INVESTIGATION ON SOLID SUSPENSION AND HYDRODYNAMICS OF LIQUID FLUIDIZED BED AND STIRRED CONTACTOR

PROJECT REPORT

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Certificate

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CERTIFICATE

This is to certify that this Project Report entitled "INVESTIGATION ON SOLID SUSPENSION AND HYDRODYNAMICS OF LIQUID-FLUIDISED BED AND STIRRED CONTACTOR" submitted by RAJESH.S. & RAJEEV.R., final year B-Tech (Chemical Engineering) Students of TKM College of Engineering, Kollam, in partial fulfilment of the requirements for the award of Degree of Bachelor of Technology in Chemical Engineering, of the University of Kerala, is a bonafide record of the work carried out by them at the Regional Research Laboratory, Thiruvananthapuram, under my guidence.

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INVESTIGATION ON SOLID SUSPENSION AND HYDRODYNAMICS OF LIQUID FLUIDIZED BED AND STIRRED CONTACTOR

DEPARTMENT OF CHEMICAL ENGINEERING
T.K.M. COLLEGE OF ENGINEERING
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CONTENTS

CHAPTER ONE

INTRODUCTION

1.1 LIQUID FLUIDISATION

When a fluid phase and a solid phase are to be brought into contact for physical or chemical processing, fluidisation is often the preferred method of operation due to its many advantages over other configurations; good solid mixing leading to uniform temperature throughout the bed, high mass and heat transfer rates easy solids handling, etc.

For a bed of solid particles to be in the fluidised state, the fluid particle-interaction force must balance the weight of the solid, so that each particle is completely supported by the fluid; this is obtained for fluid velocities greater than a certain value; the min fluidisation velocity, U_{mf}. For velocities smaller than U_{mf} the bed is in fixed state condition; for velocities greater than U_{mf} the bed is fluidised and its behaviour generally ranges between two extremes: either it expands homogeneously as the fluid velocity is increased, or the fluid in excess U_{mf} bypasses the bed as bubbles.

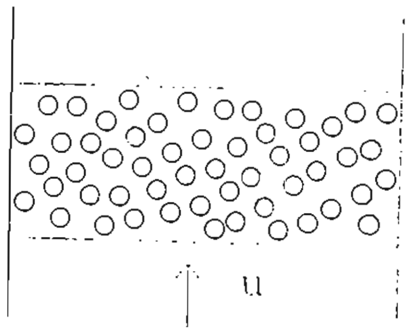


Fig. 1. Schematic representation of a monosize solid fluidised suspension

Although fluidisation can be achieved by utilising either a gas or a liquid as the fluidising medium, gas beds have received by far the greater attention from the scientific community. Actual and potential industrial applications of gas fluidised beds are vastly more numerous than those of liquid beds.

Recently, however, new process are being studied involving the utilisation of liquid fluidised units in the fields of hydrometullargy, food technology, biochemical processing, water treatment, etc. which together with the rapidly increasing industrial applications of gas-solid fluidised system, should attract more interest.

Until now, liquid-solid systems have been regarded by the majority of fluidisation researchers as of purely academic interest. Unlike gas beds, liquid beds expand homogeneously rather than giving rise to bubbling behaviour. It is this aspect, however which could be exploited by the gas fluidisation researcher; in liquid beds homogeneous behaviour facilitates understanding the basis of fluidisation whereas the phenomena in gas beds are dominated in a chaotic manner by the presence of bubbles; hydrodynamic modelling of gas-solid two phase flow would certainly greatly benefit from basic input from liquid-solid system studies.

In our project, attention will be focussed on the solid suspension aspects of liquid fluidisation rather than to problems related to mass and heat transfer.

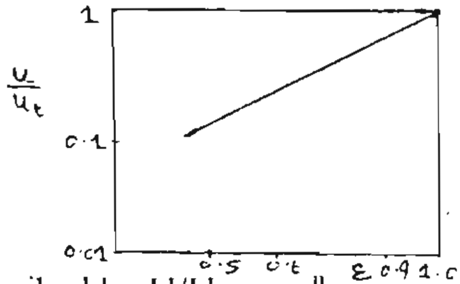
1.1.a Theoretical aspects of liquid fluidised beds

Bed expansion behaviour of Liquid-fluidized beds

Liquid beds expand in a more homogeneous manner than gas beds. .The bed expansion data are generally reported and compared with numerical relationships in terms of bed voidage as a function of fluid superfacial velocity. Broadly speaking, four different types of liquid fluidised bed expansion behaviour have been reported in literature, with gradual transitions from one to another occuring as the physical conditions are changed.

Case I

The first type can be considered as a typical liquid bed. Bed expansion appears from visual observation smooth and homogeneous over the whole voidage range. The plot of the logarithm of bed voidage against the logarithm of fluid superfacial velocity in linear and the extrapolation of the experimental points to $\varepsilon = 1$ coincides, within the limit of experimental error, with the predicted value of single particle terminal settling velocity determined from a standard correlation. The following figure summarises this case.



It may be described by $U/U_t = \varepsilon^n$.

This relationship is known as ***Richardson - Zaki equation.*** Richardson and Zaki were the first to report extensive experimental determination of the value of *n* for flow regimes ranging from creeping flow to fully inertial. They showed that n is a function only of the terminal particle Reynolds number and from their bed expansion data they recommended the following correlation

$$n = 4.65 \qquad Re_t < 0.2$$

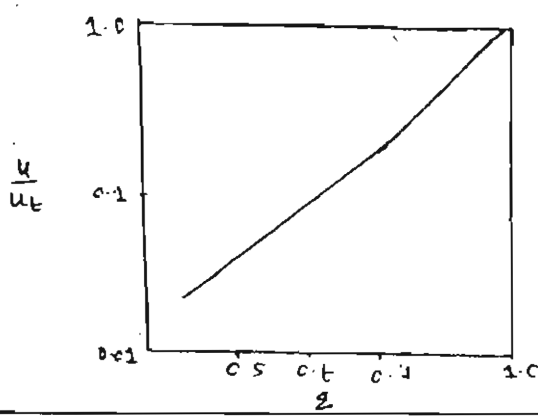
$$n = 4.4\ Re_t^{-0.03} \qquad 0.2 < Re_t < 1$$

$$n = 4.4\ Re_t^{-0.1} \qquad 1 < Re_t < 500$$

$$n = 2.4 \qquad 500 < Re_t$$

Case II

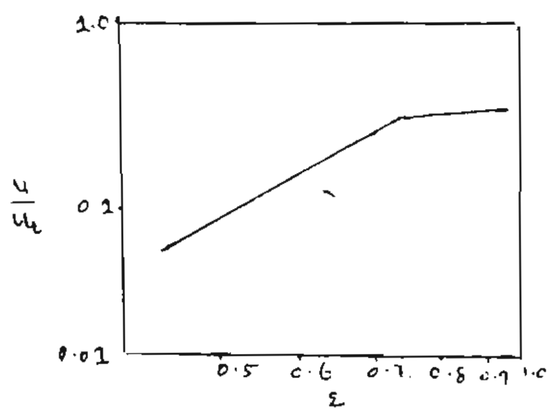
This type of expansion characteristic is depicted in the figure.



For this case it is possible to divide the experimental observations into two regions. The first for lower voidages, a straight line with extrapolation to voidage equal to 1 well below the predicted value of single particle terminal settling velocity; in the second region the slope increases with increasing void fraction, approaching this time, the correct value for U_t. The change of slope in expansion law is generally accompanied by a change in fluidisation quality which can be detected visually; from hands of high voidage travelling through the bed at low expansions, to a more homogeneous distribution of the solid at elevated bed expansions.

Case III

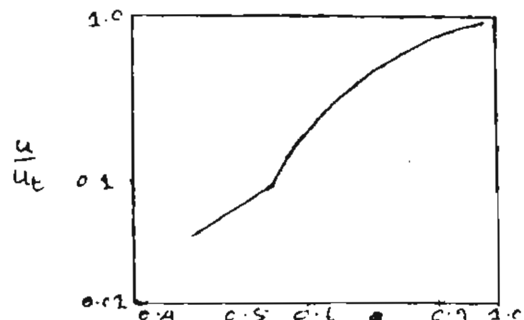
For this case the bed expansion characteristics do not differ substantially from the two previous cases for low fluid superfacial velocities: a straight line fits the experimental points well when logarithmic scales are used. The differeance arises at high bed expansions where a change in the slope of the fitting curve, this time decreasing as the voidage increases as shows in figure.



Here the initial regions of bed expansion characteristic can be well represented by Richardson-Zaki equation.

Case IV

The last type of expansion behaviour is depicted in the figure.



The lower part of the curve is represented by a straight line, followed by a sharp change of direction, the rest of the curve being concave, approaching the calculated value of unhindered settling velocity for voidages close to 1. Of all the cases discussed, it is this one for which the relation between bed expansion and fluidisation quality is strongest. The point of change of curvature corresponds to the appearance of liquid bubbles in the bed.

