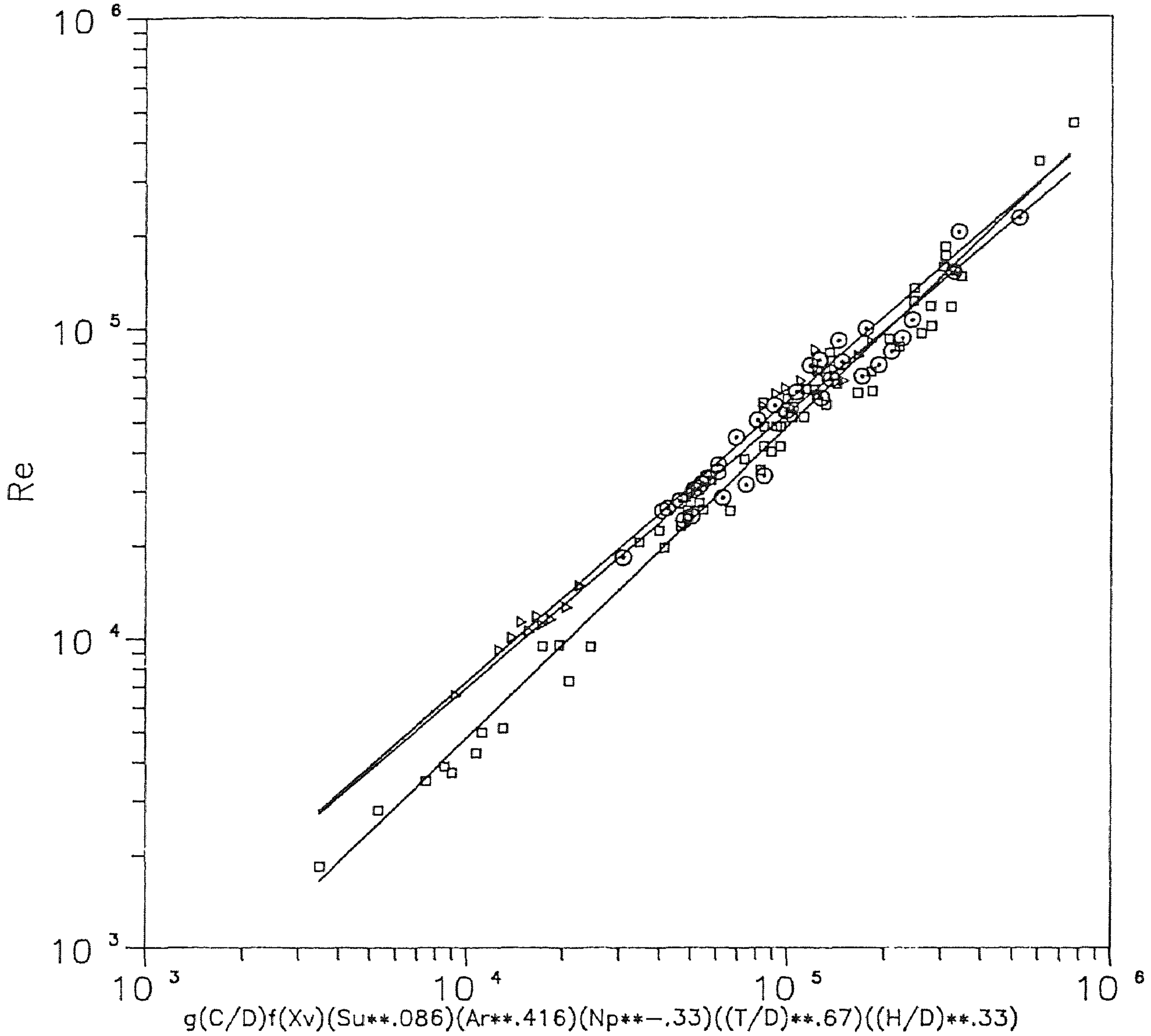


Fig26 Application of eqn 29;the data of Esch et al.(1971) & Van Heuven et al.(1971) & Godfrey et al.(1984)
□ Godfrey; ▷ Esch; ○ Van Heuven;

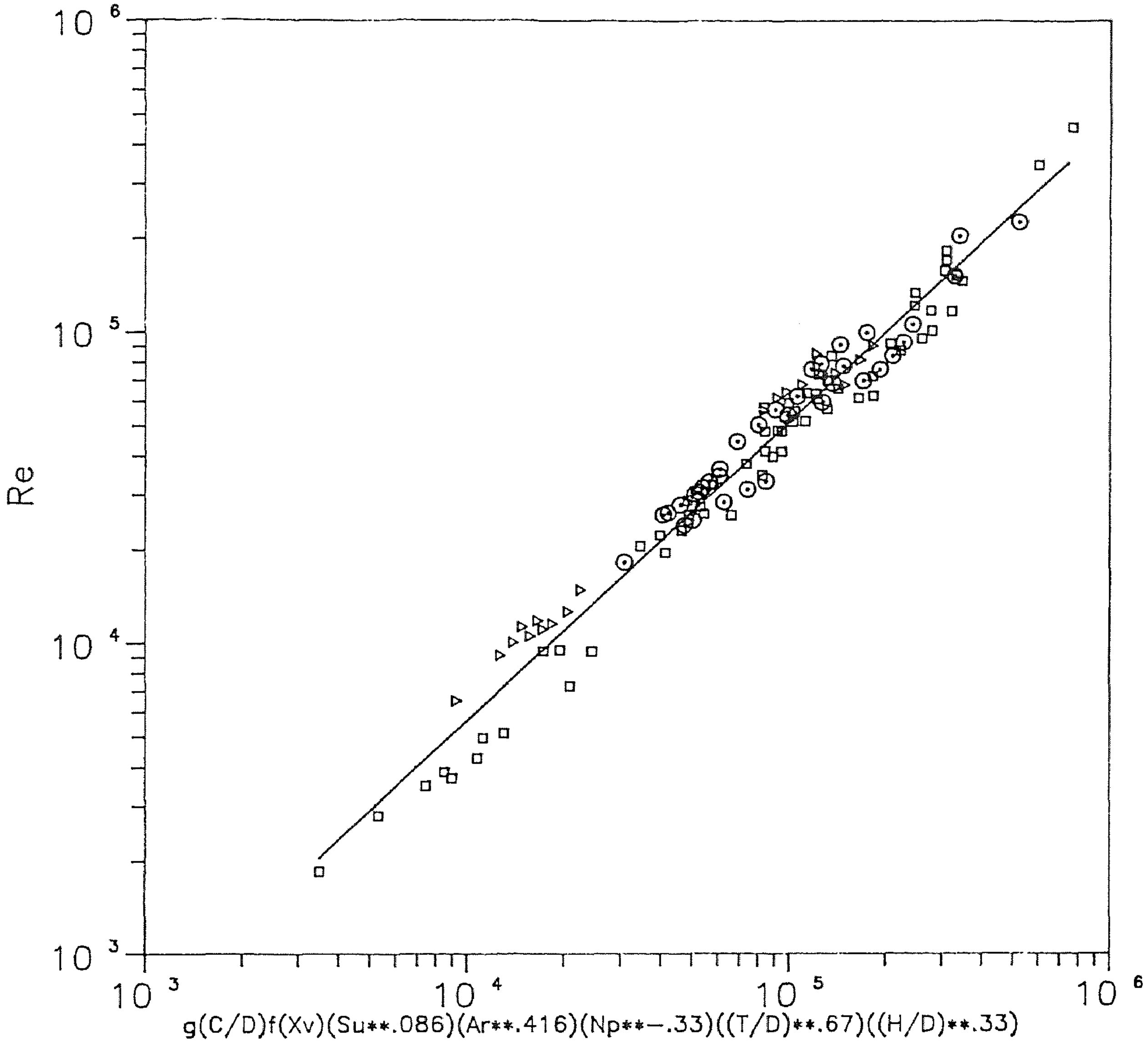


Fig27 Application of eqn 29;the data of Esch et al.(1971) &
Van Heuven et al.(1971) & Godfrey et al.(1984)
□ Godfrey; ▷ Esch; ○ Van Heuven;

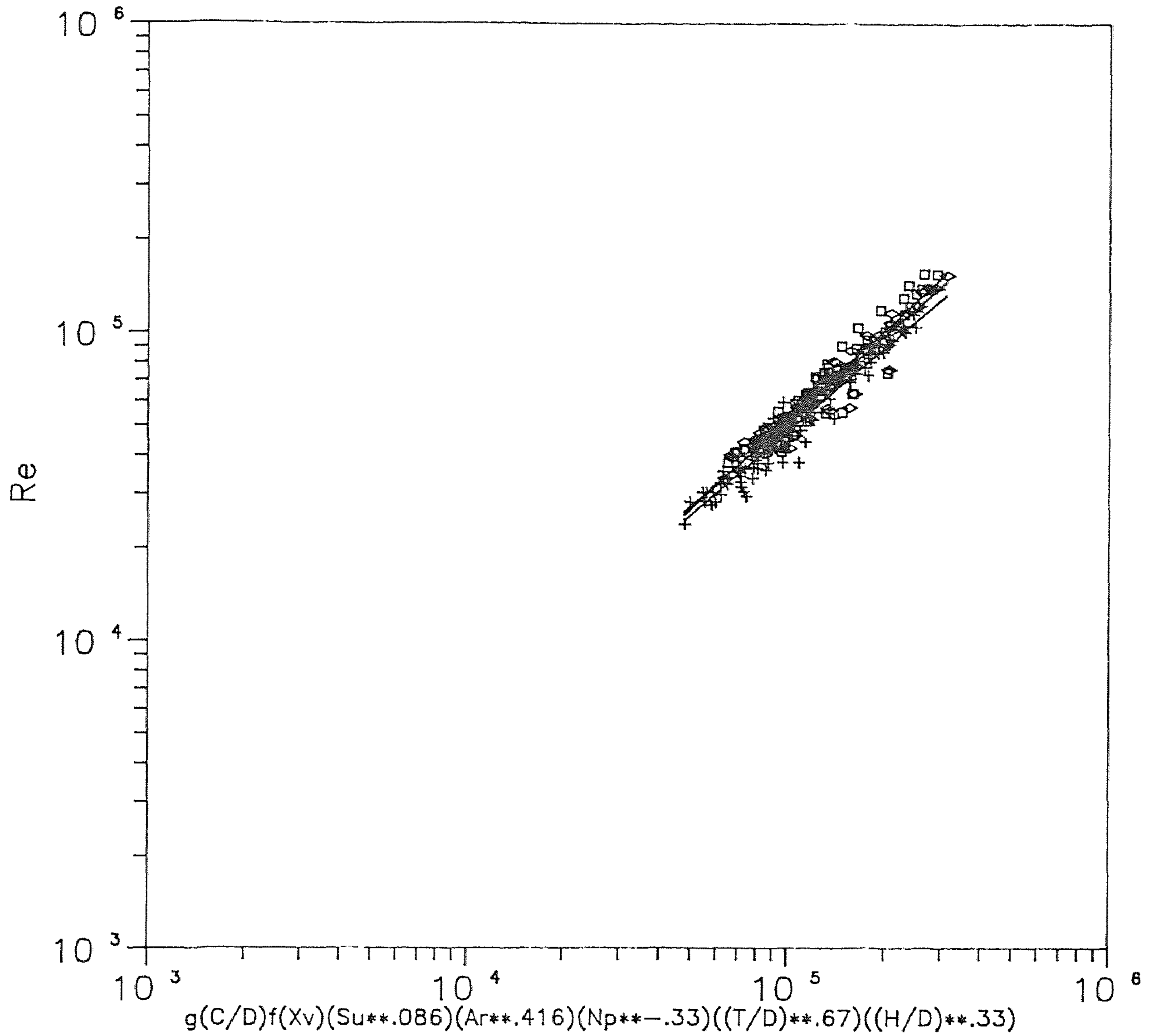


Fig28 Application of eqn 29;the data of this work
+ DT; □ FT; ▷ CT;

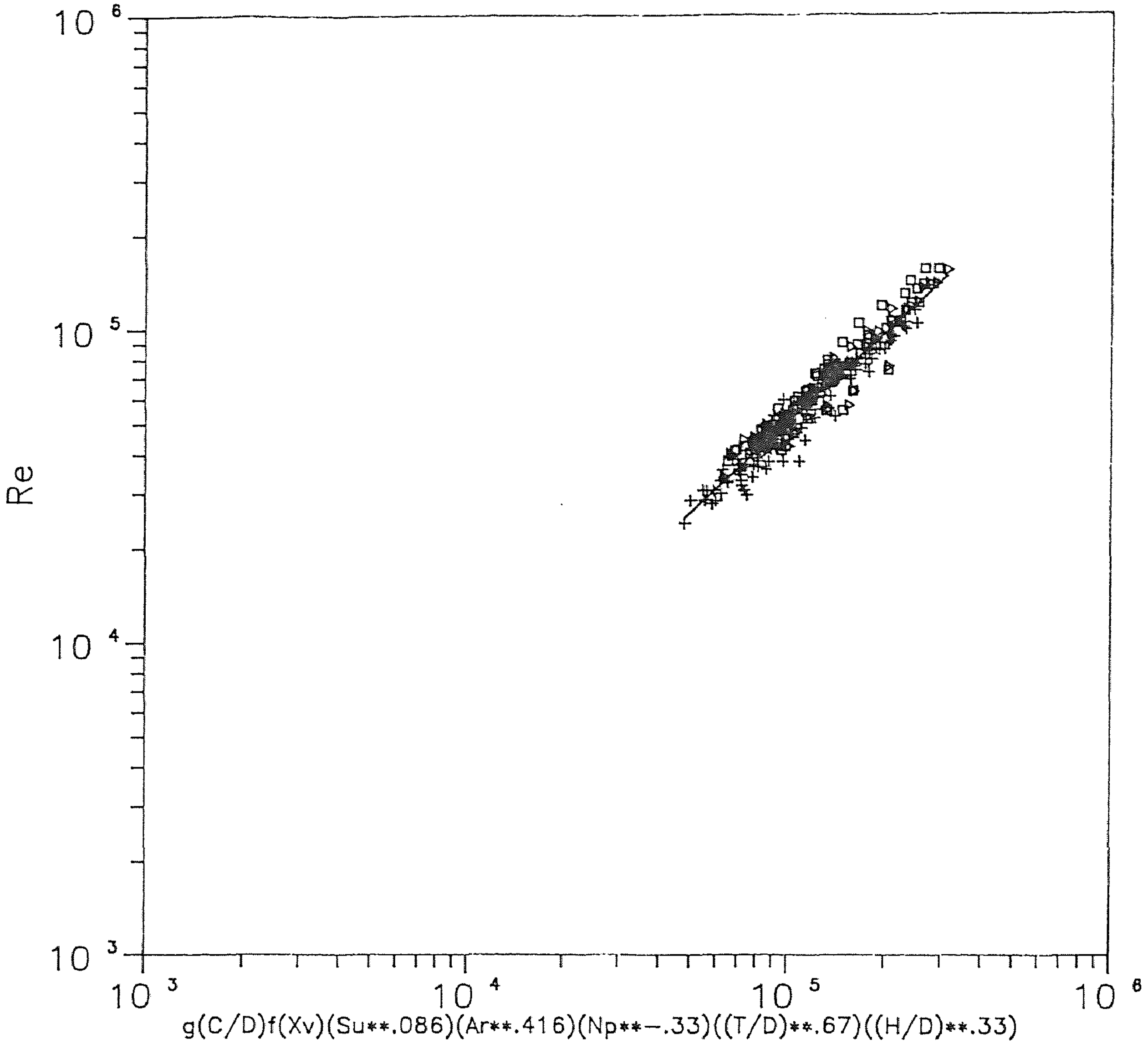


Fig29 Application of eqn 29;the data of this work
+ DT; □ FT; ▷ CT;