General Remarks

The division of the expansion characteristics into the four above groups represents an attempt to rationalize the various forms of bed expansion behaviour presented in literature. The most obvious question at this stage is the possibility of predicting, for a given liquid fluidised bed, the type of bed expansion that occur. Broadly speaking, when water is fluidising medium high-density solids (such as copper or lead) belong to Case IV,large diameter solid particles (1 mm or more) of moderate density behave as type II, the distinction between type I and type III is least, clear, although small particle size (below 0.1 mm) and a solid density close to that of water (say 1100 Kgm^{-3}) appears to favour group III behaviour.

1.2 STIRRED CONTACTORS

Many processing operations depend for their success on the effective agitation. Agitation refers to the induced motion of a material in a specified way, usually in a circulatory pattern inside some sort of container. We deals with the agitation of liquids and liquid - solid suspensions.

PURPOSE OF STIRRING

Liquids are stirred for a number of purposes, depending on the objectives of the processing step. These purpose include.

1. Suspending solid particle.
2. Blending mescible liquids, eg. CH_3OH and H_2O.
3. Dispersing a gas through the liquid in the form of small bubbles.
4. Promoting heat transfer b/w the liquid and a coil or jacket.

STIRRED CONTACTOR

Liquids are most commonly stirred in some kind of tank or vessel, usually cylinderical in form and with a vertical axis. The top of the vessel may be open to air or closed. The tank bottom is rounded, not flat to eliminate sharpcorners or regions into which fluid currents would not penetrate. The liquid depth is aproximately equal to dia of the tank. An impeller is mounted on an overhung shaft, i.e. a shaft supported from above. The impeller creates a flow pattern in system, causing the liquid to circulate through the vessel and return eventually to the impeller.

Impellers :-

Impeller agitators are divided into two classes : those that generate currents parallel with the axis of the impeller shaft and those that generate currents in a tangential or radial direction. The first are called axiel - flow impellers, the second radial - flow impeller.

The three main types of impellers are propellers, paddles and turbines.

Propellers :-

A propeller is an axial - flow, high speed impeller for liquids of low viscosity. The flow currents leaving the impeller continue through the liquid in a given direction until deflected by the floor or wall of the vessel. Because of the persistance of the flow currents, propeller agitator are effectively in very large vessels.

A revolving propeller traces out a helix in the fluid, and if there were no slip between liquid and propeller, one full revolution would move theliquid longitudinally a fixed distance depending on the angle of inclination of the propeller blades. The ratio of this distance to propeller dia is known as the pitch of the propeller. A propeller with a pitch of 1.0 is said to have square pitch.

Paddles :-

For the simpler problems an effective agitator consists of a flat paddle turning on a vertical shaft. Two - bladed and four - bladed paddles are common. Sometimes the blades are pitched; more often they are vertical. Paddles turn at slow to moderate speeds in the centre of a vessel; they push the liquid radially and tangentially with almost no vertical motion at the impeller unless the blades are pitched. In deep tanks several paddles are mounted one above the other on the same shaft.

The total length of the paddle impeller is typically 50 to 80% of the inside dia of the vessel. The width of the ;balde is one - sixth to one - tenth its length.

TURBINES :-

They resemble multibladed paddle agitators with short blades, turning at high speeds on a shaft mounted centrally in the vessel. The blades maybe straight or curved, pitched or vertical. The dia of the impeller is ;smaller than with paddles, ranging from 30 to 50 percent of the diameter of the vessel.

1.2.a THEORATICAL ASPECTS OF STIRRED CONTACTORS

The type of flow in an agitated vessel depends on the type of impeller; the characteristic of the fluid; and the size and proportions of the tank, baffles and agitator. The velocityof the fluid at any point in the tank has three components, and the overall flow pattern in the tank depends on the variations in these three velocity components from point to point. The first velocity component is radial and acts in a direction perpendicular to the shaft of the impeller. The second component is longitudinal and acts in a direction parallel with the shaft. The third component is tangential, or rotational and acts in a direction tangent to a circular path around the shaft. In the usual case of a vertical shaft. the radial and tangential components are in a horizontal plane, and the longitudinal component is vertical. The radial and longitudinal components are useful and provide the flow necessary for the mixing action. When the shaft is vertical and centrally located in the tank. the tangential component is generally disadvantageous. The tangential flow follow a circular path around the shaft and creates a vortex in the liquid . For a flat - bladed turbine. Exactly the same flow pattern would be observed with a pitched blade turbine or a propeller.

The swirling perpetuates stratification at the various levels without accomplishing longitudinal flow between levels. If solid particles are present, circulatory currents tend to throw the particles to the outside bycentrifugal force, from where they move downward and to the center of the tank at the bottom.

Instead of mixing, its reverse, concentration, occurs. Since. in circulatory flow, the liquid flows with the direction of motion of the impeller blades, the relative velocity between the blades and the liquid is reduced, and the power that can be absorbed by the liquid is limited. In an unbaffled vessel circulatory flow is induced by all types of impellers. whether axial flow or radial flow. At high impeller speeds the vortex may be so deep that it reaches the impeller, and the gas from above the liquid is drawn down into the charge. This is undesirable.

Prevention of Swirling

Circulatory flow and swirling can be prevented by any of three methods. In small tanks, the impeller can be mounted off center. The shaft is moved away from the center line of the tank, then titled in a plane perpendicular to the direction of the move. In larger tanks, the agitator may be mounted in the side of the tank, with the shaft in a horizontal plane, but at an angle with a radius.

In large tanks with vertical agitators, the preferable method of reducing swirling is to install baffles; for turbines, the width of the; baffle need be no more than one - twelth of the vessel diameter; for propellers, no more than one - eighteenth the tank diameter is needed.

FLOW NUMBER

The flow number N_Q is defined as

$$N_Q = \frac{Q}{N D_a^3}$$

D_a - impeller dia

Q - Volumetric flow rate

N - rps.

This gives the discharge flow from the tips of the impeller and not the total flow produced.

POWER NUMBER :

An important consideration in the design of an agitated vessel is the power required todrive the impeller, is given by

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

P --> Power

The power number $N_p$is analogous toa friction factor or a degree co-efficient. It is proportional to the ratio of the drag force acting on a unit area of the impeller and the inertial stress, ie the flow of momentum associated with the bulk motion of the fluid.

SUSPENSION OF SOLID PARTICLES IN STIRRED CONTACTORS

Particles and solids are suspended in liquids for many purposes, perhaps to produce a homogeneous mixture for feeding to a processing unit, to dissolve the solids, to catalyse a chemical reaction, or to promote growth of a crystalline product from a supersaturated solution. Suspension of solids in an agitated vessel is somewhat like fluidisation of solids with liquids. The fluid flow pattern created by the agitator has the regions of horizontal flow as well as upward and downward flow, and to keep the solids in suspension in a tank generally requires much higher average fluid velocities than would be needed to fluidise the solids in a vertical column.

The degree of suspension are given below in the order of increasing uniformity of suspension and increasing power input.

Nearly complete suspension with filleting :-

Most of the solid is suspended in the liquid, with a few percent in stationary fillets of solid at the outside periphery of the bottom or other places in tank.

Complete particle motion :-

All the particles are either suspended or are moving along the tank bottom.

Complete suspension :-

All the particles are suspended off the tank bottom or do not stay on the bottom more than 1 or 2 sec. When this condition is reached, there will be generally excess gradients in the suspension and there may be a region of clear liquid near the top of the tank.

Uniform suspension :-

At stirrer speeds considerably above those needed for complete suspension, there is no longer any clear liquid near the top of the tank, and the suspension appears uniform. However there may be vertical concentration gradients.

CHAPTER TWO

STATEMENT OF PROJECT

STATEMENT OF THE PROJECT

Solid suspension in a stirred reactor is a very important parameter for design, scale up etc. Conventionally solid suspension has been defined as the agitator rpm at which no solids remain at the bottom of the vessel for more than 1 or 2 seconds. A number of correlations have been developed to predict the solid suspension rpm as a function of solid characteristics, liquid characteristics and stirred contactor design factors however, in actual practice, these correlations are difficult to experimentally verify. In this project a new approach is suggested based on the analogy in the hydrodynamics of liquid fluidised bed and stirred contactors in terms of change in voidage due to increased flow.

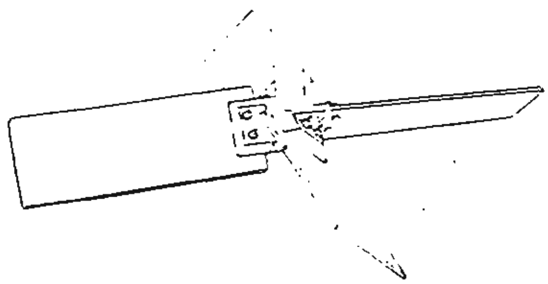
Experiments have been conducted with same solids employing a liquid fluidised bed and stirred contactor of the same diameter. Increase in voidage due to increased flow rate as well as stirrer rpm have been measured. New relationship between solid suspension rpm and the maxima and minima of flow number and power number are verified.