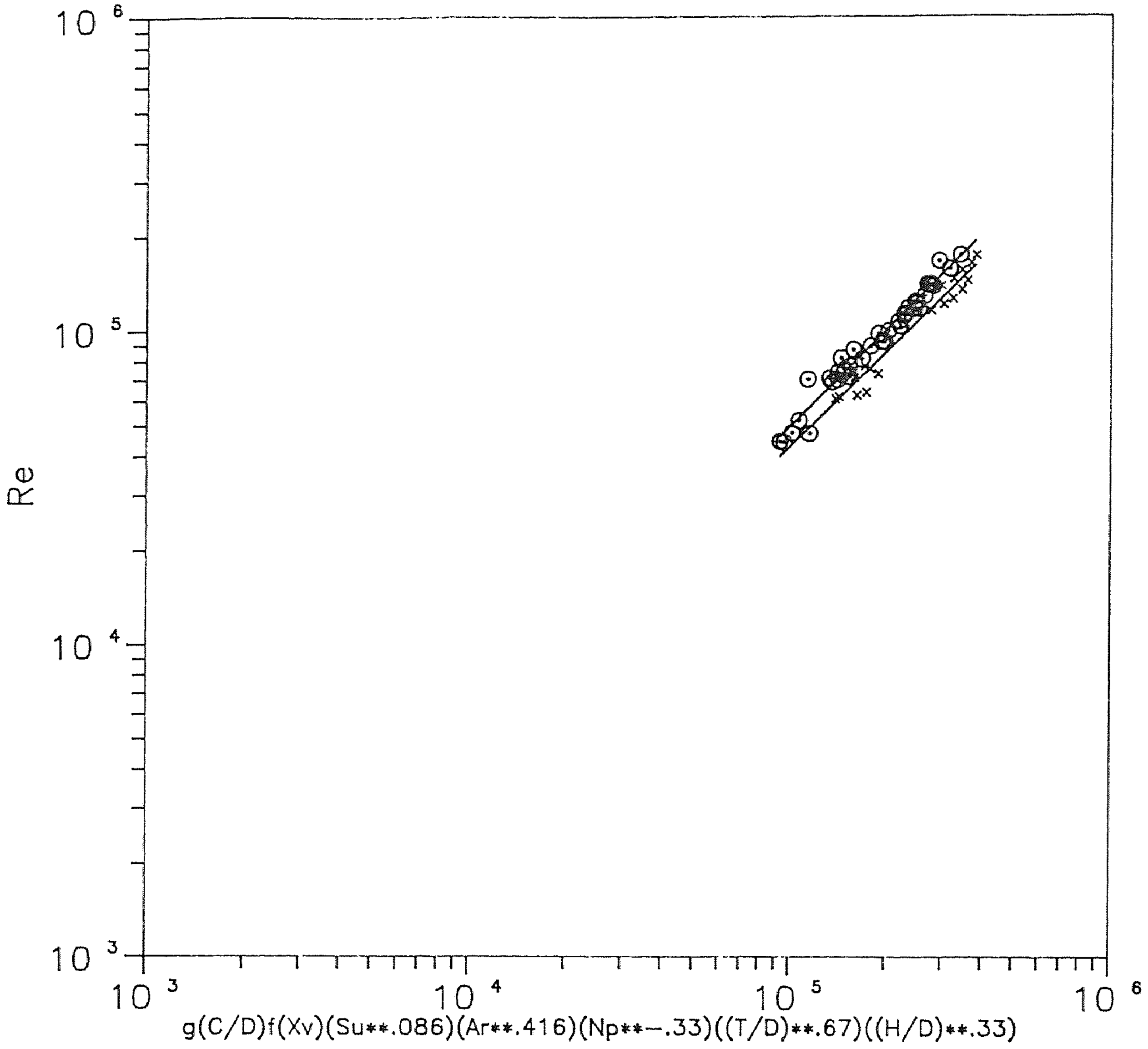


Fig30 Application of eqn 29;the data of this work
○ PT downward & dispersed phase on bottom
X Propeller downward & dispersed phase on bottom

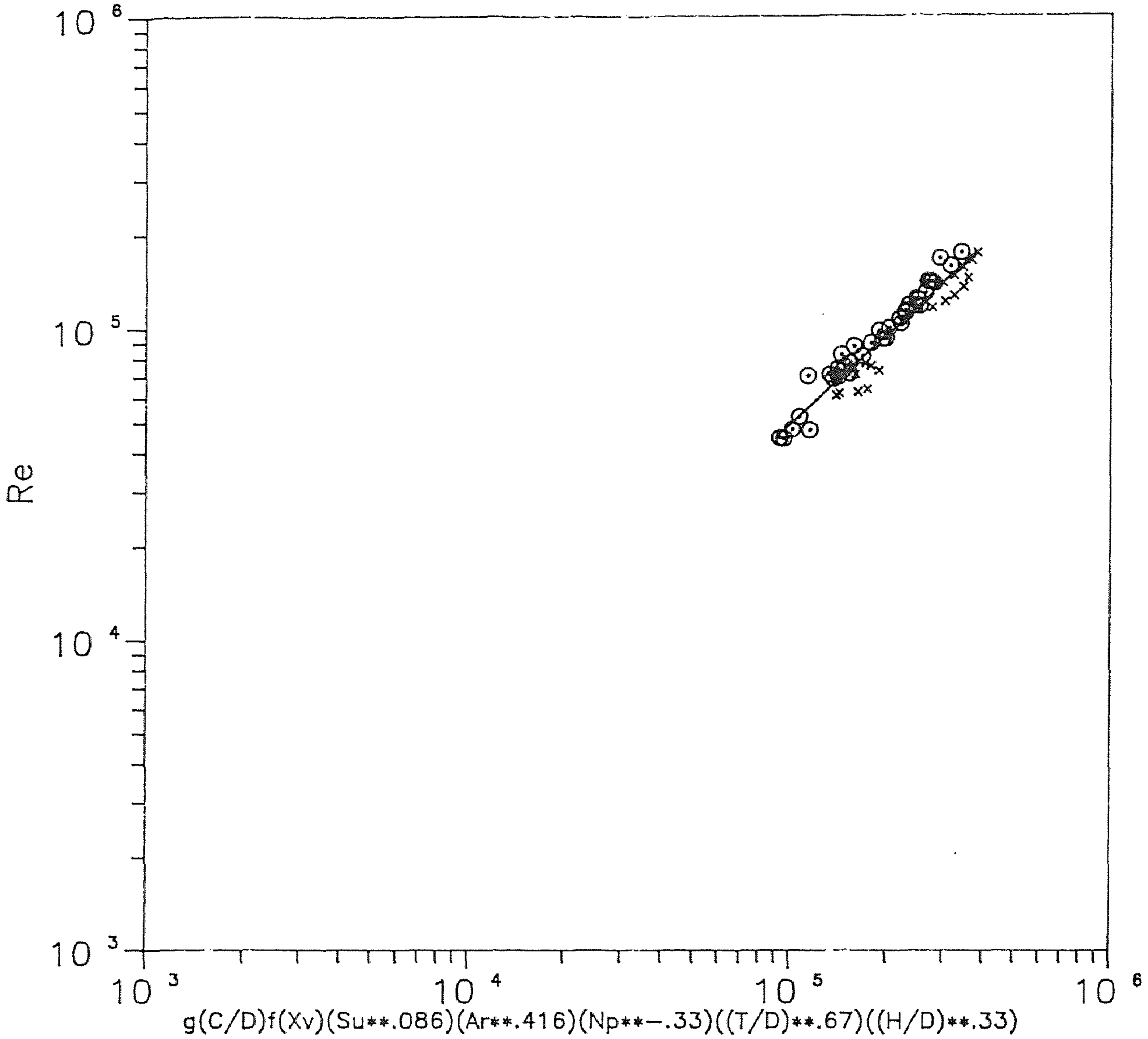


Fig31 Application of eqn 29;the data of this work
○ PT downward & dispersed phase on bottom
× Propeller downward & dispersed phase on bottom

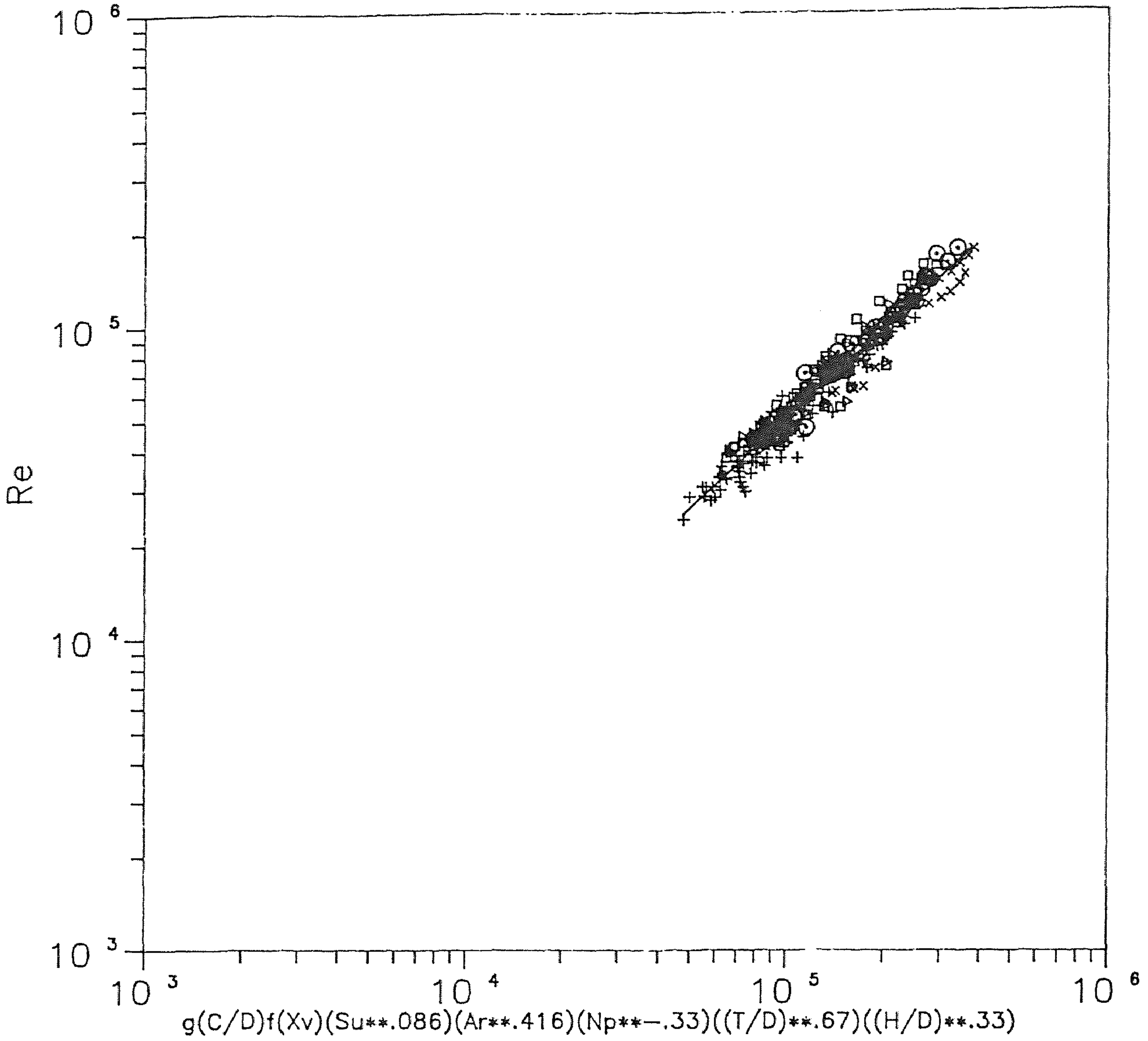


Fig32 Application of eqn 29;the data of this work

○ PT downward & dispersed phase on bottom

× Propeller downward & dispersed phase on bottom

\+ DT; □ FT; ▷ CT;

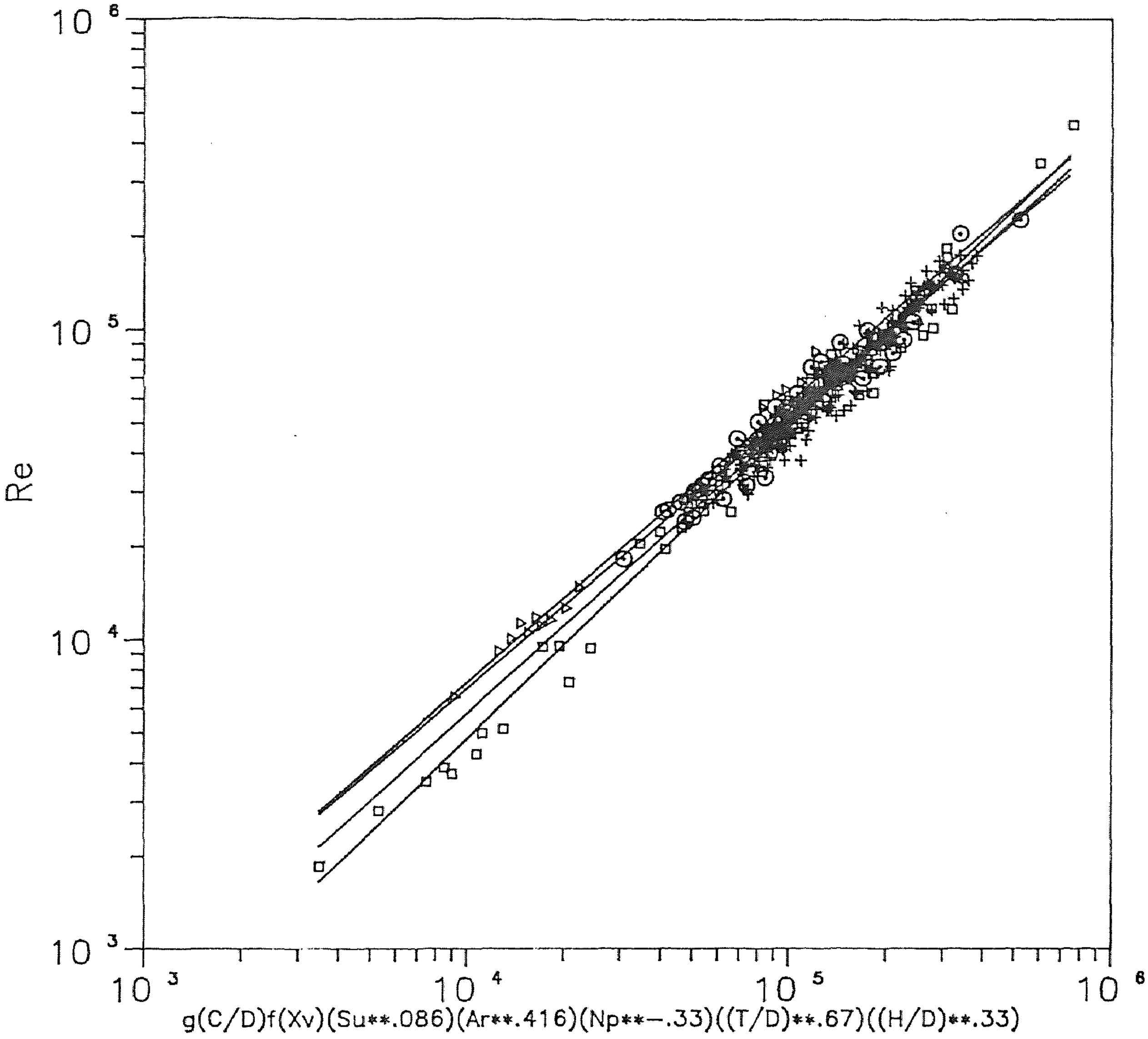


Fig33 Application of eqn 29;the data of + this work &
□ Godfrey & ▷ Esch & ○ Van Heuven

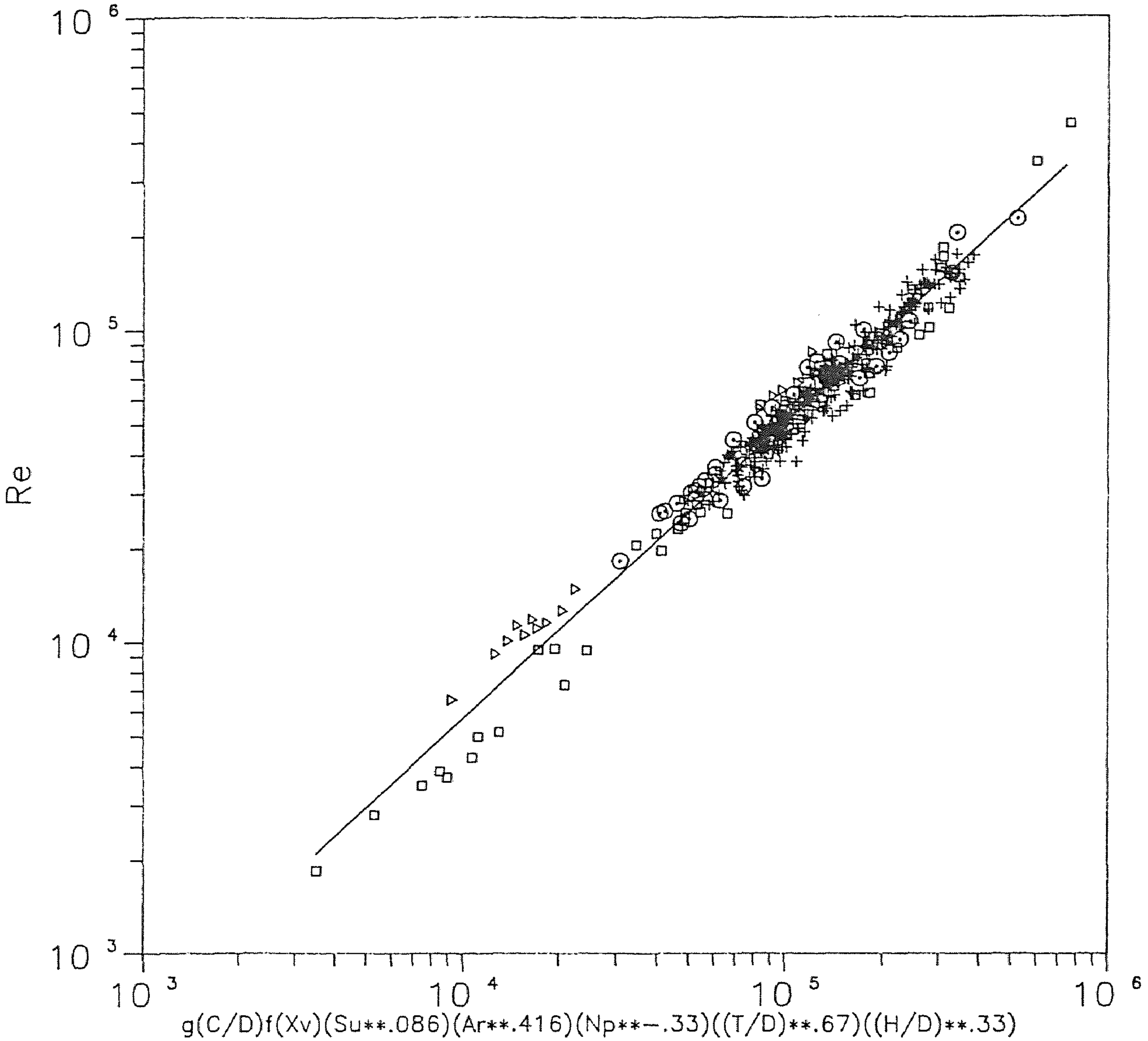


Fig34 Application of eqn 29;the data of + this work &
□ Godfrey & ▷ Esch & ○ Van Heuven