The energy consumption pattern under similar condition between liquid-solid fluidised bed and stirred contactors will also be measured.

Also we are trying to develop a predictive relationship between voidage in the stirred reactor and the solid suspension rpm. We are also finding the power consumption of stirred contactor with different impellers and with different clearances from the bottom of the vessel.

CHAPTER THREE

EXPERIMENTAL



Pitched-blade turbine

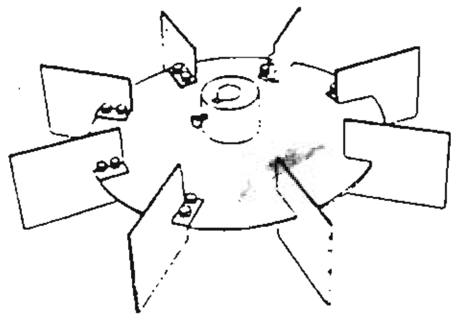


Fig. 10-5 Flat-blade turbine

3.1 ***RAW MATERIALS*** :-

The raw materials used in the experiments was ilmenite and sand. Using the sieves of size 105, 150, 180, 210, 355 μ, ilmenite and sand were sieved to the required weight. The weight of ilmenite required is 7.3 kg. and the weight of sand required is 4.4 kg. The size range of the ilmenite used are 105-150 μ, 150 - 180 μ, 210 - 355 and that of the sand are 300-355 μ

The density of ilmenite is 4.2 g/cm^3 and that of the sand is 2.5 g/cm^3.

3.2 ***DESCRIPTION OF THE EXPERIMENTAL SET UP***

3.2.a **FLUIDISED BED**

The experimental set up consist of 25cm diameter and 1.2 m long column. A distributor is kept at the bottom of the column and a fine stainless steel mesh of 0.2mm opening is placed above it to support the solids. The height of the solid bed is fixed to 5 cm from the support. Water is admitted through the bottom using 1 HP centrifugal pump. The pressure drops are found by means of manometer connections provided in the column. Water is admitted from a storage tank into the column and is continuously recycled. The column was transparent to note the bed expansion behaviour. Four manometers are provided in the column. A single limb Hg manometer is used below the distributor. The other three manometers provided in the column are also single limb but water itself is used as the manometric liquid in them.

3.2 b **Experimental set up of stirred system**

The schematic diagram of the experimental set up is shown in figure 2.

(i) ***Tank*** :-

The system consist of a tank, cylindrical in form with a vertical axis. The tank is transparent to light so that the suspension of solids inside is easily visible. The tank bottom is rounded, not flat, to eliminate sharp corners or regions into which fluid currents would not penetrate. The liquid depth is equal to the tank dia. The dia of the tank used is 25 cm and height is 75 cm.

(ii) **Impeller** :-

An impeller is mounted on an overhung shaft. ie. a shaft supported from above. The impellers used are pitch type and turbine type. Diameter of pitch bladed turbine is 12.5 cm and that of turbine type is 10 cm. A DC motor drives the shaft, in which the impeller is mounted.

(iii) ***Rectifier*** :-

The AC power input is converted to DC by a rectifier. A voltmeter and ammeter is used to measure the voltage and current and thus power input can be calculated.

(iv) ***Baffles*** :-

To reduce the swirling, baffles are installed, which impede rotational flow without interfering with radial or longitudinal flow. Effective baffling is attained by installing vertical strips perpendicular to the wall of the tank. Four such baffles are used.

A tachometer is used to find the rpm of the impeller.

3.3 METHODOLOGY

3.3.a *FLUIDIZED BED*

Measured quantity of ilmenite ie. 7.3 kg was taken in the fluidization column. The initial bed height was noted. The centrifugal pump was started after closing the inlet valve. Water was slowly admitted into the fluidization column by opening the inlet valve progressively. The pressure drop in the column, ie. total pressure drop and Pressure drop across the bed, and the bed height was noted corresponding to different water flow rate. The flow rate was also noted. The flow rate was gradually increased till the bed experience expansion, min fluidisation and complete expansion. The readings were tabulated. The experiment was repeated for three different particle size ranges. The result was tabulated in table 1 - 3.

The same experiment was repeated in fluidized bed for a different density particle. ie. sand particle of size 300-355 μm was also used. The weight of the sand for 5 cm height was calculated to be 4.4 kg. The results are tabulated in table 1.

3.3.b ***STIRRED CONTACTOR***

The clearance between impeller and bottom of tank is fixed as 0.1 T. For the first set of experiments, a turbine type impeller was used. Weighed quantity of ilmenite ie. 7.3 kg. height exactly equal to that used in fluidized bed was taken in stirred tank. The height of liquid column is equal to the diameter of the tank.

The initial bed height is noted. The DC motor was started. The rpm of the impeller was noted using a tachometer. Corresponding bed height, voltmeter reading, and ammeter reading were noted. Then the rpm of the impeller was slowly increased and the bed height current and voltage were noted for different rpm of the impeller. Results are shown in Table 5.

The same experiment was repeated for 0.2T, and 0.3T clearances. This experiment was done for three different size of ilmenite ie. 105 - 150 μ, 150 - 180 μ and 210 - 355 μ, and for different density particle ie. sand of size range (310 - 355 μ). The weight of the sand used was 4.5 kg for the same bed height as in ilmenite. The results are tabulated in table (6 - 12).

The same experiment is repeated with pitch blade turbine of 12.5 cm dia for the same clearances ie. 0.1T, 0.2T, 0.3T, and the same particle size range of ilmenite and sand. The results are tabulated in table 13-21.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

(1) Hydrodynamics of liquid fluidised beds

Figures (3) to (6) depict the voidage Vs superficial velocity relationship for both ilmenite and sand particles of various sizes. The relationship follows the classical *Richardson - Zaki* equation given by $U/U_t = \varepsilon^n$. The slopes and intercepts of various sizes of particles are given in Table 26. ε is calculated using the equation,

$$\frac{\text{Volume of liquid}}{\text{Total volume}} = \frac{h - h_0}{h}$$

h_0 = height occupied by solids if voidage is zero

$$= \frac{\text{mass of solid}}{\text{c/s area of column} \times \text{density of solid}}$$

h = height of bed for a particular flow rate

We can see from figure (3) to (6) that, irrespective of size and density, there is a change in the slope of the curve around a voidage of 0.6. This may be due to wall effects or change in the fluidisation quality .

(2) Solid suspension in stirred contactors

Figures 18 to 23 show the relationship between solid suspension in terms of voidage with Reynolds number of the impeller for various sizes of particles. Unlike in fluidised bed, the variation of voidage with flow rate is linear for low to moderate flow rates in stirred contactors.

The above data were reanalysed in terms of power number N_p, flow number N_Q by plotting against Reynolds number as depicted in figures 7 to 17 for the same voidage. The flow number was calculated by taking the flow rate for the same voidage from the fluidised bed of the same diameter and using same size and amount of particles.

(a) Flow number is calculated using the equation

$$N_Q = \frac{Q}{ND^3}$$

Q = Liquid flow rate, m^3/sec
N = Impeller speed, sec^{-1}
D = Diameter of impeller, m

(b) Power number is calculated using the equation

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

P = Power, w
N = Impeller speed, sec^{-1}
D = Diameter of impeller, m
ρ = Density of slurry, kg/m^3

(c) Reynolds number is calculated using the equation

$$N_{Re} = \frac{ND^2\rho}{\mu}$$

μ = viscosity of liquid, kg/msec

It is clearly seen that the minimum in the power number N_p and maximum in the flow number N_Q corresponds to the solid suspension rpm.

(3) Comparison of Power Consumption of stirred contactor with turbine type impeller for different clearances.

The power consumption is compared for the same voidage. From table 22, we can see that the clearance 0.2T is most efficient.

(4) __Comparison of Power comparison of stirred contactor with pitched blade turbine for different clearances.__

The power consumption is compared for the same voidage. From Table 23 we can see that at a clearance of 0.2T the power consumption is minimum.

(5) *__Comparison of Power consumption of stirred contactor with pitched blade and turbine type impeller for a clearance of 0.2T__*

The power consumption of stirred contactor with pitched blade and turbine type impeller for a clearance of 0.2T is shown in table 24. The power consumption is compared for the same voidage. We can see that a stirred contactor with pitched blade turbine at a clearance of 0.2T consumes minimum power. This may be due to the more radial flow created by the turbine type impeller which is not needed for solid suspension.

(6) __Comparison of Power consumption of stirred contactor with fluidised bed.__

Here also power consumption is compared for the same voidage. The fluidised bed is compared with stirred contactor with pitched blade turbine at a clearance of 0.2T. We can see from Table 25 that liquid fluidised bed is more efficient for solid suspension than a stirred contactor. In stirred contactor the impeller creates radial flow in addition to the axial flow. The axial flow is needed for solid suspension. Hence in stirred contactors, energy is wasted for creating the radial flow. In fluidised bed, there is considerable pressure drop in the distributor. Hence a fluidised bed with an efficient distributor is most suitable for solid suspension.

CHAPTER FIVE

CONCLUSION

CONCLUSION :

This investigation on solid suspension and hydrodynamics of liquid fluidised bed and stirred contactor brings out the following conclusions:

(1) Solid suspension rpm could be predicted by the maxima and minima of N_Q Vs N_{Re} plot and N_p Vs N_{Re} plot.
(2) A stirred contactor with pitched blade turbine at a clearance of 0.2T consumes minimum power for solid suspension.
(3) A fluidised bed with an efficient liquid distributor is most suitable for solid suspension.
(4) The expansion behaviour of liquid fluidised bed is not homogeneous over the entire voidage range.

BIBLIOGRAPHY

1) FLUIDIZATION

J. F. DAVIDSON
R. CLIFF
D. HARRISON

2) UNIT OPERATIONS OF CHEMICAL ENGINEERING

WARREN. C. Mc CABE
JULIAN. C. SMITH
PETER HARRIOTT.

3) REVIEW ARTICLE NUMBER - 47

CHEMICAL ENGINEERING SCIENCE, VOL.50, 1995

RENZO. DI. FELICE.

4) PERRY'S CHEMICAL ENGINEER'S HAND BOOK

ROBERT H. PERRY
DON GREEN.

5) MIXING FOR PROCESS INDUSTRIES
Mc DONOUGH.

6) MIXING PRINCIPLES AND APPLICATIONS.

NAGATA.

NOMENCLATURE

D	=	Impeller diameter, m
H	=	Height of liquid, m
N	=	Impeller speed, sec^{-1}
n	=	Slope
N_{Re}	=	Reynolds number, (-)
N_p	=	Power number, (-)
N_Q	=	Flow number, (-)
P	=	Power, w
T	=	Vessel diameter, m
U	=	Superificial velocity, ms^{-1}
U_t	=	Terminal settling velocity, ms^{-1}

Greek Symbols

μ	=	dynamic viscosity, PaS
ρ	=	density of liquid, kgm^{-3}
ε	=	voidage

TABLES AND FIGURES

TABLE - 1

Material - ILMENITE

Particle size = 105 - 150 μ

Initial height of the bed = 5.5 cm

U (cm/sec)	ΔP bed (N/m^2)	ΔP overall (N/m^2)	Height of bed (cm)	Voidage (ε)	ln u	ln ε	Power given to solids (watts)	Total Power supplied (watts)
0.04026	499.8	2069.7	6.0	0.4167	-3.2120	-0.8753	0.00996	0.0414
0.09058	607.6	2306.9	6.3	0.4440	-2.4015	-0.8110	0.02734	0.1038
0.21130	656.6	2934.1	7.0	0.5000	-1.5540	-0.6930	0.06894	0.3081
0.30190	666.4	3837.6	7.2	0.5138	-1.1976	-0.6659	0.09960	0.5756
0.46290	688.2	4607.9	7.5	0.5330	-0.7702	-0.6286	0.15820	1.0598
0.50320	735.0	5531.1	7.8	0.5512	-0.6867	-0.5966	0.18380	1.3827
0.60380	754.6	6977.6	8.5	0.5882	-0.5045	-0.5306	0.22640	2.0952
0.78505	802.6	10043.0	11.4	0.6929	-0.2420	-0.3668	0.31290	3.9168
0.96620	823.2	12155.9	12.5	0.7200	-0.0343	-0.3285	0.37040	5.4701

TABLE - 2

Material : ***ILMENITE***

Particle size = 150 - 180 μ

Height of bed = 5.5 cm

Superficial velocity U (cm/sec)	ΔP bed (N/m^2)	ΔP overall (N/m^2)	Height of bed (cm)	Voidage (ε)	ln u	ln ε	Power given to solids (watts)	Total energy (watts)
0.1710	362.6	2963.52	5.8	0.3960	-1.7660	-0.9263	0.0308	0.2519
0.3019	421.4	4019.96	6.1	0.4262	-1.1680	-0.8528	0.0632	0.6030
0.4026	529.2	4884.32	7.4	0.5270	-0.9098	-0.6405	0.1058	0.9770
0.6039	558.6	7653.80	7.6	0.5395	-0.5043	-0.6171	0.1680	2.2960
0.6642	578.2	9519.72	8.3	0.5783	-0.4091	-0.5476	0.1910	3.1410
0.7045	588.0	12851.72	9.1	0.6153	-0.3502	-0.4856	0.2060	4.4980
0.8353	597.8	14984.2	9.3	0.6236	-0.1799	-0.4722	0.2481	6.2180

TABLE - 3

Material : ***ILMENITE***

Particle size = 210 - 355 μ

Initial height of the bed = 5.5 cm

U (cm/sec)	ΔP bed (N/m^2)	ΔP overall (N/m^2)	Height of bed (cm)	Voidage (ε)	ln u	ln ε	Power to solid (watts)	Total Power (watts)
0.0744	666.4	2183.44	7.0	0.50000	-2.5980	-0.6931	0.025	0.081
0.1912	686.0	2563.68	7.2	0.51380	-1.6540	-0.6659	0.066	0.244
0.2516	754.6	3171.28	7.3	0.52050	-1.3790	-0.6521	0.094	0.397
0.3623	793.8	4370.80	8.2	0.55290	-1.0150	-0.5925	0.143	0.787
0.4428	823.2	5674.20	8.6	0.59300	-0.8148	-0.5275	0.181	1.248
0.5334	852.6	6863.92	9.0	0.61110	-0.6284	-0.4975	0.225	1.819
0.7045	872.2	9500.12	9.2	0.61956	-0.3502	-0.4787	0.305	3.325
0.8253	921.2	10823.12	9.4	0.62105	-0.1920	-0.4763	0.378	4.437
0.8454	950.6	11050.48	9.8	0.64280	-0.1674	-0.4418	0.399	4.641

TABLE - 4

Material : *SAND*

Particle size = 300 - 355 μ
Initial height of bed = 5.4 cm

U (cm/sec)	Δ P bed (N/m²)	ΔP overall (N/m²)	Height of bed (cm)	Voidage (ε)	ln u	ln ε	Energy to solid (watts)	Total energy consumed (watts)
0.11070	205.8	2326.52	6.1	0.4196	-2.2000	-0.8684	0.0120	0.128
0.15097	235.2	2716.56	6.3	0.4381	-1.8900	-0.8253	0.0180	0.204
0.30194	284.2	3220.28	6.6	0.4636	-1.1970	-0.7687	0.0430	0.483
0.48310	294.0	6379.80	6.7	0.4776	-0.7275	-0.7389	0.0710	1.531
0.55400	323.4	9025.80	6.8	0.4794	-0.5915	-0.7352	0.0890	2.482
0.74500	352.8	13537.7	7.2	0.5083	-0.2997	-0.6766	0.1310	5.009
0.92600	362.6	22171.5	7.5	0.5280	-0.0769	-0.6386	0.1670	10.199
1.00600	365.6	26283.6	8.3	0.5735	-0.0059	-0.5560	0.1823	13.142
1.34900	368.7	36116.9	9.6	0.6354	-0.2991	-0.4555	0.2970	24.199

TABLE - 5

TURBINE TYPE IMPELLER

Material : *ILMENITE*

Particle size = 105 - 150 μ
Initial height of bed = 6 cm

Impeller clearance
from bottom = 0.1T = 2.5 cm

RPM	Total Power input (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p(-)	N_{re}(-) x 10^{-4}	N_Q(-)
145	30.0	16.25	0.0	0.4167	4.0120	6.93	0.010
160	18.0	9.23	0.3	0.4440	1.7156	7.40	0.015
200	27.0	16.10	3.0	0.6110	1.9480	7.50	0.098
260	47.1	33.10	7.3	0.7370	2.2010	8.00	0.114
330	58.0	35.10	10.0	0.7820	1.2160	9.40	0.116
380	96.0	67.10	13.0	0.8160	1.6160	10.00	0.091
425	154.0	109.2	15.0	0.8330	2.1470	10.80	0.087
465	190.0	150.0	16.5	0.8440	2.1530	11.60	0.082
560	350.0	282.2	17.5	0.8510	2.3150	13.80	0.073

TABLE - 6

TURBINE TYPE IMPELLER

Material : *ILMENITE*

Particle Size = 105 - 150 μ
Impeller clearance = 0.2T = 5 cm
Initial height of the bed = 6 cm

RPM	Total Power (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p (-)	N_{Re} (-) x 10^{-4}	N_Q (-)
65	7.0	1.00	1.6	0.539	3.1790	2.70	0.227
115	8.0	1.10	2.1	0.568	0.6560	4.50	0.140
160	10.0	1.25	3.7	0.639	0.3060	5.70	0.144
210	20.0	9.20	4.5	0.667	1.0380	7.20	0.112
278	32.4	15.20	7.5	0.741	0.8740	8.50	0.107
305	52.4	33.40	9.7	0.777	1.4920	8.80	0.104
350	62.0	37.25	11.6	0.811	1.1497	9.50	0.102
405	92.4	60.10	15.5	0.837	1.2830	10.26	0.099
460	152.0	110.10	17.0	0.848	1.6730	11.40	0.093
511	209.1	161.90	17.5	0.851	1.7740	12.60	0.080