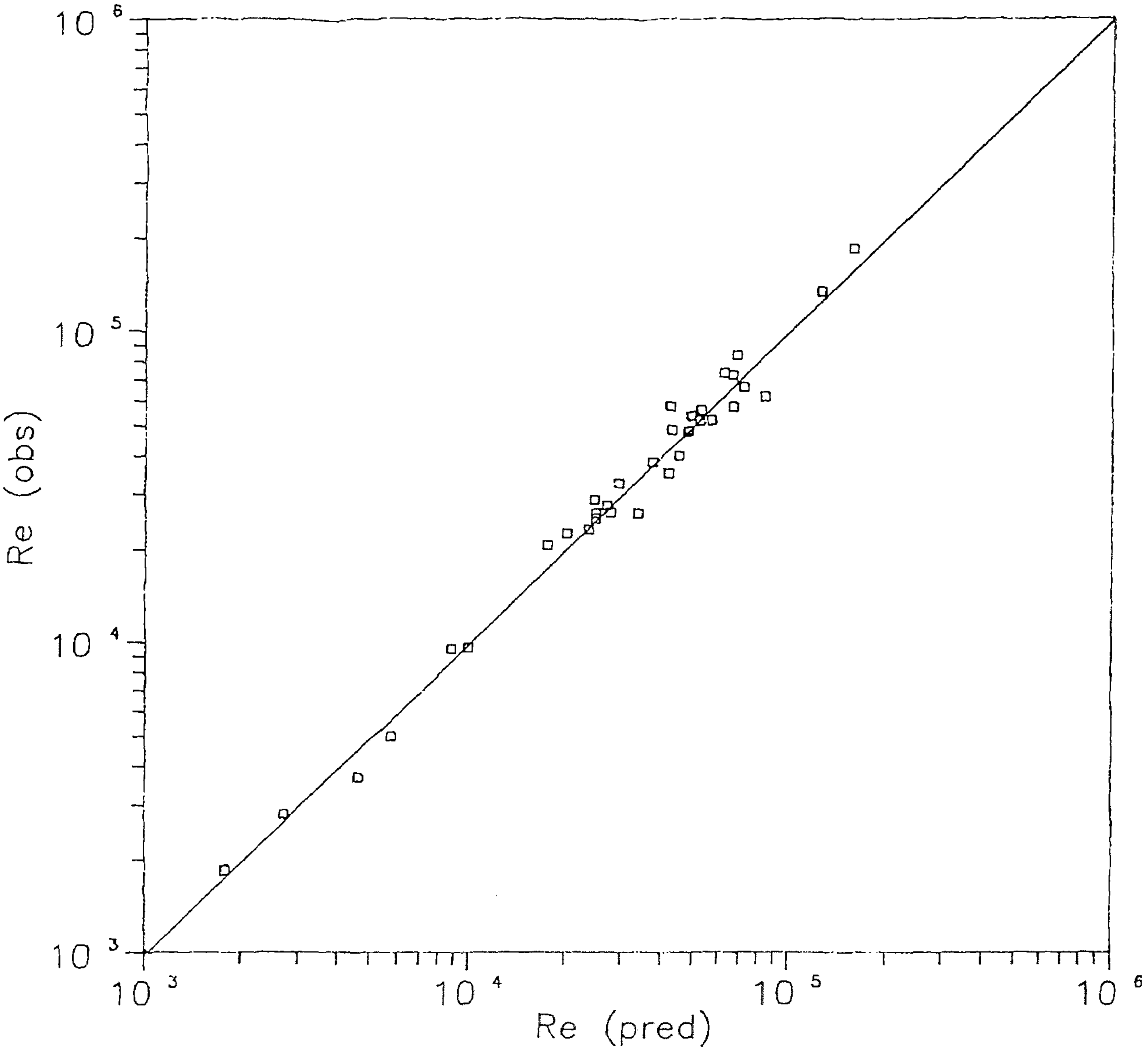


Fig35 Comparison of Predicted vs. Observed value of Re
using turbine data of Godfrey & Reeve (1984)
(Predicted value from Fig 20 & Eqn 31)

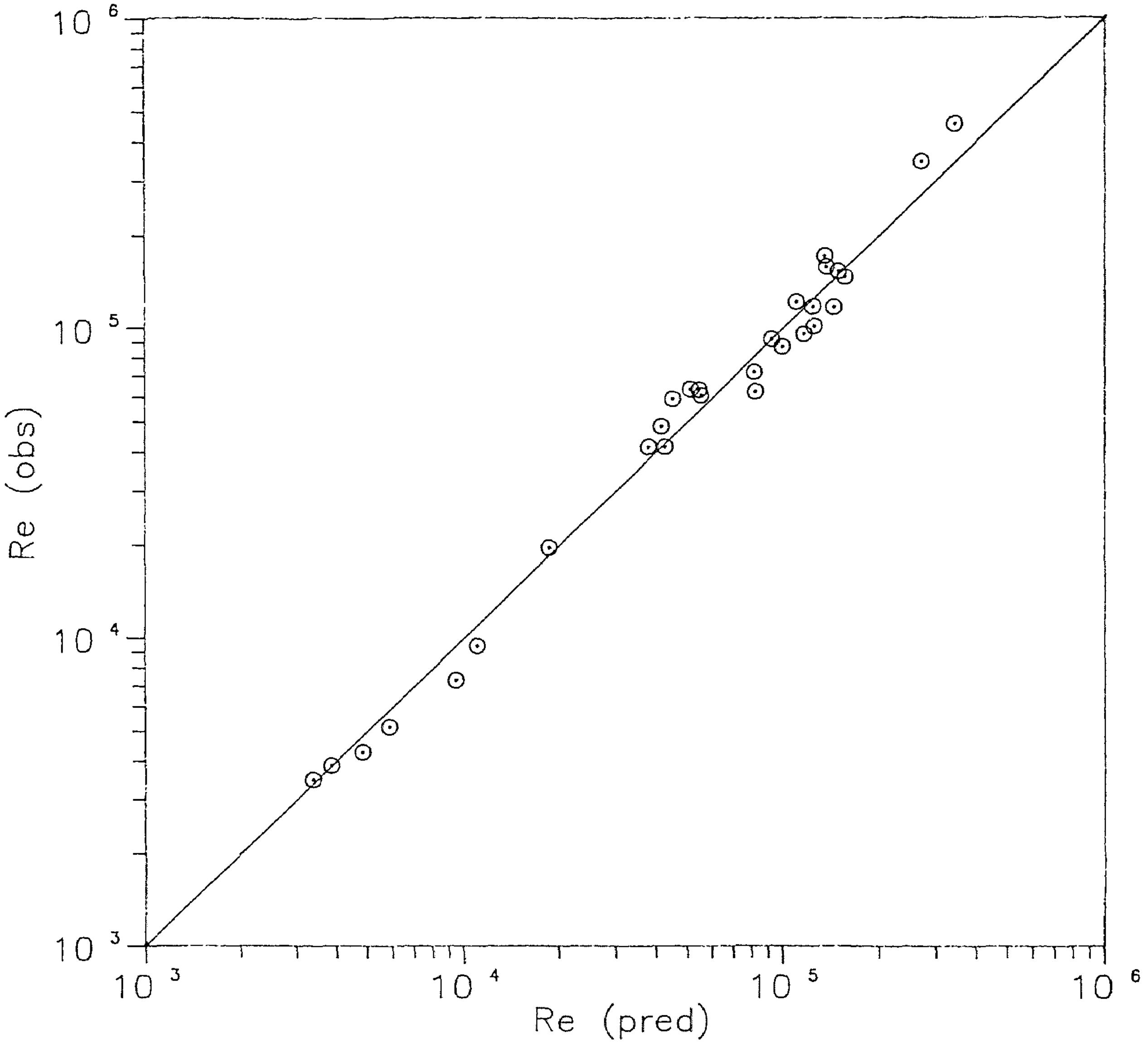


Fig36 Comparison of Predicted vs. Observed value of Re using propeller data of Godfrey & Reeve (1984) (Predicted value from Fig 21 & Eqn 31)

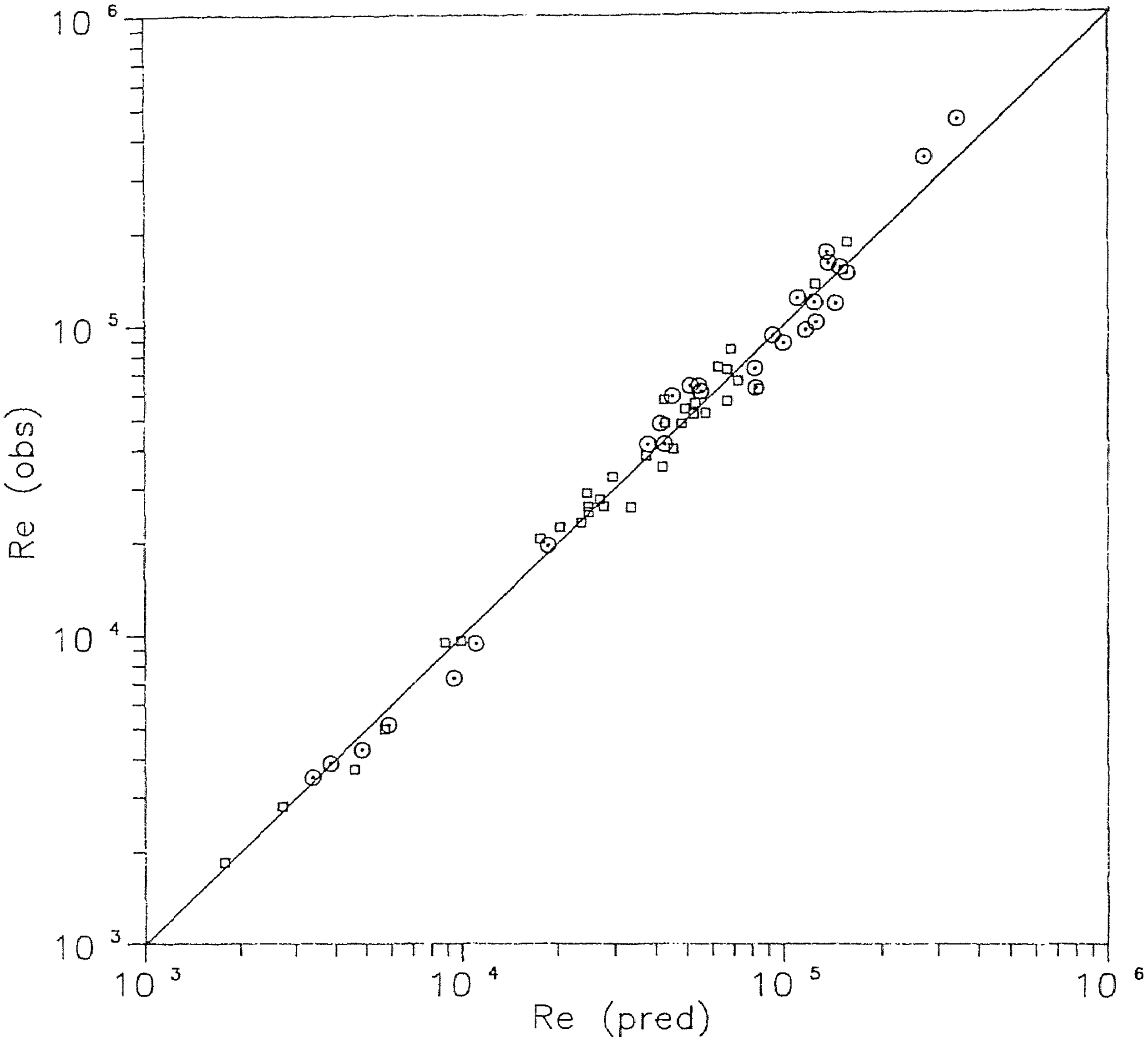


Fig37 Comparison of Predicted vs. Observed value of Re
using all data of Godfrey & Reeve (1984)
(Predicted value from Fig 23 &. Eqn 31)
□ DT; ○ Propeller;

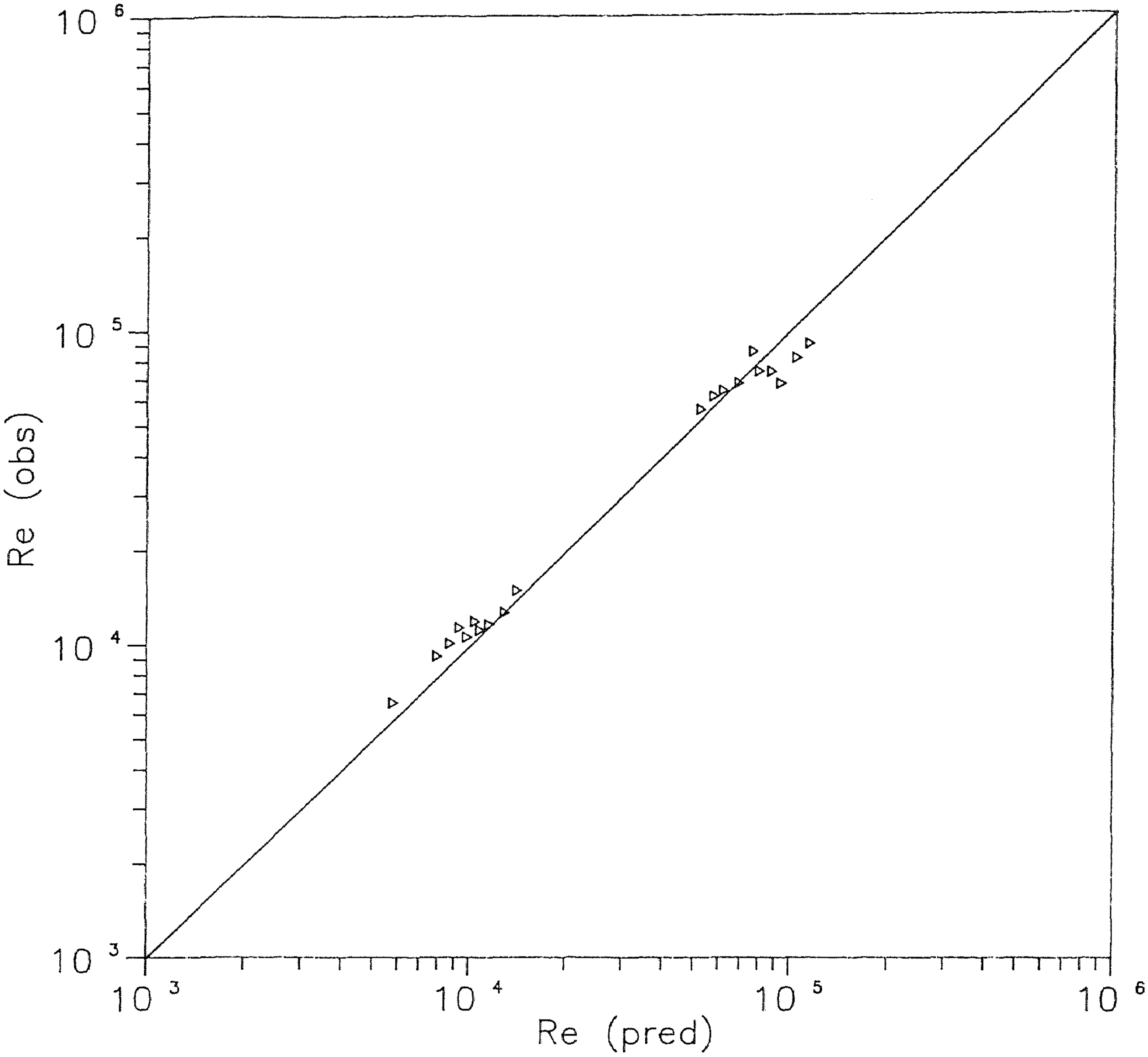


Fig38 Comparison of Predicted vs. Observed value of Re
using all data of Esch et al (1971)
(Predicted value from Fig 24 & Eqn 31)