TABLE - 7

TURBINE TYPE IMPELLER

Material : ***ILMENITE***
Particle size = 105 - 150 μ

Initial height of bed = 6 cm
Impeller clearance = 0.3T = 7.5 cm

RPM	Total Power consumption (watts)	Power input to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p (-)	N_{Re} (-) x 10^{-4}	N_Q(-)
62	8.5	3.5	1.0	0.500	2.200	2.68	0.116
103	4.5	2.5	4.8	0.676	2.426	3.35	0.237
140	10.0	2.2	9.1	0.768	0.994	4.06	0.235
190	20.0	9.2	10.1	0.783	1.708	5.40	0.177
272	37.8	23.3	10.5	0.788	1.418	7.60	0.126
300	52.2	34.2	10.8	0.792	1.642	8.30	0.117
350	60.0	36.0	12.0	0.806	1.118	9.40	0.104
401	96.0	63.6	15.7	0.839	1.405	10.13	0.097
439	147.0	110.9	17.0	0.848	1.905	10.90	0.091
485	190.0	147.0	17.4	0.851	1.882	11.95	0.083

TABLE - 8

TURBINE TYPE IMPELLER

Material : *ILMENITE*

Particle Size = 150 - 180 μ
Initial height of bed = 6 cm
Impeller clearance = 0.1T = 2.5 cm

RPM	Total Power consumption	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p (-)	N_{Re} (-) x 10^{-4}	N_Q(-)
70	18.0	12.5	0.4	0.417	25.060	3.34	0.008
142	31.0	23.2	0.6	0.417	6.106	6.78	0.010
193	15.0	8.5	1.5	0.533	1.024	8.02	0.015
245	19.2	10.8	3.0	0.611	0.706	9.16	0.113
263	34.0	19.0	4.4	0.664	1.086	9.30	0.117
305	45.0	26.4	6.4	0.718	1.055	9.60	0.090
330	60.0	37.0	7.3	0.737	1.114	10.40	0.086
390	93.0	61.5	10.1	0.783	1.320	11.00	0.082
440	11.2	76.0	14.0	0.825	1.235	11.40	0.072
525	23.2	180.0	17.0	0.848	1.811	13.00	0.070

TABLE - 9

TURBINE TYPE IMPELLER

Material : *ILMENITE*

Particle Size = 150 - 180 μ
Impeller Clearance = 0.2T

Initial height of bed = 6 cm.

RPM	Total Power (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p (-)	N_{Re} (-) x 10^{-4}	N_Q(-)
95	4.00	0.68	0.0	0.42	0.588	4.50	0.100
125	7.12	0.86	3.5	0.63	0.438	5.15	0.130
152	9.11	1.13	4.2	0.65	0.330	6.07	0.140
172	11.12	2.45	4.8	0.67	0.506	8.20	0.145
240	16.20	3.60	5.2	0.69	0.522	9.70	0.112
302	44.80	26.20	7.0	0.73	0.818	10.26	0.107
342	60.00	35.30	10.1	0.78	1.101	10.68	0.104
367	65.10	37.10	10.3	0.80	1.060	11.33	0.102
440	102.00	64.40	14.2	0.83	1.160	12.48	0.099
506	175.00	126.00	17.0	0.85	1.412	13.51	0.093

TABLE - 10

TURBINE TYPE IMPELLER

Material : *SAND*

Particle Size = 300 - 355 μ
Impeller Clearance = 0.1T = 2.5 cm
Initial Bed Height = 6 cm.

RPM	Total Power consumption (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p (-)	N_{Re} (-) x 10^{-4}	N_Q(-)
75	6.0	1.0	0.0	0.410	3.20	2.0	0.033
140	8.8	1.8	0.2	0.420	0.90	3.7	0.026
202	10.8	2.2	2.0	0.558	0.37	5.3	0.147
260	16.0	2.8	6.0	0.705	0.22	6.8	0.191
290	24.0	7.5	7.4	0.736	0.43	7.6	0.187
330	50.4	28.0	11.3	0.795	1.07	8.6	0.200
4350	58.0	33.3	12.1	0.805	1.05	9.2	0.193
432	102.0	67.0	15.2	0.833	1.14	11.3	0.170
510	171.1	121.0	17.0	0.846	1.25	13.4	0.162
562	246.0	192.0	17.1	0.847	1.50	14.7	0.150

TABLE - 11

TURBINE TYPE IMPELLER

Material : *SAND*

Particle Size = 300 - 355 μ
Impeller clearance = 0.2T = 5.0 cm
Initial bed height = 6 cm

RPM	Total Power consumption (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p (-)	N_{Re} (-) x 10^{-4}	N_Q(-)
75	4.0	0.86	0.4	0.4530	2.800	2.1	0.104
130	6.0	1.56	0.6	0.4700	0.980	3.4	0.084
180	7.7	3.56	3.4	0.6276	0.840	4.7	0.210
215	10.4	4.23	3.9	0.6464	0.580	5.6	0.191
260	16.0	5.30	6.4	0.7177	0.414	6.8	0.200
290	24.0	6.50	9.0	0.8011	0.370	7.6	0.206
325	50.4	28.00	11.6	0.8284	1.120	8.5	0.203
360	72.5	43.50	14.4	0.8330	1.280	9.4	0.199
430	120.9	85.80	15.0	0.8471	1.480	11.2	0.170
460	128.0	88.00	17.0	0.8484	1.240	12.1	0.162
500	159.6	110.00	17.1	0.8853	1.270	13.1	0.150

TABLE - 12

TURBINE TYPE IMPELLER

Material : *SAND*

Particle Size = 300 - 355 μ
Impeller clearance = 0.3T = 7.5 cm
Initial Bed height = 6 cm

RPM	Total Power consumption (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p(-)	N_{Re} (-) x 10^{-4}	N_Q(-)
88	6.00	0.75	0.4	0.447	1.520	2.30	0.075
122	7.77	0.87	1.0	0.494	0.660	3.20	0.164
158	9.10	0.96	2.0	0.558	0.330	4.14	0.188
192	10.40	1.42	5.3	0.687	0.276	5.03	0.245
228	12.60	2.02	6.6	0.719	0.255	5.98	0.223
282	20.00	3.50	8.6	0.757	0.214	7.40	0.203
312	42.00	23.00	11.2	0.794	1.040	8.20	0.208
348	55.10	33.10	15.1	0.832	0.990	9.12	0.210
380	60.00	43.80	16.1	0.840	1.090	9.90	0.177
450	118.00	81.40	17.0	0.846	1.220	11.80	0.168
495	152.00	108.00	17.1	0.847	1.230	12.90	0.141

TABLE - 13

PITCHED BLADE TURBINE (ANTICLOCKWISE ROTATION - OUTWARD PUMPING)

Material : *SAND*

Particle size = 300 - 355 μ

Impeller Clearance = 0.1T = 2.5 cm

Initial Bed height = 6 cm

RPM	Total Power consumption (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p (-)	N_{Re} (-) x 10^{-4}	N_Q(-)
100	6.66	0.88	0.50	0.455	0.400	4.10	0.050
145	9.11	1.10	1.10	0.502	0.162	5.90	0.083
200	22.00	9.40	4.10	0.650	0.530	8.10	0.096
250	50.40	35.90	7.30	0.734	1.036	10.20	0.112
300	60.00	41.40	10.90	0.791	0.700	12.26	0.109
350	70.40	45.65	13.10	0.815	0.480	14.30	0.100
370	98.60	69.10	14.30	0.826	0.613	15.13	0.097
430	152.1	117.00	16.30	0.842	0.662	17.63	0.089
520	300.0	248.00	17.50	0.849	0.705	21.24	0.075

TABLE - 14

PITCH BLADED TURBINE - (ANTICLOCKWISE ROTATION - OUTWARD PUMPING)

Material : *SAND*

Particle size = 300 - 355 μ

Impeller clearance = 0.2T = 5.0 cm

Initial Bed Height = 6 cm

RPM	Total Power consumption (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p(-)	$N_{Re} \times 10^{-4}$(-)	N_Q(-)
100	5.0	6.560	0.5	0.455	0.295	4.06	0.040
130	6.7	0.832	1.9	0.552	0.180	5.30	0.112
160	8.4	1.200	2.6	0.588	0.130	6.54	0.105
190	16.0	2.200	3.3	0.619	0.144	7.76	0.100
220	19.1	2.700	6.4	0.715	0.114	9.01	0.120
285	31.1	14.500	10.1	0.780	0.282	11.64	0.101
325	52.1	29.500	13.2	0.816	0.387	13.28	0.100
390	64.1	32.500	15.9	0.838	0.246	15.94	0.097
442	152.1	98.500	17.5	0.849	0.513	18.06	0.088

TABLE - 15

PITCHED BLADE TURBINE (ANTICLOCKWISE ROTATION - OUTWARD PUMPING)