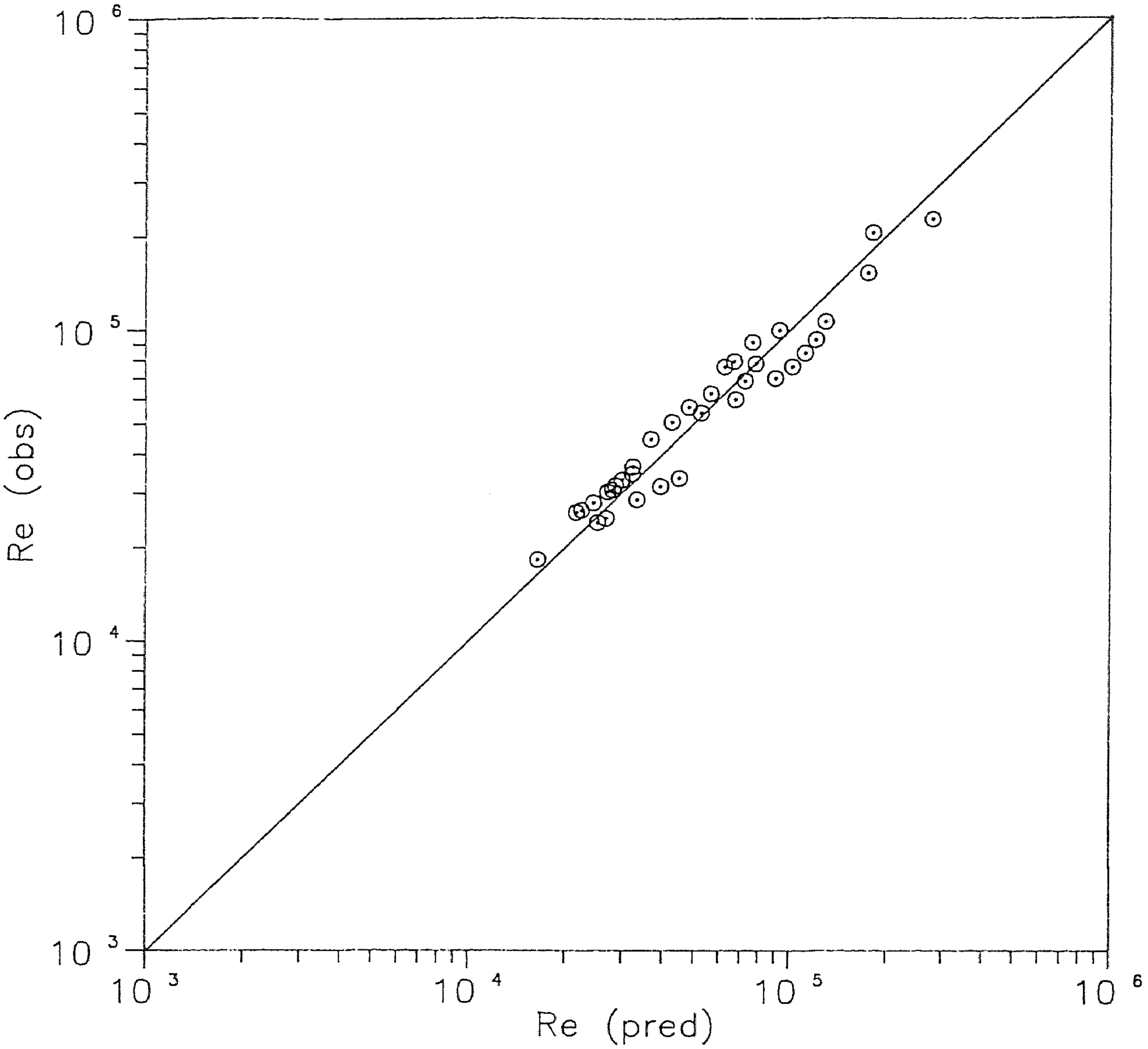


Fig39 Comparison of Predicted vs. Observed value of Re
using all data of Van Heuven & Beek (1971)
(Predicted value from Fig 25 &. Eqn 31)

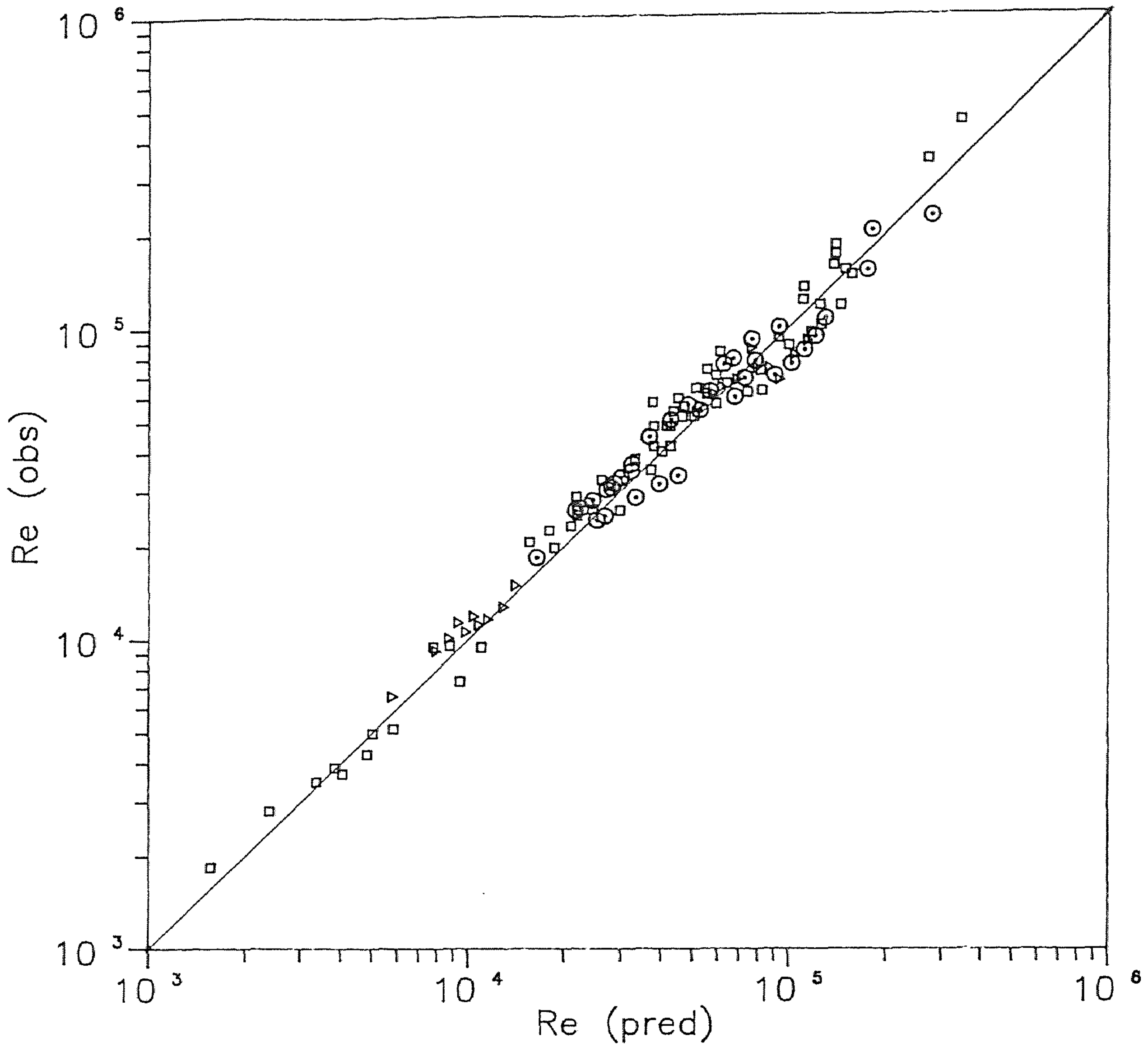


Fig40 Comparison of Predicted vs. Observed value of Re using data of Godfrey(□) & Esch(▷) & Van Heuven(○) (Predicted value from Fig 27 & Eqn 31)

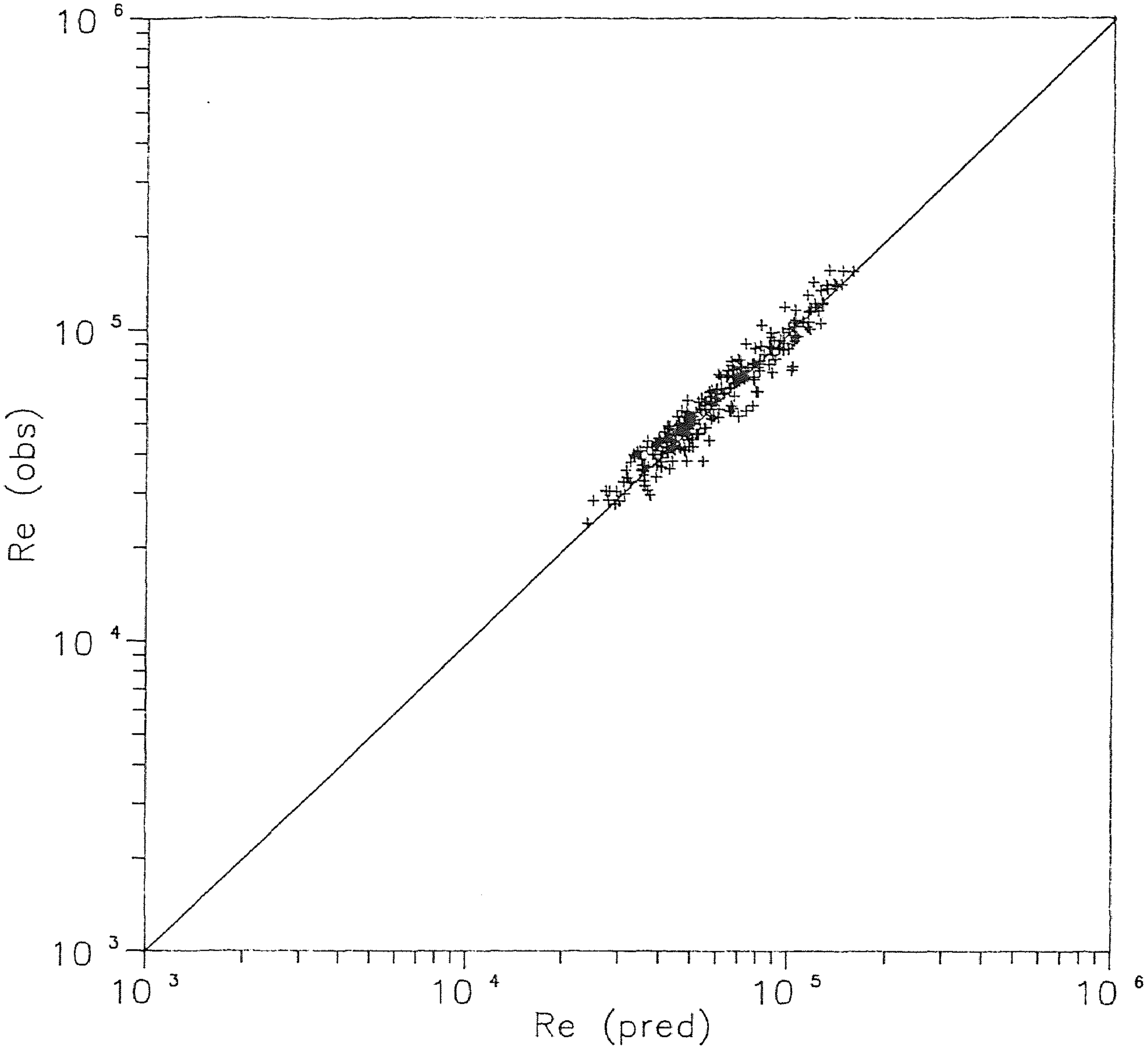


Fig41 Comparison of Predicted vs. Observed value of Re
using data of this work (DT & FT & CT)
(predicted value from Fig 29 & Eqn 31)

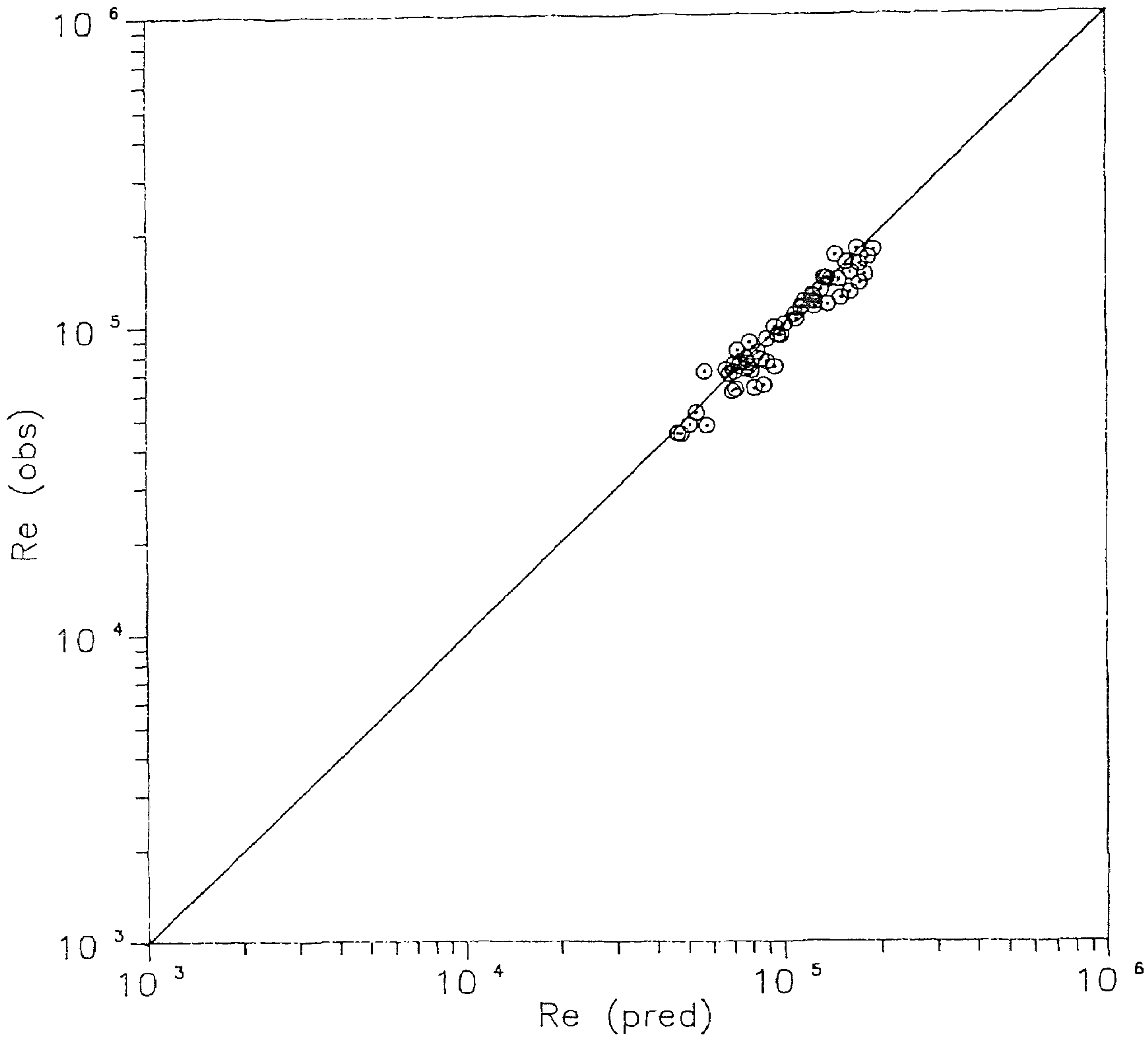


Fig42 Comparison of Predicted vs. Observed value of Re
using data of this work
(PT & Propeller at dispersed phase on bottom)
(predicted value from Fig 31 & Eqn 31)

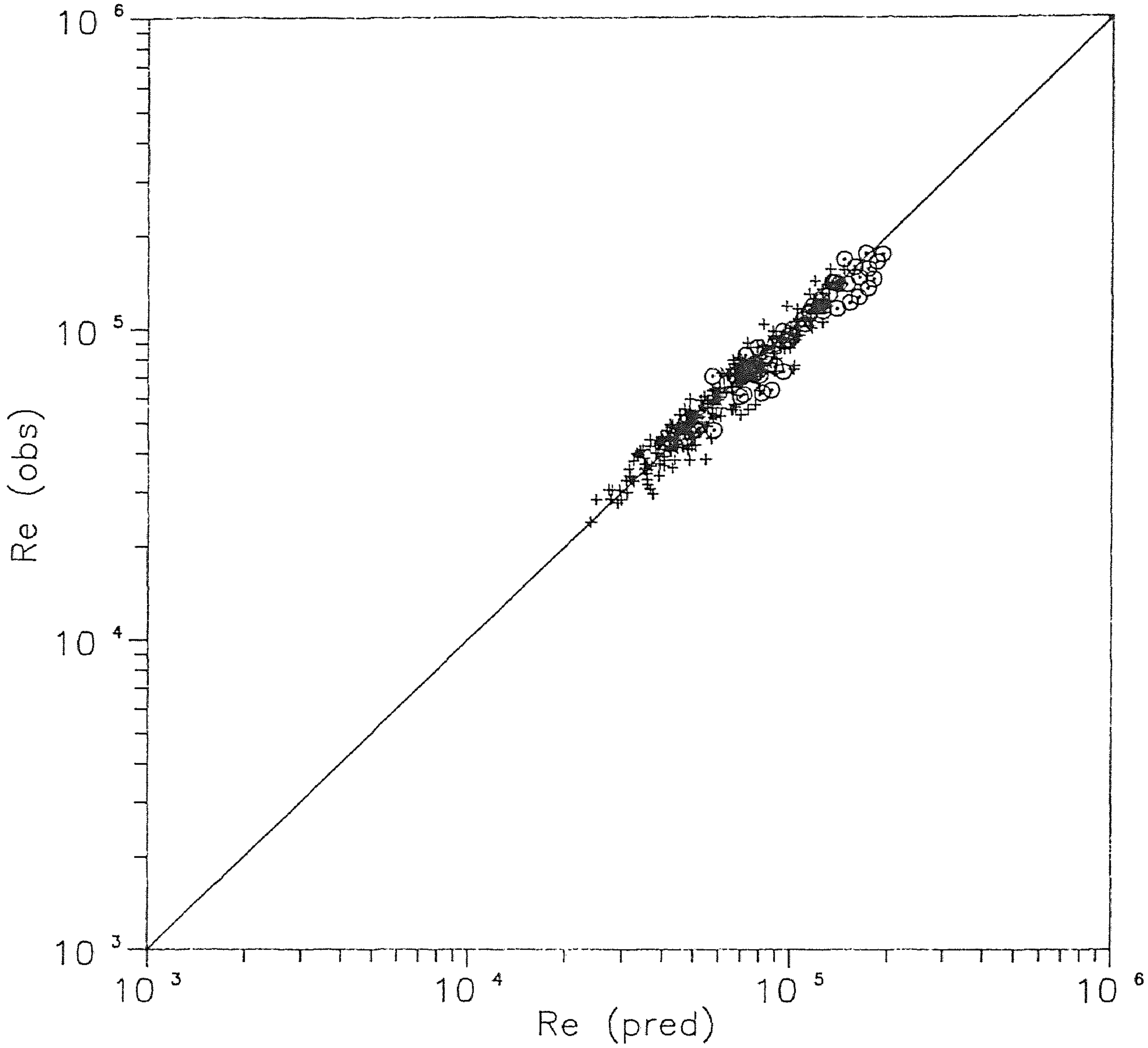


Fig43 Comparison of Predicted vs. Observed value of Re
using data of this work (+ −DT & FT & CT)
(○ −PT & Propeller at dispersed phase on bottom)
(predicted value from Fig 32 & Eqn 31)