Material : *SAND*

Particle Size = 300 - 355 μ

Impeller clearance = 0.3T = 7.5 cm

Initial height of bed = 6 cm

RPM	Total Power consumption (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p (-)	N_{Re} x 10^{-4}(-)	N_Q(-)
110	6.0	1.05	2.2	0.5683	0.355	4.40	0.138
142	8.4	2.15	4.1	0.6495	0.338	5.80	0.149
180	13.5	3.50	6.3	0.7122	0.270	7.40	0.145
220	24.0	11.40	8.3	0.7524	0.482	8.99	0.134
230	40.5	26.00	10.1	0.7811	0.962	9.40	0.139
260	52.2	35.60	11.9	0.8022	0.912	10.62	0.130
300	56.0	38.05	14.3	0.8256	0.635	12.26	0.122
400	84.0	49.80	17.5	0.8494	0.350	16.34	0.097

TABLE - 16

PITCHED BLADE TURBINE (ANTI-CLOCKWISE ROTATION - OUTWARD PUMPING)

Material : ***ILMENITE***

Particle Size = 150 - 180 μ

Initial height of the bed = 6 cm

Impeller clearance = 0.1T = 2.5 cm

RPM	Total Power consumption (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p (-)	$N_{Re} \times 10^{-4}$ (-)	N_Q(-)
102	6.0	0.87	0.4	0.453	0.330	4.60	0.045
130	7.1	1.80	0.6	0.469	0.320	5.90	0.047
140	10.5	2.70	1.4	0.527	0.398	6.40	0.055
185	13.6	3.85	3.0	0.611	0.246	8.40	0.063
210	20.0	7.40	4.6	0.650	0.322	9.60	0.064
280	34.8	18.30	8.4	0.757	0.336	12.78	0.065
332	64.0	41.60	11.3	0.798	0.460	15.14	0.060
402	136.5	102.30	15.8	0.839	0.636	18.34	0.054
480	269.5	210.30	16.6	0.845	0.768	21.90	0.046
572	482.0	403.80	17.5	0.852	0.831	26.09	0.039

TABLE - 17

PITCHED BLADE TURBINE

Material : ***ILMENITE***

Particle size = 150 - 180 μ

Initial height of bed = 6 cm

Impeller clearance = 0.2T = 5.0 cm

RPM	Total Power consumption (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p(-)	N_{Re} x 10^{-4}(-)	N_Q(-)
62	5.0	0.63	0.6	0.469	0.0720	2.80	0.066
132	6.6	0.85	2.8	0.613	0.1504	6.02	0.068
152	9.1	1.10	3.1	0.616	0.1286	6.93	0.070
198	17.1	6.30	4.6	0.669	0.3280	9.03	0.071
235	33.6	19.10	7.3	0.737	0.5940	10.72	0.071
270	49.3	32.80	8.6	0.760	0.6730	12.32	0.066
305	60.0	41.40	10.7	0.791	0.5900	13.92	0.063
362	144.3	114.30	13.6	0.821	0.6304	16.52	0.059
430	160.0	124.30	16.6	0.843	0.8430	19.62	0.052
500	177.0	128.00	17.5	0.851	0.4140	22.81	0.045

TABLE - 18

PITCHED BLADE TURBINE

Material : ***ILMENITE***

Particle size = 150 - 180 μ

Initial height of bed = 6 cm

Impeller clearance = 0.3T = 7.5 cm

RPM	Total Power consumption (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p(-)	N_{Re} x 10^{-4}(-)	N_Q(-)
102	6.0	0.9	0.5	0.462	0.343	4.65	0.049
150	9.6	1.8	6.3	0.708	0.216	6.84	0.063
190	15.0	4.2	9.4	0.773	0.250	8.67	0.073
215	24.0	11.4	9.9	0.780	0.463	9.81	0.076
255	42.0	27.5	10.1	0.783	0.670	11.63	0.071
282	51.0	34.5	11.6	0.801	0.622	12.86	0.067
320	64.0	41.6	13.7	0.822	0.513	14.60	0.063
352	81.6	56.8	16.0	0.841	0.526	16.06	0.055
410	156.0	121.8	16.8	0.847	0.714	18.70	0.050
450	215.0	177.0	17.5	0.851	0.785	20.53	0.049

TABLE - 19

PITCHED BLADE TURBINE (OUTWARD PUMPING)

Material : *ILMENITE*

Particle size = 105 - 150 μ

Impeller clearance = 0.1T = 2.5 cm

Initial height of bed = 6 cm

RPM	Total Power consumption (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p(-)	N_{Re} x 10^{-4}(-)	N_Q(-)
50	20.3	15.3	0.4	0.453	4.940	2.28	0.032
102	8.8	1.7	0.8	0.485	0.723	4.65	0.035
130	11.7	3.9	1.2	0.514	0.717	5.93	0.037
140	13.3	4.5	1.4	0.527	0.670	6.38	0.040
180	16.0	5.1	3.9	0.647	0.353	8.21	0.063
245	54.0	39.5	8.4	0.757	1.086	11.18	0.065
280	66.0	49.0	10.7	0.791	0.702	12.77	0.058
340	99.5	71.0	13.4	0.820	0.730	15.51	0.057
372	148.7	119.0	15.3	0.836	0.940	16.97	0.046
435	225.0	188.0	17.2	0.849	0.920	19.81	0.044
475	300.0	260.0	17.5	0.837	0.980	21.67	0.043

TABLE - 20

PITCHED BLADE TURBINE (OUTWARD PUMPING)

Material : *ILMENITE*

Particle size = 105 - 150 μ

Impeller clearance = 0.2T = 5 cm

Initial height of bed = 6 cm

RPM	Total Power consumption (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p(-)	N_{Re} x 10^{-4}(-)	N_Q(-)
102	6.0	0.87	0.4	0.453	0.330	4.6	0.031
130	7.1	1.80	0.6	0.469	0.320	5.9	0.040
140	10.1	2.70	1.4	0.527	0.398	6.4	0.057
185	13.6	3.85	3.0	0.611	0.246	8.4	0.063
210	50.0	7.40	4.6	0.650	0.322	9.6	0.064
280	64.8	38.30	8.4	0.757	0.336	12.7	0.065
332	78.0	41.60	11.3	0.798	0.460	15.1	0.060
402	136.5	102.30	15.8	0.839	0.636	18.3	0.064
480	269.5	210.30	16.6	0.845	0.768	21.9	0.060
572	482.0	403.80	17.5	0.852	0.870	26.1	0.052

TABLE - 21

PITCHED BLADE TURBINE (OUTWARD PUMPING)

Material : *ILMENITE*

Particle size = 105 - 150 μ

Impeller clearance = 0.3T = 7.5 cm

Initial height of bed = 6 cm

RPM	Total Power consumption (watts)	Power given to slurry (watts)	Expansion (cm)	Voidage (ε)	N_p(-)	N_{Re} x 10^{-4}(-)	N_Q(-)
100	6.0	0.72	4.6	0.669	0.324	4.56	0.172
145	8.4	0.96	6.6	0.722	0.143	6.61	0.101
180	11.2	1.45	7.8	0.746	0.112	8.21	0.086
212	13.0	4.40	9.1	0.768	0.208	9.67	0.079
290	39.2	22.50	12.9	0.814	0.415	13.23	0.065
322	62.0	39.60	15.5	0.837	0.534	14.69	0.063
355	91.0	66.25	16.4	0.844	0.667	16.14	0.058
420	160.0	125.80	17.5	0.851	0.765	19.16	0.050

TABLE - 22

STIRRED CONTACTOR WITH TURBINE TYPE IMPELLER

POWER CONSUMPTION FOR DIFFERENT CLEARANCES

Particle size	Voidage (ε)	0.1 T Power (watts)	0.2T Power (watts)	0.3 T Power (watts)
ILMENITE 150-180 μ	0.53	19.0	6.0	9.1
	0.73	27.0	18.2	26.5
	0.83	61.5	56.5	60.3
ILMENITE 105-150 μ	0.50	18.0	5.0	9.0
	0.60	27.0	9.0	15.5
	0.81	72.0	52.0	68.0
SAND 300-355 μ	0.55	12.0	6.0	8.0
	0.70	28.0	16.0	19.0
	0.63	58.0	38.0	55.1

TABLE - 23

STIRRED CONTACTOR WITH PITCHED BLADE TURBINE

POWER CONSUMPTION FOR DIFFERENT CLEARANCES

Particle size	Voidage (ε)	0.1T Power (watts)	0.2T Power (watts)	0.3T Power (watts)
ILMENITE 150 - 180 μ	0.61	19.0	5.0	8.0
	0.72	24.0	16.8	22.0
	0.83	51.0	45.0	49.0
ILEMNITE 105 - 150 μ	0.61	17.0	4.0	15.0
	0.72	23.0	7.0	21.0
	0.83	62.0	49.0	59.0
SAND 300 - 355 μ	0.61	10.0	3.0	7.0
	0.72	24.0	14.0	22.0
	0.83	54.0	34.0	50.0

TABLE - 24

COMPARISON OF POWER CONSUMPTION OF STIRRED CONTACTOR WITH TURBINE TYPE IMPELLER AND PITCHED BLADE TURBINE FOR 0.2T CLEARANCE