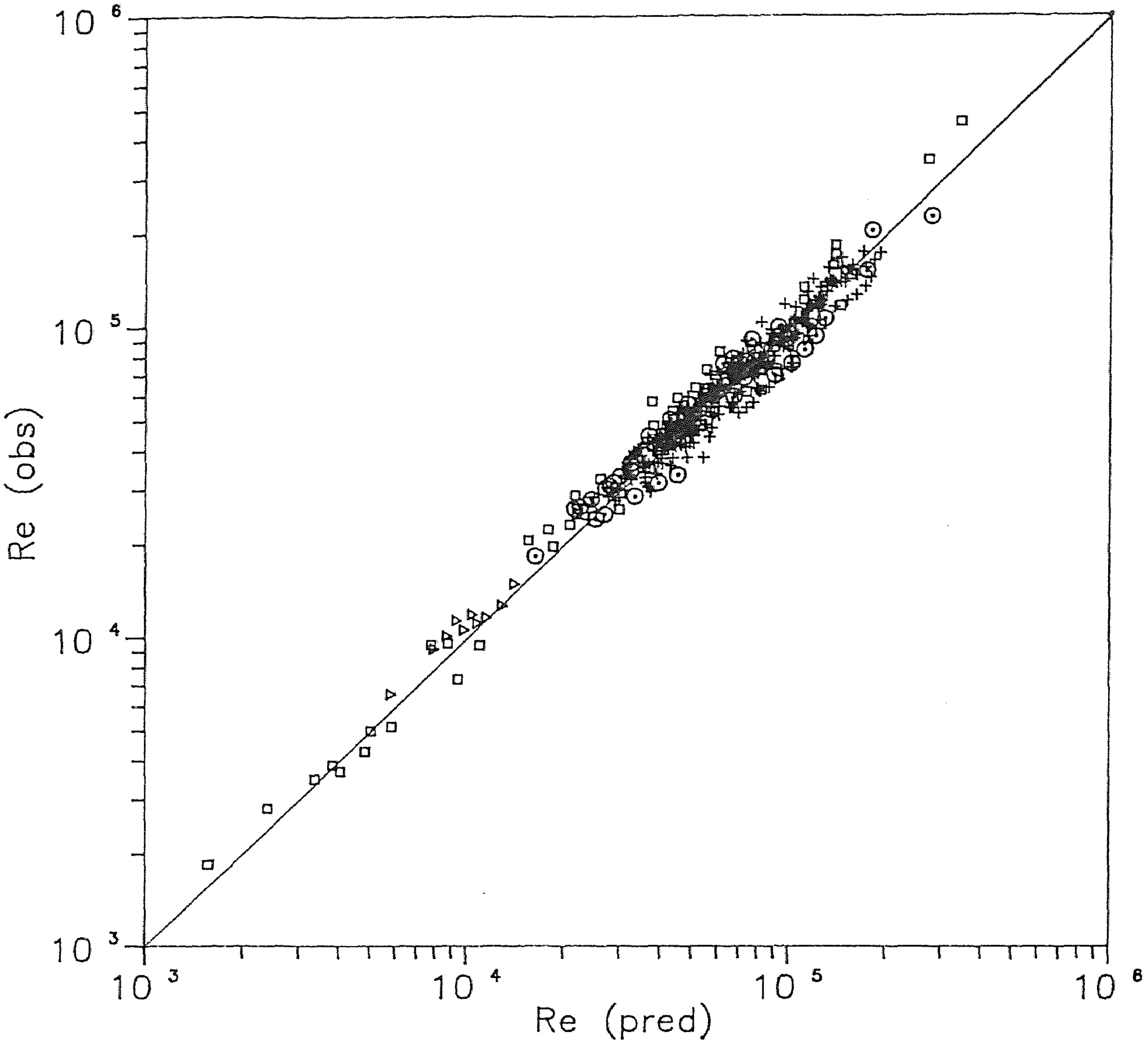


Fig44 Comparison of Predicted vs. Observed value of Re
using data of Godfrey(□) & Esch(▷) & Van Heuven(○)
& this work (+ −DT & FT & CT & PT & Propeller)
(predicted value from Fig 34 & Eqn 31)

Table 19 Regression of the coefficient for Eqn. 31 & 30

File	b	a	A
G1	1.01	0.445	0.523
G2	1.04	0.299	0.492
G5	1.01	0.380	0.439
G6	1.05	0.234	0.469
G7	1.01	0.450	0.511
G8	1.03	0.316	0.451
G9	1.01	0.450	0.482
Es	0.906	1.72	0.629
Van	0.886	1.98	0.533
GEV	0.960	0.818	0.520
D2	0.897	1.56	0.474
F2	0.962	0.806	0.497
C2	0.917	1.326	0.483
Pi2	1.02	0.380	0.500
Pr2	0.998	0.438	0.425
DFC	0.946	0.927	0.497
IR	0.951	0.858	0.473
DFCIR	0.939	1.01	0.492
GEVA	0.947	0.924	0.500

Comparison of the Results with the Literature

From the previous papers on liquid dispersion and solid suspension, there are not great differences between the mechanisms of complete dispersion and suspension. In this section, we compare our results with the literature from complete dispersion and suspension.

Comparison of Liquid Properties

Table 20 shows the resulting exponents on the various parameters of liquid properties evaluated from many works, such as this work, Van Heuvan (1971), and Skelland (1987)

Table 20 Comparison of the exponents of liquid properties from various sources

	exponent on		
Source	ρ_c	ρ	σ
Van Heuvan et al.(1971)	0.54	0.38	0.08
Skelland et al.(1987)	0.54	0.42	0.04
This work (theoretical)	0.5	0.416	0.083

Comparison of Power Number

We try to correlate the data of Table 7, Chapman (1983), if this information is excluded 4MFU because of different flow pattern, then for changing impeller type in a given system we can get $N_{js} \propto Np^{-0.322}$. Results from Chapman's data produced reasonable agreement with our results, giving $N \propto Np^{-0.333}$

Comparison of Impeller Diameter

In this section, comparison of the effect of diameter from many sources will be separated into two parts, (1) C/D=constant, and (2) C=constant, and will be presented in Table 21 & 22.

Table 22 Comparison of the exponent with N vs. D at C=constant from verious sources

Author	exponent on D for				
	DT	FT	CT	PT	Propeller
Skelland et al.(1987) (liquid-liquid)		-2.56	-2.72	-2.15	-1.38
Zwietering(1957) (solid-liquid)	-2.35			-2.15	-1.67
Nienow(1968) (solid-liquid)	-2.21				
Chapman et al.(1983) (solid-liquid)	-2.45				-1.50
This work (experimental)	-2.34	-2.39	-2.44	-2.24	-1.83

Table 21 Comparison of the exponent with N vs. D at C/D=constant from verious sources

Author	exponent on D
Esch et al.(1971) (liquid-liquid)	-1.61
Baldi et al.(1977) (solid-liquid)	-1.67
This work (theoretical)	-1.67

Comparison of Scale-up

Analysis of our results and comparison of literature, there are two case, the following expression

(1) C/D=conatant, T/D=H/D=constant; Table 23

(2) C=constant, D=constant, H=T; Table 24

Table 23 Comparison of the exponent for scale-up; case 1

Author	system	exponent
Van Heuvan et al.(1971)	(liquid-liquid)	-0.77
Skelland et al.(1987)	(liquid-liquid)	-0.71
Zwietering(1957)	(solid-liquid)	-0.85
Baldi et al.(1977)	(solid-liquid)	-0.67
Chapman et al.(1983)	(solid-liquid)	-0.76
This work(theoretical)	(liquid-liquid)	-0.67

Table 24 Comparison of the exponent for scale-up; case2

Author	system	exponent
Baldi et al.(1977)	(solid-liquid)	1
This work(theoretical)	(liquid-liquid)	1

CONCLUSIONS

The semitheoretical model proposed here for the prediction of the minimum agitation for complete dispersion of emulsions can be mathematically represented by the equation:

$$Re=A\ g(C/D)f(Xv)(Su^{.083})(Ar^{.416})(Np^{-.33})((T/D)^{.67})((H/D)^{.33})$$

This expression was tested against an extensive amount of data collected in this work as well as compared with experimental results obtained by previous investigators. In all cases the comparison appears favorable. The effect of the main geometric and physical variables (such as C/D, T/D, H/D, p_C, and σ) on the minimum agitation N can be quantitatively obtained from the above equation. The dependence on N an such variables was also specifically tested experimentally with favorable results. The above equation can be derived theoretically from a momentum balance, however, it does not include, at the present time, the effect of C/D,(i.e. the effect of the clearance of the impeller off the bottom or top.) Consequentally, the effect of C/D on N was determined experimently. If the ratio C/D is kept constant then only one proportionality constant, A, must be determined experimentally. It was found that the value for this constant, A, is equal to 0.5. All the experimental data collected in this work, as well as those from previous investigators, could be correlated in this way, (i.e. using the same value of the proportionality constant), provided the ratio C/D was constant.

In order to account for C/D effects an additional constant must be introduced which apears as the exponent of the term (C/D). The numerical value of this constant changes with the type of flow and with the type of impeller used.

To the best of the author's knowledge, the present model is the only available theoretical model to determine the minimum agitation speed for complete dispersion of liquid-liquid systems in stirred tanks. Previous investigations have only relied on experiments and on the correlation o fthe experimental data through best-fit approaches. Therefore, the present model represents a marked improvement over our current fundamental knowledge of dispersion behavior.

Further work will be required to describe the effect of the macroscopic fluid flow and to incorporate its effect on the attainment of the complete dispersed state into the model.

APPENDIX A

- Data of Godfrey et al.
- Data of Esch et al.
- Data of Van Heuven et al.

GODFREY DATA (G1) - DISC TURBINE;
OCT:OCTANOL; KER:KEROSENE; HEP:HEPTANE; ETH:ETHYLACETATE;
HEX:HEXANE; CYC:CYCLOHEXANE; CCL:CCl_4; W:WATER;

NO	MIXTURE	D	XV	PM	PC	NC	ND	a	N
		(m)	/	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(rpm)
1	OCT/W	.051	.3	947.6	998	0.93	8.60	8.4	440
2	KER/W	.051	.4	911.4	997	0.85	2.05	34.9	540
3	CCL/W	.051	.3	1174.1	998	0.94	0.92	44.0	560
4	HEP/W	.051	.3	901.6	997	0.84	0.39	50.0	630
5	HEX/W	.051	.6	794.0	998	0.96	0.33	51.0	840
6	HEX/W	.051	.7	760.0	998	0.96	0.33	51.0	770
7	W/OCT	.051	.3	880.4	830	8.40	0.90	8.4	430
8	W/OCT	.051	.3	876.0	825	5.50	0.55	8.0	430
9	W/KER	.051	.5	894.5	790	4.00	0.90	38.0	580
10	W/KER	.051	.4	868.6	783	2.05	0.90	34.9	575
11	W/KER	.051	.3	847.2	783	2.05	0.90	34.9	570
12	W/CCL	.051	.3	1408.9	1585	0.93	0.90	44.0	650
13	W/CCL	.051	.4	1350.2	1585	0.93	0.90	44.0	650
14	W/CYC	.051	.3	840.3	773	0.76	0.90	46.0	650
15	W/CYC	.051	.4	862.6	773	0.76	0.90	46.0	590
16	W/HEX	.051	.25	743.8	659	0.31	0.90	51.0	790
17	W/HEX	.051	.3	760.7	659	0.31	0.90	51.0	775
18	W/ETH	.051	.3	932.9	905	0.49	1.21	8.5	310
19	W/HEP	.051	.15	726.7	679	0.39	0.90	50.0	760
20	W/HEP	.051	.25	758.8	679	0.39	0.90	50.0	710
21	W/HEP	.051	.3	774.4	679	0.39	0.90	50.0	680

GODFREY DATA (G2) - DISC TURBINE;
OCT:OCTANOL; KER:KEROSENE; HEP:HERPTANE; ETH:ETHYLACETATE;
HEX:HEXANE; CYC:CYCLOHEXANE; CCL:CCl_4; W:WATER;

NO	MIXTURE	D (m)	XV /	PM (kg/m^3)	PC (kg/m^3)	NC (mPa.s)	ND (mPa.s)	a (mN/m)	N (rpm)
1	KER/W	.1	.3	937.1	998	0.95	2.05	49.0	318
2	KER/W	.1	.5	896.5	998	0.95	2.05	49.0	322
3	KER/W	.1	.7	855.9	998	0.95	2.05	49.0	350
4	KER/W	.1	.343	923.6	997	0.92	2.05	34.9	285
5	OCT/W	.1	.329	941.7	997	0.92	8.6	8.4	220
6	HEX/W	.1	.328	885.5	997	0.90	0.33	51.0	355
7	W/OCT	.1	.269	874.2	829	7.7	0.9	8.4	205
8	W/KER	.1	.247	835.9	783	2.05	0.9	34.9	350
9	W/KER	.1	.42	872.9	783	2.05	0.9	34.9	407
10	W/KER	.1	.3	855.9	795	1.9	0.9	49.0	330
11	W/CCL	.1	.438	1327.6	1585	0.92	0.9	44.0	465
12	W/CYC	.1	.33	864.9	773	0.76	0.9	46.0	490
13	W/HEX	.1	.244	740.0	657	0.3	0.9	51.0	500

GODFREY DATA (G5) - PROPELLER;
OCT: OCTANOL; KER:KEROSENE; HEP:HEPTANE; ETH:ETHYLACETATE;
HEX:HEXANE; CYC : CYCLOHEXANE; CCL : CCl_4; W:WATER;

NO	MIXTURE	D (m)	XV /	PM (kg/m^3)	PC (kg/m^3)	NC (mPa.s)	ND (mPa.s)	a (mN/m)	N (rpm)
1	OCT/W	.051	.3	946.9	997	0.93	8.6	8.4	890
2	OCT/W	.051	.4	930.2	997	0.93	8.6	8.4	890
3	KER/W	.051	.4	911.4	997	0.91	2.05	34.9	1330
4	CCL/W	.051	.4	1233.6	998	0.94	0.92	44.0	1350
5	HEX/W	.051	.6	794.6	998	0.95	0.33	51.0	1580
6	W/OCT	.051	.2	863.6	830	8.4	0.90	8.4	810
7	W/OCT	.051	.3	880.4	830	8.4	0.90	8.4	900
8	W/OCT	.051	.3	876.0	825	5.5	0.55	8.0	790
9	W/OCT	.051	.5	913.9	830	8.4	0.90	8.4	995
10	W/KER	.051	.3	847.5	783	2.1	0.90	34.9	1210
11	W/KER	.051	.4	872.4	788	4.0	0.90	37.0	1100
12	W/CCL	.051	.3	1408.9	1585	0.93	0.90	44.0	1245
13	W/CCL	.051	.5	1291.5	1585	0.93	0.90	44.0	1290
14	W/HEP	.051	.3	774.7	679	0.40	0.90	50.0	1650
15	W/HEP	.051	.4	806.6	679	0.40	0.90	50.0	1590
16	W/HEX	.051	.25	743.0	658	0.31	0.90	51.0	1850
17	W/HEX	.051	.3	759.0	657	0.30	0.90	51.0	1600

GODFREY DATA (G6) - PROPELLER;
OCT:OCTANOL; KER:KEROSENE; HEP:HEPTANE; ETH:ETHYLACETATE;
HEX:HEXANE; CYC:CTCLOHEXANE; CCL:CCl_4; W:WATER;