Particle size	Voidage (ε)	TURBINE TYPE IMPELLER Power (watts)	PITCHED BLADE TURBINE Power (watts)
ILMENITE 150 - 180 μ	0.61	12.0	5.0
	0.72	21.0	16.8
	0.83	78.0	45.0
ILMENITE 105 - 150 μ	0.61	10.0	4.0
	0.72	20.0	7.0
	0.83	75.0	49.0
SAND 300 - 355 μ	0.61	11.0	3.0
	0.72	21.0	14.0
	0.83	77.0	34.0

TABLE - 25

COMPARISON OF POWER CONSUMPTION OF FLUIDISED BED AND STIRRED CONTACTOR WITH PITCHED BLADE TURBINE (0.2T CLEARANCE)

Particle size	Voidage (ε)	STIRRED CONTACTOR Power (watts)	FLUIDIZED BED Power (watts)
ILMENITE 150 - 180 μ	0.42	4.22	0.651
	0.53	5.82	2.311
	0.67	17.10	8.218
ILMENITE 105 - 150 μ	0.42	3.12	0.3012
	0.53	4.82	0.8791
	0.67	14.82	6.3120
SAND 300 - 355 μ	0.42	3.88	0.4918
	0.53	5.02	1.3120
	0.67	15.65	7.6120

TABLE - 26

THE SLOPES AND INTERCEPTS OF ln u Vs ln ε PLOT FOR VARIOUS PARTICLE SIZES

Material	Slope, n	Intercept, ln U_t	Single particle terminal settling velocity, U_t cm/sec
ILMENITE 105 - 150 μ	2.24	0.66	1.94
ILMENITE 150 - 180 μ	1.844	0.71	2.04
ILMENITE 210 - 355 μ	4.12	1.2	3.32
SAND 300 - 355 μ	2.245	0.66	1.94