NO	MIXTURE	D	XV	PM	PC	NC	ND	a	N
		(m)	/	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(rpm)
1	KER/W	.1	.5	896.3	998	0.95	2.05	49.0	663
2	KER/W	.1	.34	924.3	998	0.91	2.05	35.0	551
3	OCT/W	.1	.329	942.1	997	0.90	8.6	8.4	470
4	HEX/W	.1	.326	886.2	997	0.90	0.33	51.0	790
5	W/KER	.1	.15	825.5	795	1.9	0.90	49.0	690
6	W/KER	.1	.3	855.9	795	1.9	0.90	49.0	910
7	W/OCT	.1	.262	873.8	830	8.0	0.90	8.5	420
8	W/KER	.1	.247	835.9	783	2.0	0.90	34.9	905
9	W/KER	.1	.42	872.9	783	2.0	0.90	34.9	930
10	W/CCL	.1	.438	1327.5	1585	0.92	0.90	44.0	1200
11	W/CYC	.1	.343	849.9	773	0.76	0.90	46.0	925
12	W/HEX	.1	.248	741.2	657	0.30	0.90	51.0	1250

ESCH DATA (ES) - DISC TURBINE;
HEP:HEPTANE; OIL:OIL; C:CORN SYRUP SOLUTION
S:SULPHURIC ACID; W:WATER;

NO	MIXTURE	D	XC	PD	PC	NC	ND	a	N
		(m)	/	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(rps)
1	W/HEP	.1	.323	679	996	0.861	0.391	50	7.78
2	W/HEP	.1	.403	679	996	0.861	0.391	50	7.00
3	W/HEP	.1	.500	679	996	0.861	0.391	50	5.81
4	W/HEP	.1	.564	679	996	0.861	0.391	50	6.35
5	W/HEP	.1	.645	679	996	0.861	0.391	50	6.35
6	C/HEP	.1	.323	679	1203	9.15	0.391	35	11.27
7	C/HEP	.1	.403	679	1203	9.15	0.391	35	9.60
8	C/HEP	.1	.500	679	1203	9.15	0.391	35	8.77
9	C/HEP	.1	.564	679	1203	9.15	0.391	35	8.42
10	C/HEP	.1	.645	679	1203	9.15	0.391	35	8.00
11	W/OIL	.1	.307	875	996	0.861	215.0	43	7.35
12	W/OIL	.1	.403	875	996	0.861	215.0	43	5.83
13	W/OIL	.1	.500	875	996	0.861	215.0	43	5.53
14	W/OIL	.1	.564	875	996	0.861	215.0	43	5.30
15	W/OIL	.1	.645	875	996	0.861	215.0	43	4.83
16	C/OIL	.1	.403	875	1203	9.15	215.0	28	8.98
17	C/OIL	.1	.500	875	1203	9.15	215.0	28	8.58
18	C/OIL	.1	.564	875	1203	9.15	215.0	28	7.65
19	C/OIL	.1	.645	875	1203	9.15	215.0	28	6.97
20	S/HEP	.1	.35	679	1840	37.0	0.391	34	13.10

VAN HEUVEN DATA (VAN)-DISC TURBINE

NO	PC	PD	NC	ND	a	XV	D	T	H	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	/	(cm)	(cm)	(cm)	(rps)
1	998	660	1	0.33	49.5	.01	5.7	19.1	19.1	7.42
2	998	660	1	0.33	49.5	.02	5.7	19.1	19.1	7.67
3	998	660	1	0.33	49.5	.10	5.7	19.1	19.1	8.80
4	998	660	1	0.33	49.5	.20	5.7	19.1	19.1	9.70
5	998	660	1	0.33	49.5	.30	5.7	19.1	19.1	10.30
6	998	827	1	10.00	8.5	.01	5.7	19.1	19.1	5.63
7	998	827	1	10.00	8.5	.12	5.7	19.1	19.1	8.13
8	998	827	1	10.00	8.5	.24	5.7	19.1	19.1	9.33
9	998	827	1	10.00	8.5	.32	5.7	19.1	19.1	10.20
10	998	910	1	0.60	35.5	.01	7.6	26.4	26.4	4.50
11	998	910	1	0.60	35.5	.09	7.6	26.4	26.4	5.33
12	998	910	1	0.60	35.5	.17	7.6	26.4	26.4	6.33
13	998	910	1	0.60	35.5	.26	7.6	26.4	26.4	7.75
14	998	880	1	0.65	35.0	.01	7.6	26.4	26.4	4.84
15	998	880	1	0.65	35.0	.05	7.6	26.4	26.4	5.50
16	998	880	1	0.65	35.0	.10	7.6	26.4	26.4	6.00
17	998	910	1	0.60	35.5	.01	13.5	45.0	45.0	2.78
18	998	910	1	0.60	35.5	.10	13.5	45.0	45.0	3.42
19	998	910	1	0.60	35.5	.20	13.5	45.0	45.0	4.34
20	998	910	1	0.60	35.5	.30	13.5	45.0	45.0	5.00

VAN HEUVEN DATA (VAN)

NO	PC	PD	NC	ND	a	XV	D	T	H	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	/	(cm)	(cm)	(cm)	(rps)
21	998	880	1	0.65	35.0	.01	13.5	45.0	45.0	3.10
22	998	880	1	0.65	35.0	.09	13.5	45.0	45.0	4.17
23	998	660	1	0.33	49.5	.05	13.5	45.0	45.0	3.83
24	998	660	1	0.33	49.5	.10	13.5	45.0	45.0	4.17
25	998	660	1	0.33	49.5	.15	13.5	45.0	45.0	4.62
26	998	660	1	0.33	49.5	.20	13.5	45.0	45.0	5.10
27	998	660	1	0.33	49.5	.25	13.5	45.0	45.0	5.83
28	998	827	1	10.00	8.5	.02	13.5	45.0	45.0	2.97
29	998	827	1	10.00	8.5	.11	13.5	45.0	45.0	3.27
30	998	827	1	10.00	8.5	.15	13.5	45.0	45.0	3.76
31	998	827	1	10.00	8.5	.20	13.5	45.0	45.0	4.27
32	998	827	1	10.00	8.5	.33	13.5	45.0	45.0	5.47
33	998	660	1	0.33	49.5	.01	40.0	120.0	120.0	1.42
34	998	827	1	10.00	8.5	.01	40.0	120.0	120.0	1.28
35	998	880	1	0.65	35.5	.01	40.0	120.0	120.0	0.95

APPENDIX B

- Data of Disk Turbine
- Data of Flat Turbine
- Data of Curved Turbine
- Data of Pitched Turbine
  (dispersed phase on bottom)
- Data of Propeller
  (dispersed phase on bottom)
- Data of Pitched Turbine
  (dispersed phase on top)
- Data of Propeller
  (dispersed phase on top)

DISC DATA OF THIS WORK (D2)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
1	815	998	0.60	0.94	9.8	6.4	24.7	24.7	6.4	6.0	.15	320
2	815	998	0.60	0.94	9.8	6.4	24.7	24.7	7.7	5.9	.15	380
3	815	998	0.60	0.94	9.8	6.4	24.7	24.7	12.8	5.2	.15	500
4	815	998	0.60	0.94	9.8	6.4	24.7	24.7	14	5.1	.15	520
5	815	998	0.60	0.94	9.8	6.4	24.7	24.7	15.4	4.7	.15	560
6	815	998	0.60	0.94	9.8	7.7	24.7	24.7	6.4	5.4	.15	210
7	815	998	0.60	0.94	9.8	7.7	24.7	24.7	7.7	5.9	.15	240
8	815	998	0.60	0.94	9.8	7.7	24.7	24.7	12.8	5.7	.15	310
9	815	998	0.60	0.94	9.8	7.7	24.7	24.7	14	5.4	.15	330
10	815	998	0.60	0.94	9.8	7.7	24.7	24.7	15.4	5.1	.15	360
11	815	998	0.60	0.94	9.8	10.2	24.7	24.7	10.2	5.9	.15	150
12	815	998	0.60	0.94	9.8	10.2	24.7	24.7	14	5.8	.15	180
13	998	679	0.94	0.39	50.0	7.7	19	19	15.9	5.2	.2	480
14	998	679	0.94	0.39	50.0	7.7	19	19	13.7	5.6	.2	390
15	998	679	0.94	0.39	50.0	7.7	19	19	12.5	5.3	.2	360
16	998	679	0.94	0.39	50.0	7.7	19	19	10.3	5.2	.2	325
17	998	679	0.94	0.39	50.0	7.7	19	19	7	5.0	.2	290
18	998	679	0.94	0.39	50.0	6.4	19	19	14.8	5.3	.15	570
19	998	679	0.94	0.39	50.0	6.4	19	19	12.6	5.1	.15	500
20	998	679	0.94	0.39	50.0	6.4	19	19	10.4	5.0	.15	450

DISC DATA OF THIS WORK (D2)

NO	PC (kg/m^3)	PD (kg/m^3)	NC (mPa.s)	ND (mPa.s)	a (mN/m)	D (cm)	T (cm)	H (cm)	C (cm)	NP /	XV /	N (rpm)
21	998	679	0.94	0.39	50.0	6.4	19	19	8.2	5.8	.15	380
22	998	679	0.94	0.39	50.0	6.4	19	19	6	5.6	.15	330
23	998	679	0.94	0.39	50.0	7.7	19	21	14.2	5.4	.16	400
24	998	679	0.94	0.39	50.0	7.7	19	21	11.2	4.2	.16	350
25	998	679	0.94	0.39	50.0	7.7	19	21	9.2	5.0	.16	310
26	998	679	0.94	0.39	50.0	7.7	19	21	17.2	5.6	.16	475
27	998	679	0.94	0.39	50.0	7.7	19	21	6.2	5.0	.16	270
28	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	6.4	5.0	.1	730
29	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	8.4	5.1	.1	840
30	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	10.4	5.1	.1	950
31	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	12.4	5.3	.1	1060
32	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	14.4	5.3	.1	1180
33	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	16.4	5.4	.1	1260
34	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	7.8	5.0	.18	650
35	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	9.8	5.2	.18	700
36	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	11.8	5.4	.18	760
37	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	13.8	5.6	.18	820
38	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	15.8	6.0	.18	900
39	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	7.8	4.6	.18	970
40	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	9.8	4.9	.18	1000

DISC DATA OF THIS WORK (D2)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
41	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	11.8	4.7	.18	1240
42	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	13.8	4.6	.18	1400
43	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	15.8	4.8	.18	1580
44	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	7.8	5.6	.18	350
45	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	9.8	5.7	.18	380
46	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	11.8	5.8	.18	410
47	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	13.8	5.9	.18	450
48	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	15.8	6.1	.18	490
49	998	2482	0.94	0.99	36.8	10.2	24.7	28.8	9.8	5.0	.22	430
50	998	2482	0.94	0.99	36.8	10.2	24.7	28.8	11.8	4.8	.22	470
51	998	2482	0.94	0.99	36.8	10.2	24.7	28.8	13.8	4.7	.22	510
52	998	2482	0.94	0.99	36.8	10.2	24.7	28.8	15.8	4.6	.22	570
53	998	2482	0.94	0.99	36.8	7.7	28.6	22	9.8	5.2	.22	880
54	998	2482	0.94	0.99	36.8	7.7	28.6	22	11.8	4.9	.22	910
55	998	2482	0.94	0.99	36.8	7.7	28.6	22	13.8	4.8	.22	950
56	998	2482	0.94	0.99	36.8	7.7	28.6	22	15.8	5.0	.22	990
57	998	815	0.94	0.60	9.8	7.7	24.7	24	8.5	4.5	.17	270
58	998	815	0.94	0.60	9.8	7.7	24.7	24	10.5	4.6	.17	320
59	998	815	0.94	0.60	9.8	7.7	24.7	24	12.5	4.7	.17	350
60	998	815	0.94	0.60	9.8	7.7	24.7	24	14.5	4.8	.17	380

DISC DATA OF THIS WORK (D2)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
61	998	815	0.94	0.60	9.8	7.7	24.7	24	16.5	4.9	.17	420
62	998	815	0.94	0.60	9.8	7.7	24.7	24	18.5	5.0	.17	460
63	998	815	0.94	0.60	9.8	7.7	24.7	24	20.5	5.2	.17	480
64	998	815	0.94	0.60	9.8	6.4	24.7	24	7.5	4.6	.17	420
65	998	815	0.94	0.60	9.8	6.4	24.7	24	9.5	4.8	.17	490
66	998	815	0.94	0.60	9.8	6.4	24.7	24	11.5	5.1	.17	530
67	998	815	0.94	0.60	9.8	6.4	24.7	24	13.5	5.2	.17	590
68	998	815	0.94	0.60	9.8	6.4	24.7	24	15.5	5.3	.17	680
69	998	815	0.94	0.60	9.8	6.4	24.7	24	17.5	5.5	.17	730
70	998	815	0.94	0.60	9.8	6.4	24.7	24	19.5	5.5	.17	820
71	998	815	0.94	0.60	9.8	6.4	28.6	24.5	9	4.7	.12	450
72	998	815	0.94	0.60	9.8	6.4	28.6	24.5	12	4.9	.12	500
73	998	815	0.94	0.60	9.8	6.4	28.6	24.5	15	4.0	.12	580
74	998	815	0.94	0.60	9.8	6.4	28.6	24.5	18	4.9	.12	750
75	998	815	0.94	0.60	9.8	7.7	28.6	24.5	9	4.5	.12	290
77	998	815	0.94	0.60	9.8	7.7	28.6	24.5	12	4.6	.12	340
78	998	815	0.94	0.60	9.8	7.7	28.6	24.5	15	4.8	.12	390
79	998	815	0.94	0.60	9.8	7.7	28.6	24.5	18	4.8	.12	450
80	998	815	0.94	0.60	9.8	10.2	28.6	29	10	5.1	.26	200

DISC DATA OF THIS WORK (D2)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
81	998	815	0.94	0.60	9.8	10.2	28.6	29	12	5.2	.26	210
82	998	815	0.94	0.60	9.8	10.2	28.6	29	14	5.2	.26	230
83	998	815	0.94	0.60	9.8	10.2	28.6	29	16	5.2	.26	250
84	998	815	0.94	0.60	9.8	10.2	28.6	29	18	5.1	.26	270
85	998	815	0.94	0.60	9.8	10.2	28.6	29	20	5.0	.26	300
86	998	679	0.94	0.39	50.0	6.4	19	19	12.6	5.2	.1	420
87	998	679	0.94	0.39	50.0	7.7	24.7	24.7	17	5.1	.1	360
88	998	679	0.94	0.39	50.0	10.2	28.6	28.6	18.4	5.0	.1	300
89	998	679	0.94	0.39	50.0	7.7	19	19	14.4	5.4	.1	280
90	998	679	0.94	0.39	50.0	7.7	24.7	24.7	14.4	5.2	.1	360
91	998	679	0.94	0.39	50.0	7.7	28.6	28.6	14.4	5.0	.1	420
92	998	679	0.94	0.39	50.0	7.7	34.5	34.5	14.4	4.8	.1	500
93	998	679	0.94	0.39	50.0	7.7	24.7	15.3	12	5.5	.1	300
94	998	679	0.94	0.39	50.0	7.7	24.7	19.5	12	5.4	.1	320
95	998	679	0.94	0.39	50.0	7.7	24.7	24.7	12	5.2	.1	340
96	998	679	0.94	0.39	50.0	7.7	24.7	32.2	12	4.9	.1	360

FLAT DATA OF THIS WORK (F2)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
1	815	998	0.60	0.94	9.8	6.4	24.7	24.7	6.4	2.2	.15	470
2	815	998	0.60	0.94	9.8	6.4	24.7	24.7	7.7	2.4	.15	520
3	815	998	0.60	0.94	9.8	6.4	24.7	24.7	12.8	2.6	.15	720
4	815	998	0.60	0.94	9.8	6.4	24.7	24.7	14	2.6	.15	770
5	815	998	0.60	0.94	9.8	6.4	24.7	24.7	15.4	2.5	.15	830
6	815	998	0.60	0.94	9.8	7.7	24.7	24.7	6.4	1.9	.15	310
7	815	998	0.60	0.94	9.8	7.7	24.7	24.7	7.7	1.9	.15	340
8	815	998	0.60	0.94	9.8	7.7	24.7	24.7	12.8	2.5	.15	460
9	815	998	0.60	0.94	9.8	7.7	24.7	24.7	14	2.3	.15	500
10	815	998	0.60	0.94	9.8	7.7	24.7	24.7	15.4	2.5	.15	530
11	998	679	0.94	0.39	50	7.7	19	19	7	1.8	.2	405
12	998	679	0.94	0.39	50	7.7	19	19	9.2	2.4	.2	425
13	998	679	0.94	0.39	50	7.7	19	19	11.4	2.4	.2	475
14	998	679	0.94	0.39	50	7.7	19	19	13.6	2.4	.2	550
15	998	679	0.94	0.39	50	7.7	19	19	15.8	2.1	.2	670
16	998	679	0.94	0.39	50	6.4	19	19	14.8	2.0	.15	970
17	998	679	0.94	0.39	50	6.4	19	19	12.6	2.4	.15	830
18	998	679	0.94	0.39	50	6.4	19	19	10.4	2.0	.15	730
19	998	679	0.94	0.39	50	6.4	19	19	8.2	2.3	.15	610
20	998	679	0.94	0.39	50	6.4	19	19	6	2.2	.15	520

FLAT DATA OF THIS WORK (F2)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
21	998	679	0.94	0.39	50	7.7	19	21	6.2	1.8	.16	390
22	998	679	0.94	0.39	50	7.7	19	21	9.2	2.0	.16	440
23	998	679	0.94	0.39	50	7.7	19	21	11.2	2.1	.16	480
24	998	679	0.94	0.39	50	7.7	19	21	14.2	2.1	.16	560
25	998	679	0.94	0.39	50	7.7	19	21	17.2	2.2	.16	670
26	998	679	0.94	0.39	50	10.2	24.7	24.7	15.4	2.6	.1	330
27	998	679	0.94	0.39	50	10.2	24.7	24.7	12.4	2.0	.1	310
28	998	679	0.94	0.39	50	10.2	24.7	24.7	9.4	1.8	.1	300
29	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	6.4	2.6	.1	1040
30	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	8.4	2.4	.1	1200
31	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	10.4	2.6	.1	1380
32	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	12.4	2.5	.1	1570
33	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	14.4	2.7	.1	1840
34	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	7.8	2.6	.18	900
35	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	9.8	2.6	.18	1000
36	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	11.8	2.5	.18	1150
37	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	13.8	2.7	.18	1320
38	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	15.8	2.6	.18	1470
39	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	7.8	2.3	.18	560
40	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	9.8	2.3	.18	640

FLAT DATA OF THIS WORK (F2)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
41	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	11.8	2.1	.18	700
42	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	13.8	2.6	.18	770
43	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	15.8	2.5	.18	840
44	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	7.8	2.8	.18	1210
45	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	9.8	2.7	.18	1460
46	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	11.8	2.7	.18	1660
47	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	13.8	2.8	.18	1900
48	998	815	0.94	0.60	9.8	6.4	24.7	24	8.5	2.1	.17	600
49	998	815	0.94	0.60	9.8	6.4	24.7	24	10.5	2.2	.17	680
50	998	815	0.94	0.60	9.8	6.4	24.7	24	12.5	2.4	.17	730
51	998	815	0.94	0.60	9.8	6.4	24.7	24	14.5	2.6	.17	770
52	998	815	0.94	0.60	9.8	6.4	24.7	24	16.5	2.7	.17	880
53	998	815	0.94	0.60	9.8	6.4	24.7	24	18.5	2.3	.17	1090
54	998	815	0.94	0.60	9.8	6.4	24.7	24	20.5	2.1	.17	1240
55	998	815	0.94	0.60	9.8	7.7	24.7	24	8.5	2.0	.17	400
56	998	815	0.94	0.60	9.8	7.7	24.7	24	10.5	2.0	.17	460
57	998	815	0.94	0.60	9.8	7.7	24.7	24	12.5	2.0	.17	500
58	998	815	0.94	0.60	9.8	7.7	24.7	24	14.5	2.1	.17	560
59	998	815	0.94	0.60	9.8	7.7	24.7	24	16.5	2.2	.17	600
60	998	815	0.94	0.60	9.8	7.7	24.7	24	18.5	2.2	.17	670

FLAT DATA OF THIS WORK (F2)

NO	PC (kg/m^3)	PD (kg/m^3)	NC (mPa.s)	ND (mPa.s)	a (mN/m)	D (cm)	T (cm)	H (cm)	C (cm)	NP /	XV /	N (rpm)
61	998	815	0.94	0.60	9.8	7.7	24.7	24	20.5	2.2	.17	730
62	998	815	0.94	0.60	9.8	10.2	24.7	24	8.5	1.8	.17	220
63	998	815	0.94	0.60	9.8	10.2	24.7	24	10.5	1.8	.17	235
64	998	815	0.94	0.60	9.8	10.2	24.7	24	12.5	1.8	.17	250
65	998	815	0.94	0.60	9.8	10.2	24.7	24	14.5	1.9	.17	270
66	998	815	0.94	0.60	9.8	10.2	24.7	24	16.5	1.9	.17	300
67	998	815	0.94	0.60	9.8	10.2	24.7	24	18.5	1.7	.17	390
68	998	815	0.94	0.60	9.8	6.4	28.6	24.5	9	2.0	.12	600
69	998	815	0.94	0.60	9.8	6.4	28.6	24.5	12	2.2	.12	690
70	998	815	0.94	0.60	9.8	6.4	28.6	24.5	15	2.3	.12	800
71	998	815	0.94	0.60	9.8	6.4	28.6	24.5	18	2.4	.12	1020
72	998	815	0.94	0.60	9.8	10.2	28.6	24.5	9	1.4	.12	230
73	998	815	0.94	0.60	9.8	10.2	28.6	24.5	12	1.5	.12	260
74	998	815	0.94	0.60	9.8	10.2	28.6	24.5	15	1.5	.12	300
75	998	815	0.94	0.60	9.8	10.2	28.6	24.5	18	1.6	.12	350
76	998	815	0.94	0.60	9.8	10.2	28.6	29	12	1.8	.26	320
77	998	815	0.94	0.60	9.8	10.2	28.6	29	14	1.9	.26	340
78	998	815	0.94	0.60	9.8	10.2	28.6	29	16	1.9	.26	370
79	998	815	0.94	0.60	9.8	10.2	28.6	29	18	2.0	.26	410
80	998	815	0.94	0.60	9.8	10.2	28.6	29	20	1.9	.26	480

FLAT DATA OF THIS WORK (F2)

NO	PC	PD	NC	ND	a	D	H	T	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
81	998	679	0.94	0.39	50	6.4	19	19	12.6	2.4	.1	610
82	998	679	0.94	0.39	50	7.7	24.7	24.7	17	2.3	.1	520
83	998	679	0.94	0.39	50	10.2	28.6	28.6	18.4	2.1	.1	450
84	998	679	0.94	0.39	50	7.7	19	19	14.4	2.6	.1	400
85	998	679	0.94	0.39	50	7.7	24.7	24.7	14.4	2.3	.1	520
86	998	679	0.94	0.39	50	7.7	28.6	28.6	14.4	2.0	.1	600
87	998	679	0.94	0.39	50	7.7	34.5	34.5	14.4	1.7	.1	700
88	998	679	0.94	0.39	50	7.7	24.7	15.3	12	2.5	.1	390
89	998	679	0.94	0.39	50	7.7	24.7	19.5	12	2.4	.1	440
90	998	679	0.94	0.39	50	7.7	24.7	24.7	12	2.3	.1	490
91	998	679	0.94	0.39	50	7.7	24.7	32.2	12	2.0	.1	520

CURVED DATA OF THIS WORK (C2)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
1	815	998	0.60	0.94	9.8	6.4	24.7	24.7	6.4	2.1	.15	460
2	815	998	0.60	0.94	9.8	6.4	24.7	24.7	7.7	2.3	.15	530
3	815	998	0.60	0.94	9.8	6.4	24.7	24.7	12.8	2.5	.15	740
4	815	998	0.60	0.94	9.8	6.4	24.7	24.7	14	2.6	.15	760
5	815	998	0.60	0.94	9.8	6.4	24.7	24.7	15.4	2.7	.15	840
6	815	998	0.60	0.94	9.8	7.7	24.7	24.7	6.4	1.8	.15	300
7	815	998	0.60	0.94	9.8	7.7	24.7	24.7	7.7	1.8	.15	350
8	815	998	0.60	0.94	9.8	7.7	24.7	24.7	12.8	2.4	.15	480
9	815	998	0.60	0.94	9.8	7.7	24.7	24.7	14	2.4	.15	520
10	815	998	0.60	0.94	9.8	7.7	24.7	24.7	15.4	2.6	.15	550
11	998	679	0.94	0.39	50	7.7	19	19	15.8	2.0	.2	660
12	998	679	0.94	0.39	50	7.7	19	19	13.6	2.4	.2	560
13	998	679	0.94	0.39	50	7.7	19	19	11.4	2.8	.2	490
14	998	679	0.94	0.39	50	7.7	19	19	9.2	2.4	.2	440
15	998	679	0.94	0.39	50	7.7	19	19	7	1.8	.2	410
16	998	679	0.94	0.39	50	6.4	19	19	14.8	1.8	.15	990
17	998	679	0.94	0.39	50	6.4	19	19	12.6	2.2	.15	840
18	998	679	0.94	0.39	50	6.4	19	19	10.4	1.9	.15	750
19	998	679	0.94	0.39	50	6.4	19	19	8.2	2.1	.15	620
20	998	679	0.94	0.39	50	6.4	19	19	6	2.0	.15	540

CURVED DATA OF THIS WORK (C2)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
21	998	679	0.94	0.39	50	7.7	19	21	6.2	2.0	.16	380
22	998	679	0.94	0.39	50	7.7	19	21	9.2	1.8	.16	450
23	998	679	0.94	0.39	50	7.7	19	21	11.2	2.4	.16	470
24	998	679	0.94	0.39	50	7.7	19	21	14.2	2.2	.16	570
25	998	679	0.94	0.39	50	7.7	19	21	17.2	2.1	.16	680
26	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	6.4	2.5	.1	1050
27	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	8.4	2.5	.1	1200
28	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	10.4	2.4	.1	1400
29	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	12.4	2.6	.1	1590
30	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	14.4	2.6	.1	1860
31	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	7.8	2.8	.18	1270
32	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	9.8	2.9	.18	1450
33	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	11.8	2.9	.18	1680
34	998	2482	0.94	0.99	36.8	6.4	24.7	26.5	13.8	2.8	.18	1920
35	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	7.8	2.6	.18	930
36	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	9.8	2.6	.18	1020
37	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	11.8	2.6	.18	1120
38	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	13.8	2.5	.18	1330
39	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	15.8	2.3	.18	1460
40	998	815	0.94	0.60	9.8	6.4	24.7	24	8.5	2.1	.17	620

CURVED DATA OF THIS WORK (C2)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
41	998	815	0.94	0.60	9.8	6.4	24.7	24	10.5	2.2	.17	690
42	998	815	0.94	0.60	9.8	6.4	24.7	24	12.5	2.4	.17	730
43	998	815	0.94	0.60	9.8	6.4	24.7	24	14.5	2.6	.17	790
44	998	815	0.94	0.60	9.8	6.4	24.7	24	16.5	2.7	.17	890
45	998	815	0.94	0.60	9.8	6.4	24.7	24	18.5	2.3	.17	1110
46	998	815	0.94	0.60	9.8	6.4	24.7	24	20.5	2.0	.17	1200
47	998	815	0.94	0.60	9.8	7.7	24.7	24	8.5	2.0	.17	420
48	998	815	0.94	0.60	9.8	7.7	24.7	24	10.5	2.0	.17	470
49	998	815	0.94	0.60	9.8	7.7	24.7	24	12.5	2.0	.17	510
50	998	815	0.94	0.60	9.8	7.7	24.7	24	14.5	2.0	.17	560
51	998	815	0.94	0.60	9.8	7.7	24.7	24	16.5	2.1	.17	610
52	998	815	0.94	0.60	9.8	7.7	24.7	24	18.5	2.1	.17	680
53	998	815	0.94	0.60	9.8	7.7	24.7	24	20.5	2.1	.17	760
54	998	815	0.94	0.60	9.8	7.7	28.6	19	7	2.0	.16	320
55	998	815	0.94	0.60	9.8	7.7	28.6	19	9	2.1	.16	380
56	998	815	0.94	0.60	9.8	7.7	28.6	19	11	2.1	.16	420
57	998	815	0.94	0.60	9.8	7.7	28.6	19	13	2.1	.16	480
58	998	815	0.94	0.60	9.8	7.7	28.6	24.5	9	1.7	.12	450
59	998	815	0.94	0.60	9.8	7.7	28.6	24.5	12	1.8	.12	490
60	998	815	0.94	0.60	9.8	7.7	28.6	24.5	15	1.8	.12	560

CURVED DATA OF THIS WORK (C2)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
61	998	815	0.94	0.60	9.8	7.7	28.6	24.5	18	1.9	.12	710
62	998	815	0.94	0.60	9.8	6.4	28.6	24.5	9	2.0	.12	640
63	998	815	0.94	0.60	9.8	6.4	28.6	24.5	12	2.2	.12	710
64	998	815	0.94	0.60	9.8	6.4	28.6	24.5	15	2.4	.12	830
65	998	815	0.94	0.60	9.8	6.4	28.6	24.5	18	2.4	.12	1030
66	998	815	0.94	0.60	9.8	7.7	28.6	29	12	1.8	.26	620
67	998	815	0.94	0.60	9.8	7.7	28.6	29	14	1.9	.26	660
68	998	815	0.94	0.60	9.8	7.7	28.6	29	16	1.9	.26	740
69	998	815	0.94	0.60	9.8	7.7	28.6	29	18	2.0	.26	840
70	998	815	0.94	0.60	9.8	7.7	28.6	29	20	1.9	.26	930
71	998	815	0.94	0.60	9.8	7.7	28.6	29	22	1.8	.26	1100
72	998	679	0.94	0.39	50	6.4	19	19	12.6	2.5	.1	620
73	998	679	0.94	0.39	50	7.7	24.7	24.7	17	2.2	.1	540
74	998	679	0.94	0.39	50	7.7	19	19	14.4	2.6	.1	400
75	998	679	0.94	0.39	50	7.7	24.7	24.7	14.4	2.4	.1	540
76	998	679	0.94	0.39	50	7.7	28.6	28.6	14.4	2.1	.1	600
77	998	679	0.94	0.39	50	7.7	34.5	34.5	14.4	1.8	.1	720
78	998	679	0.94	0.39	50	7.7	24.7	15.3	12	2.7	.1	400
79	998	679	0.94	0.39	50	7.7	24.7	19.5	12	2.5	.1	440
80	998	679	0.94	0.39	50	7.7	24.7	24.7	12	2.3	.1	500
81	998	679	0.94	0.39	50	7.7	24.7	32.2	12	2.0	.1	530

PITCHED DATA OF THIS WORK (PI2)
(DOWNWARD; DISPERSED PHASE ON BOTTOM)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
1	815	998	0.60	0.94	9.8	6.4	24.7	24.7	6.4	1.7	.15	480
2	815	998	0.60	0.94	9.8	6.4	24.7	24.7	7.7	1.8	.15	510
3	815	998	0.60	0.94	9.8	6.4	24.7	24.7	12.8	1.7	.15	750
4	815	998	0.60	0.94	9.8	6.4	24.7	24.7	14	1.7	.15	780
5	815	998	0.60	0.94	9.8	6.4	24.7	24.7	15.4	1.8	.15	830
6	815	998	0.60	0.94	9.8	7.7	24.7	24.7	6.4	1.4	.15	330
7	815	998	0.60	0.94	9.8	7.7	24.7	24.7	7.7	1.0	.15	350
8	815	998	0.60	0.94	9.8	7.7	24.7	24.7	12.8	1.5	.15	510
9	815	998	0.60	0.94	9.8	7.7	24.7	24.7	14	1.3	.15	530
10	815	998	0.60	0.94	9.8	7.7	24.7	24.7	15.4	1.6	.15	560
11	815	998	0.60	0.94	9.8	10.2	24.7	24.7	10.2	1.8	.15	220
12	815	998	0.60	0.94	9.8	10.2	24.7	24.7	14	1.6	.15	300
13	998	2482	0.94	0.99	36.8	7.7	24.7	24.7	14.4	1.3	.1	1340
14	998	2482	0.94	0.99	36.8	7.7	24.7	24.7	12.4	1.3	.1	1180
15	998	2482	0.94	0.99	36.8	7.7	24.7	24.7	10.4	1.2	.1	1070
16	998	2482	0.94	0.99	36.8	7.7	24.7	24.7	8.4	1.2	.1	950
17	998	2482	0.94	0.99	36.8	7.7	24.7	24.7	6.4	1.1	.1	850
18	998	2482	0.94	0.99	36.8	7.7	24.7	24.7	4.4	1.1	.1	780
19	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	4.4	1.0	.1	1200
20	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	6.4	1.1	.1	1350

PITCHED DATA OF THIS WORK (PI2)
(DOWNWARD; DISPERSED PHASE ON BOTTOM)

NO	PC (kg/m^3)	PD (kg/m^3)	NC (mPa.s)	ND (mPa.s)	a (mN/m)	D (cm)	T (cm)	H (cm)	C (cm)	NP /	XV /	N (rpm)
21	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	8.4	1.0	.1	1540
22	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	10.4	1.1	.1	1690
23	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	12.4	1.1	.1	1940
24	998	2482	0.94	0.99	36.8	6.4	24.7	24.7	14.4	1.2	.1	2300
25	998	2482	0.94	0.99	36.8	10.2	24.7	24.7	4.4	1.8	.1	380
26	998	2482	0.94	0.99	36.8	10.2	24.7	24.7	6.4	1.8	.1	400
27	998	2482	0.94	0.99	36.8	10.2	24.7	24.7	8.4	1.7	.1	440
28	998	2482	0.94	0.99	36.8	10.2	24.7	24.7	10.4	1.6	.1	500
29	998	2482	0.94	0.99	36.8	10.2	24.7	24.7	12.4	1.5	.1	580
30	998	2482	0.94	0.99	36.8	10.2	24.7	24.7	14.4	1.6	.1	640
31	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	7.8	1.2	.18	1080
32	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	9.8	1.3	.18	1120
33	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	11.8	1.3	.18	1320
34	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	13.8	1.2	.18	1500
35	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	15.8	1.2	.18	1660
36	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	7.8	1.5	.18	500
37	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	9.8	1.6	.18	560
38	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	11.8	1.6	.18	640
39	998	2482	0.94	0.99	36.8	10.2	24.7	26.5	13.8	1.7	.18	700
40	998	2482	0.94	0.99	26.8	10.2	24.7	26.5	15.8	1.8	.18	760

PROPELLER DATA OF THIS WORK (PR2)
(DOWNWARD; DISPERSED PHASE ON BOTTOM)

NO	PC	PD	NC	ND	A	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
1	815	998	0.60	0.94	9.8	6.4	24.7	24.7	6.4	.54	.15	650
2	815	998	0.60	0.94	9.8	6.4	24.7	24.7	7.7	.58	.15	660
3	815	998	0.60	0.94	9.8	6.4	24.7	24.7	12.8	.61	.15	760
4	815	998	0.60	0.94	9.8	6.4	24.7	24.7	14	.69	.15	780
5	815	998	0.60	0.94	9.8	6.4	24.7	24.7	15.4	.76	.15	800
6	815	998	0.60	0.94	9.8	7.7	24.7	24.7	6.4	.34	.15	460
7	815	998	0.60	0.94	9.8	7.7	24.7	24.7	7.7	.32	.15	470
8	815	998	0.60	0.94	9.8	7.7	24.7	24.7	12.8	.37	.15	540
9	815	998	0.60	0.94	9.8	7.7	24.7	24.7	14	.47	.15	560
10	815	998	0.60	0.94	9.8	7.7	24.7	24.7	15.4	.57	.15	570
11	998	2482	0.94	0.99	36.8	7.7	24.7	24.7	4.4	.35	.1	1080
12	998	2482	0.94	0.99	36.8	7.7	24.7	24.7	6.4	.35	.1	1100
13	998	2482	0.94	0.99	36.8	7.7	24.7	24.7	8.4	.33	.1	1150
14	998	2482	0.94	0.99	36.8	7.7	24.7	24.7	10.4	.32	.1	1200
15	998	2482	0.94	0.99	36.8	7.7	24.7	24.7	12.4	.30	.1	1280
16	998	2482	0.94	0.99	36.8	7.7	24.7	24.7	14.4	.30	.1	1370
17	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	6.4	.45	.1	1320
18	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	8.4	.43	.1	1390
19	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	10.4	.42	.1	1480
20	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	12.4	.40	.1	1560
21	998	2482	0.94	0.99	36.8	7.7	24.7	26.5	14.4	.40	.1	1650

PITCHED DATA OF THIS WORK (PI1)
(DOWNWARD; DISPERSED PHASE ON TOP)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
1	998	679	0.94	0.39	50	6.4	19	19	14.8	0.9	.05	880
2	998	679	0.94	0.39	50	6.4	19	19	12.6	1.0	.05	960
3	998	679	0.94	0.39	50	6.4	19	19	15.9	1.0	.05	820
4	998	679	0.94	0.39	50	6.4	19	19	11.5	1.2	.05	1000
5	998	679	0.94	0.39	50	6.4	19	19	10.4	1.4	.05	930
6	998	679	0.94	0.39	50	6.4	19	19	9.3	1.1	.05	820
7	998	679	0.94	0.39	50	6.4	19	19	8.2	1.0	.05	700
8	998	679	0.94	0.39	50	7.7	19	19	11.5	1.3	.2	730
9	998	679	0.94	0.39	50	7.7	19	19	10.4	1.5	.2	640
10	998	679	0.94	0.39	50	7.7	19	19	8.2	1.4	.2	510
11	998	679	0.94	0.39	50	7.7	19	19	7	1.3	.2	450
12	998	679	0.94	0.39	50	7.7	19	19	12.6	1.9	.2	820
13	998	679	0.94	0.39	50	7.7	19	19	13.7	1.9	.2	780
14	998	679	0.94	0.39	50	7.7	19	19	15.9	1.9	.2	740
15	998	679	0.94	0.39	50	7.7	19	21	17.2	1.0	.16	825
16	998	679	0.94	0.39	50	7.7	19	21	16.2	1.0	.16	860
17	998	679	0.94	0.39	50	7.7	19	21	14.2	0.9	.16	960
18	998	679	0.94	0.39	50	7.7	19	21	12.2	1.6	.16	710
19	998	679	0.94	0.39	50	7.7	19	21	10.2	1.8	.16	550
20	998	679	0.94	0.39	50	7.7	19	21	8.2	1.5	.16	480

PITCHED DATA OF THIS WORK (PI1)
(DOWNWARD; DISPERSED PHASE ON TOP)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
21	998	679	0.94	0.39	50	7.7	19	21	6.2	1.4	.16	390
22	998	679	0.94	0.39	50	10.2	24.7	24.7	6.4	0.9	.1	270
23	998	679	0.94	0.39	50	10.2	24.7	24.7	8.4	1.0	.1	310
24	998	679	0.94	0.39	50	10.2	24.7	24.7	10.4	1.2	.1	350
25	998	679	0.94	0.39	50	10.2	24.7	24.7	12.4	1.3	.1	405
26	998	679	0.94	0.39	50	10.2	24.7	24.7	14.4	0.9	.1	540
27	998	679	0.94	0.39	50	10.2	24.7	24.7	16.4	1.8	.1	560
28	998	679	0.94	0.39	50	10.2	24.7	24.7	17.4	1.8	.1	540
29	998	679	0.94	0.39	50	10.2	19	21	8.2	1.8	.16	225
30	998	679	0.94	0.39	50	10.2	19	21	10.2	1.9	.16	260
31	998	679	0.94	0.39	50	10.2	19	21	12.2	1.9	.16	310
32	998	679	0.94	0.39	50	10.2	19	21	14.2	1.8	.16	380
33	998	679	0.94	0.39	50	10.2	19	21	17.2	1.8	.16	500
34	998	815	0.94	0.60	9.8	7.7	24.7	24	7.5	0.7	.17	510
35	998	815	0.94	0.60	9.8	7.7	24.7	24	9.5	0.8	.17	640
36	998	815	0.94	0.60	9.8	7.7	24.7	24	11.5	0.9	.17	730
37	998	815	0.94	0.60	9.8	7.7	24.7	24	13.5	0.9	.17	870
38	998	815	0.94	0.60	9.8	7.7	24.7	24	15.5	1.0	.17	770
39	998	815	0.94	0.60	9.8	7.7	24.7	24	17.5	1.1	.17	710
40	998	815	0.94	0.60	9.8	7.7	24.7	24	19.5	1.1	.17	640

PITCHED DATA OF THIS WORK (PI1)
(DOWNWARD; DISPERSED PHASE ON TOP)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
41	998	815	0.94	0.60	9.8	7.7	24.7	24	21.5	1.2	.17	600
42	998	815	0.94	0.60	9.8	6.4	24.7	24	7.5	0.9	.17	760
43	998	815	0.94	0.60	9.8	6.4	24.7	24	9.5	1.1	.17	900
44	998	815	0.94	0.60	9.8	6.4	24.7	24	11.5	1.0	.17	1010
45	998	815	0.94	0.60	9.8	6.4	24.7	24	13.5	1.1	.17	1100
46	998	815	0.94	0.60	9.8	6.4	28.6	25	8	1.1	.13	750
47	998	815	0.94	0.60	9.8	6.4	28.6	25	10	1.2	.13	1050
48	998	815	0.94	0.60	9.8	6.4	28.6	25	12	1.2	.13	1080
49	998	815	0.94	0.60	9.8	6.4	28.6	25	14	1.3	.13	1000
50	998	815	0.94	0.60	9.8	6.4	28.6	25	16	1.3	.13	950
51	998	815	0.94	0.60	9.8	6.4	28.6	25	18	1.3	.13	900
52	998	815	0.94	0.60	9.8	7.7	28.6	25	8	1.0	.13	490
53	998	815	0.94	0.60	9.8	7.7	28.6	25	10	1.1	.13	590
54	998	815	0.94	0.60	9.8	7.7	28.6	25	12	1.2	.13	720
55	998	815	0.94	0.60	9.8	7.7	28.6	25	14	1.3	.13	770
56	998	815	0.94	0.60	9.8	7.7	28.6	25	16	1.3	.13	720
57	998	815	0.94	0.60	9.8	7.7	28.6	25	18	1.4	.13	660
58	998	815	0.94	0.60	9.8	10.2	28.6	29	12	1.0	.26	430
59	998	815	0.94	0.60	9.8	10.2	28.6	29	14	1.0	.26	520
60	998	815	0.94	0.60	9.8	10.2	28.6	29	16	1.1	.26	600

PITCHED DATA OF THIS WORK (PI1)
(DOWNWARD; DISPERSED PHASE ON TOP)

NO	PC (kg/m^3)	PD (kg/m^3)	NC (mPa.s)	ND (mPa.s)	a (mN/m)	D (cm)	T (cm)	H (cm)	C (cm)	NP /	XV /	N (rpm)
61	998	815	0.94	0.60	9.8	10.2	28.6	29	18	1.1	.26	660
62	998	815	0.94	0.60	9.8	10.2	28.6	29	20	1.1	.26	620
63	998	815	0.94	0.60	9.8	10.2	28.6	29	22	1.2	.26	570
64	998	679	0.94	0.39	50	6.4	19	19	12.6	1.3	.1	830
65	998	679	0.94	0.39	50	7.7	24.7	24.7	17	1.3	.1	690
66	998	679	0.94	0.39	50	10.2	28.6	28.6	18.4	1.5	.1	600
67	998	679	0.94	0.39	50	7.7	19	19	14.4	1.6	.1	530
68	998	679	0.94	0.39	50	7.7	24.7	24.7	14.4	1.3	.1	690
69	998	679	0.94	0.39	50	7.7	28.6	28.6	14.4	1.1	.1	790
70	998	679	0.94	0.39	50	7.7	34.5	34.5	14.4	0.9	.1	900
71	998	679	0.94	0.39	50	7.7	24.7	15.3	12	1.6	.1	480
72	998	679	0.94	0.39	50	7.7	24.7	19.5	12	1.4	.1	540
73	998	679	0.94	0.39	50	7.7	24.7	24.7	12	1.3	.1	600
74	998	679	0.94	0.39	50	7.7	24.7	32.2	12	1.1	.1	640

PROPELLER DATA OF THIS WORK (PR1)
(DOWNWARD; DISPERSED PHASE ON TOP)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
1	998	679	0.94	0.39	50	7.7	19	19	7	.27	.2	990
2	998	679	0.94	0.39	50	7.7	19	19	9.2	.28	.2	1070
3	998	679	0.94	0.39	50	7.7	19	19	12.2	.31	.2	1150
4	998	679	0.94	0.39	50	6.4	24.7	24.7	6.7	.40	.1	1330
5	998	679	0.94	0.39	50	6.4	24.7	24.7	8.2	.41	.1	1430
6	998	679	0.94	0.39	50	6.4	24.7	24.7	9.7	.42	.1	1550
7	998	679	0.94	0.39	50	6.4	24.7	24.7	12.7	.27	.1	1600
8	998	679	0.94	0.39	50	6.4	24.7	24.7	15.7	.26	.1	1450
9	998	679	0.94	0.39	50	6.4	24.7	24.7	18.4	.25	.1	1310
10	998	679	0.94	0.39	50	6.4	24.7	24.7	14.2	.27	.1	1520
11	998	679	0.94	0.39	50	7.7	24.7	24.7	18.4	.34	.1	980
12	998	679	0.94	0.39	50	7.7	24.7	24.7	16.4	.33	.1	1000
13	998	679	0.94	0.39	50	7.7	24.7	24.7	14.4	.33	.1	1200
14	998	679	0.94	0.39	50	7.7	24.7	24.7	12.4	.35	.1	1180
15	998	679	0.94	0.39	50	7.7	24.7	24.7	10.4	.33	.1	1140
16	998	679	0.94	0.39	50	7.7	24.7	24.7	8.4	.30	.1	1080
17	998	679	0.94	0.39	50	7.7	24.7	24.7	6.4	.32	.1	970
18	998	679	0.94	0.39	50	7.7	24.7	30.6	12.3	.22	.07	1450
19	998	679	0.94	0.39	50	7.7	24.7	30.6	14.3	.20	.07	1460
20	998	679	0.94	0.39	50	7.7	24.7	30.6	9.3	.33	.07	1100

PROPELLER DATA OF THIS WORK (PR1)
(DOWNWARD; DISPERSED PHASE ON TOP)

NO	PC	PD	NC	ND	a	D	T	H	C	NP	XV	N
	(kg/m^3)	(kg/m^3)	(mPa.s)	(mPa.s)	(mN/m)	(cm)	(cm)	(cm)	(cm)	/	/	(rpm)
21	998	679	0.94	0.39	50	7.7	24.7	30.6	16.3	.26	.07	1460
22	998	815	0.94	0.60	9.8	7.7	24.7	24	7.5	.25	.17	900
23	998	815	0.94	0.60	9.8	7.7	24.7	24	9.5	.26	.17	980
24	998	815	0.94	0.60	9.8	7.7	24.7	24	11.5	.26	.17	1060
25	998	815	0.94	0.60	9.8	7.7	24.7	24	13.5	.23	.17	1100
26	998	815	0.94	0.60	9.8	7.7	24.7	24	15.5	.21	.17	1070
27	998	815	0.94	0.60	9.8	7.7	24.7	24	17.5	.20	.17	980
28	998	815	0.94	0.60	9.8	7.7	24.7	24	19.5	.19	.17	940
29	998	815	0.94	0.60	9.8	6.4	24.7	24	7.5	.24	.17	1280
30	998	815	0.94	0.60	9.8	6.4	24.7	24	9.5	.24	.17	1410
31	998	815	0.94	0.60	9.8	6.4	24.7	24	11.5	.24	.17	1360
32	998	815	0.94	0.60	9.8	6.4	24.7	24	13.5	.25	.17	1270
33	998	815	0.94	0.60	9.8	6.4	24.7	24	15.5	.25	.17	1200
34	998	815	0.94	0.60	9.8	6.4	28.6	25	8	.33	.13	1180
35	998	815	0.94	0.60	9.8	6.4	28.6	25	10	.34	.13	1320
36	998	815	0.94	0.60	9.8	6.4	28.6	25	12	.28	.13	1470
37	998	815	0.94	0.60	9.8	6.4	28.6	25	14	.25	.13	1400
38	998	815	0.94	0.60	9.8	6.4	28.6	25	16	.23	.13	1330
39	998	815	0.94	0.60	9.8	6.4	28.6	25	18	.26	.13	1240
40	998	815	0.94	0.60	9.8	7.7	28.6	25	8	.40	.13	840

PROPELLER DATA OF THIS WORK (PR1)
(DOWNWARD; DISPERSED PHASE ON TOP)

NO	PC (kg/m^3)	PD (kg/m^3)	NC (mPa.s)	ND (mPa.s)	a (mN/m)	D (cm)	T (cm)	H (cm)	C (cm)	NP /	XV /	N (rpm)
41	998	815	0.94	0.60	9.8	7.7	28.6	25	10	.41	.13	890
42	998	815	0.94	0.60	9.8	7.7	28.6	25	12	.42	.13	990
43	998	815	0.94	0.60	9.8	7.7	28.6	25	14	.43	.13	930
44	998	815	0.94	0.60	9.8	7.7	28.6	25	16	.44	.13	890
45	998	815	0.94	0.60	9.8	7.7	28.6	25	18	.45	.13	840
46	998	815	0.94	0.60	9.8	7.7	28.6	29	12	.48	.26	1100
47	998	815	0.94	0.60	9.8	7.7	28.6	29	14	.46	.26	1170
48	998	815	0.94	0.60	9.8	7.7	28.6	29	16	.45	.26	1240
49	998	815	0.94	0.60	9.8	7.7	28.6	29	18	.40	.26	1190
50	998	815	0.94	0.60	9.8	7.7	28.6	29	20	.38	.26	1120
51	998	815	0.94	0.60	9.8	7.7	28.6	29	22	.36	.26	1060
52	998	679	0.94	0.39	50	6.4	19	19	12.6	.35	.1	1310
53	998	679	0.94	0.39	50	7.7	24.7	24.7	17	.37	.1	1100
54	998	679	0.94	0.39	50	7.7	19	19	14.4	.45	.1	890
55	998	679	0.94	0.39	50	7.7	24.7	24.7	14.4	.35	.1	1100
56	998	679	0.94	0.39	50	7.7	28.6	28.6	14.4	.31	.1	1210
57	998	679	0.94	0.39	50	7.7	34.5	34.5	14.4	.28	.1	1460
58	998	679	0.94	0.39	50	7.7	24.7	15.3	12	.45	.1	790
59	998	679	0.94	0.39	50	7.7	24.7	19.5	12	.41	.1	880
60	998	679	0.94	0.39	50	7.7	24.7	24.7	12	.35	.1	980
61	998	679	0.94	0.39	50	7.7	24.7	32.2	12	.30	.1	1050

NOMENCLATURE

A,B	constant
p	density, kg m^{-3}
σ ,a	interfacial tension, N.m^{-1}
n	viscosity, Pa.s
v	velocity in the vicinity of the drops, m s^{-1}
d	particle diameter, m
τ	drop inertial force
P/V	power per unit volume, w m^{-3}
X_V	volumetric hold-up
Δ p	density difference, kg m^{-3}
g	acceleration due to gravity m s^{-2}
N	impeller speed, s^{-1}
T	tank diameter, m
H	liquid height, m
D	impeller diameter, m
C	clearance distance, m

Subscripts:

c	continuous
d	dispersed
m	mean
min	minmum

Dimensionless groups:

Power number $$Np=\frac{P}{p_c\ N^3\ D^5}$$

Archimedes number $$Ar=\frac{g\ p_c\ \Delta p\ D^3}{n_c^2}$$

Reynolds number $$Re=\frac{p_c\ N\ D^2}{n_c}$$

Suratman number $$Su=\frac{p_c\ \sigma\ D}{n_c^2}$$

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