FLUIDISATION CHARACTERISTICS

FIGURE- 3

Material-Ilmenite

Particle size - 105-150 Microns

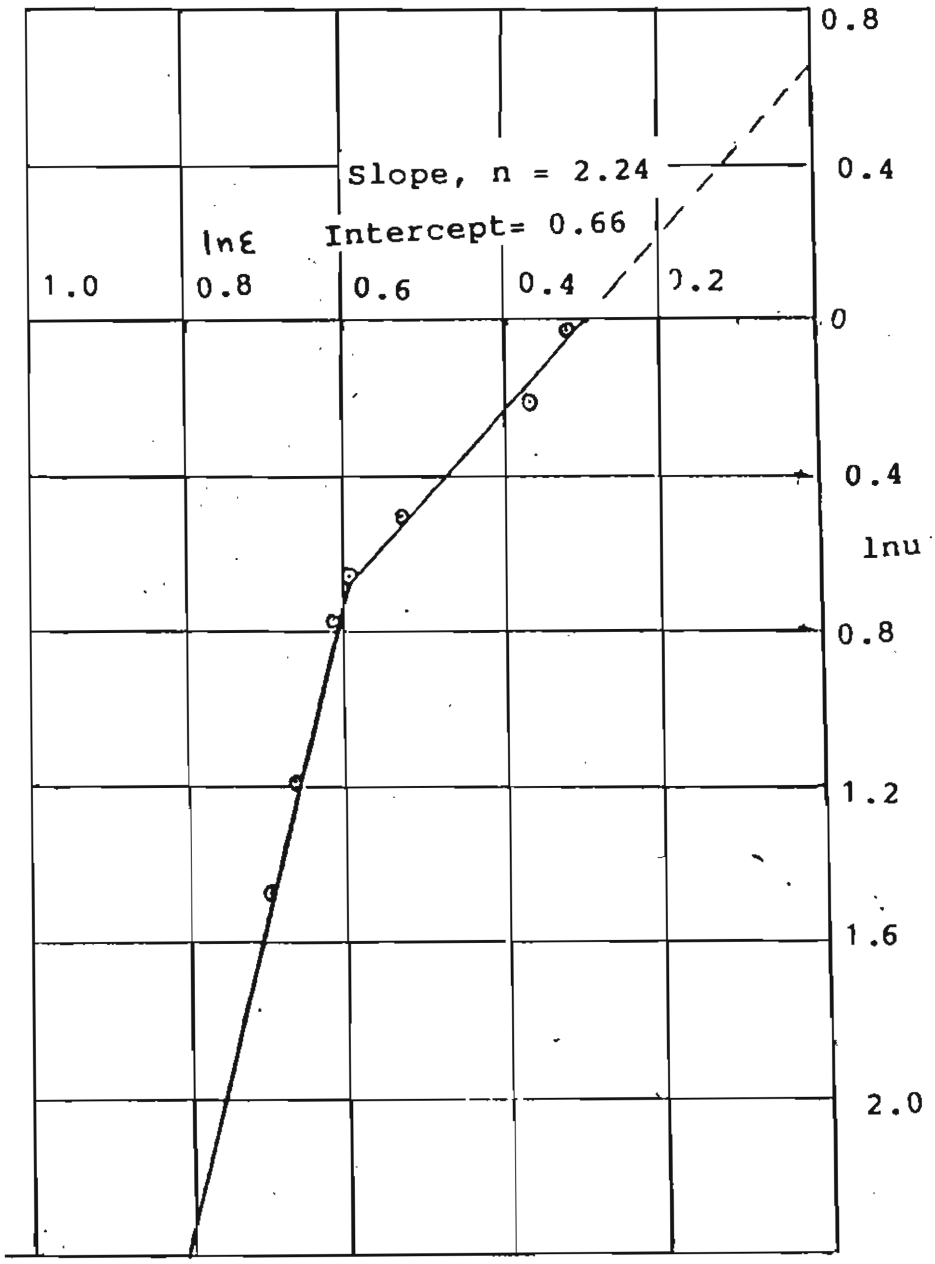


FIGURE- IV

Material - Ilmenite

Particlesize - 150-180 microns

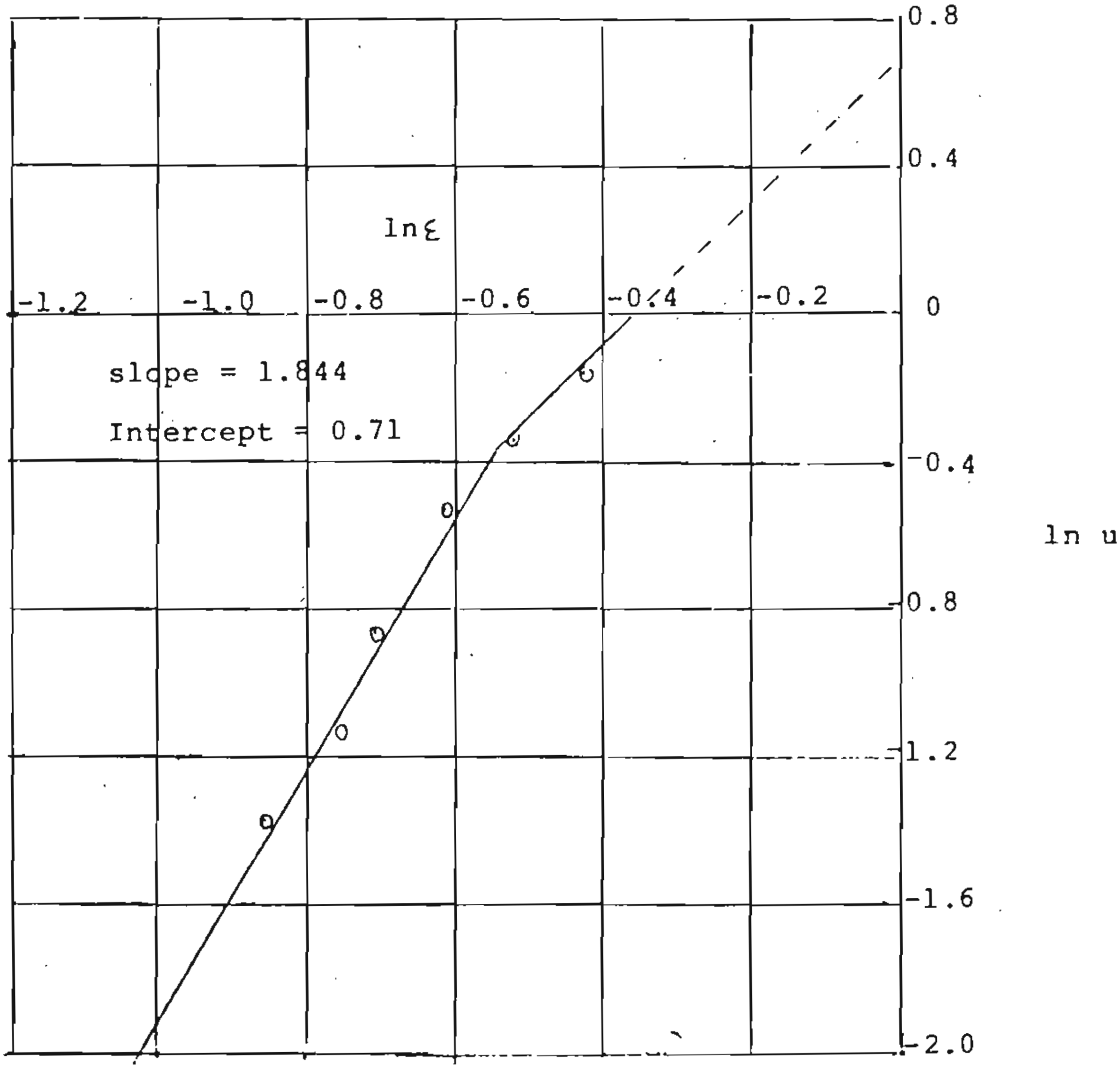


FIGURE - V

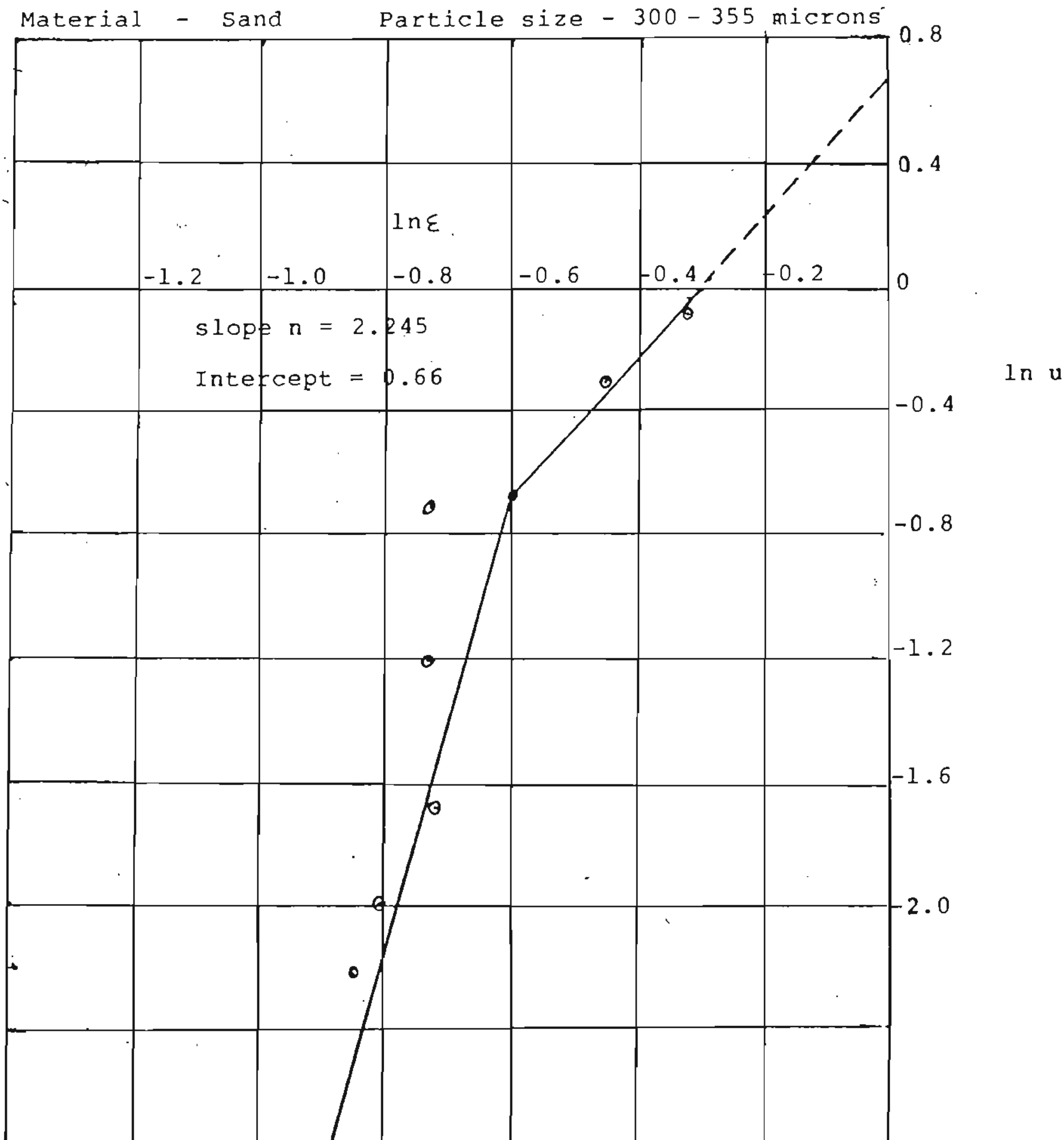
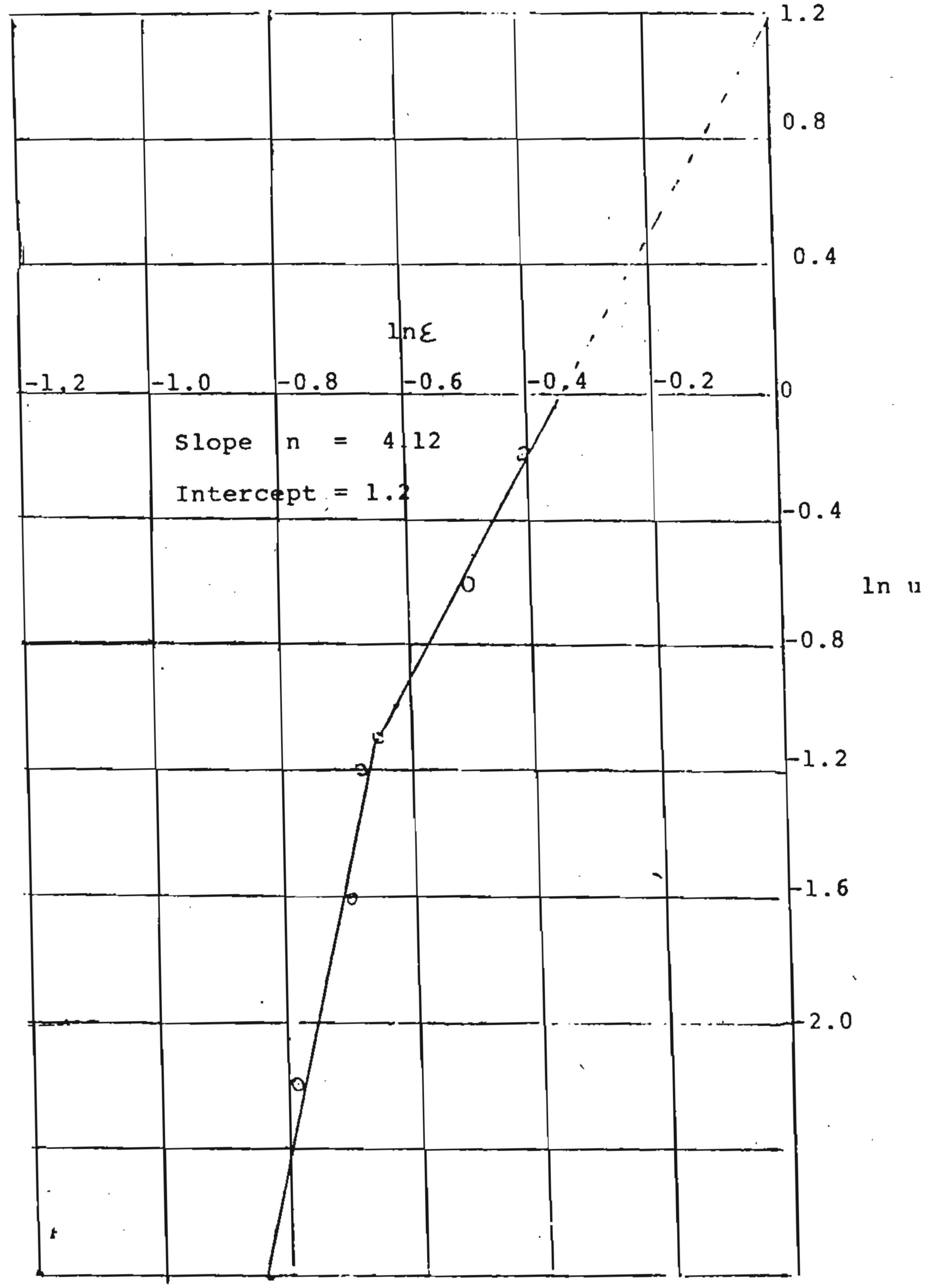

Material - Sand
Particle size - 300 - 355 microns
ln ε
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.8
0.4
0
-0.4
-0.8
-1.2
-1.6
-2.0
ln u
slope n = 2.245
Intercept = 0.66

FIGURE - VI

Material - ILMENITE

Particle size = 210 - 355 microns



STIRRED CONTACTORS

FIGURE - VII

TURBINE TYPE IMPELLER

Material - ILMENITE

Particle size = 105 - 150 microns

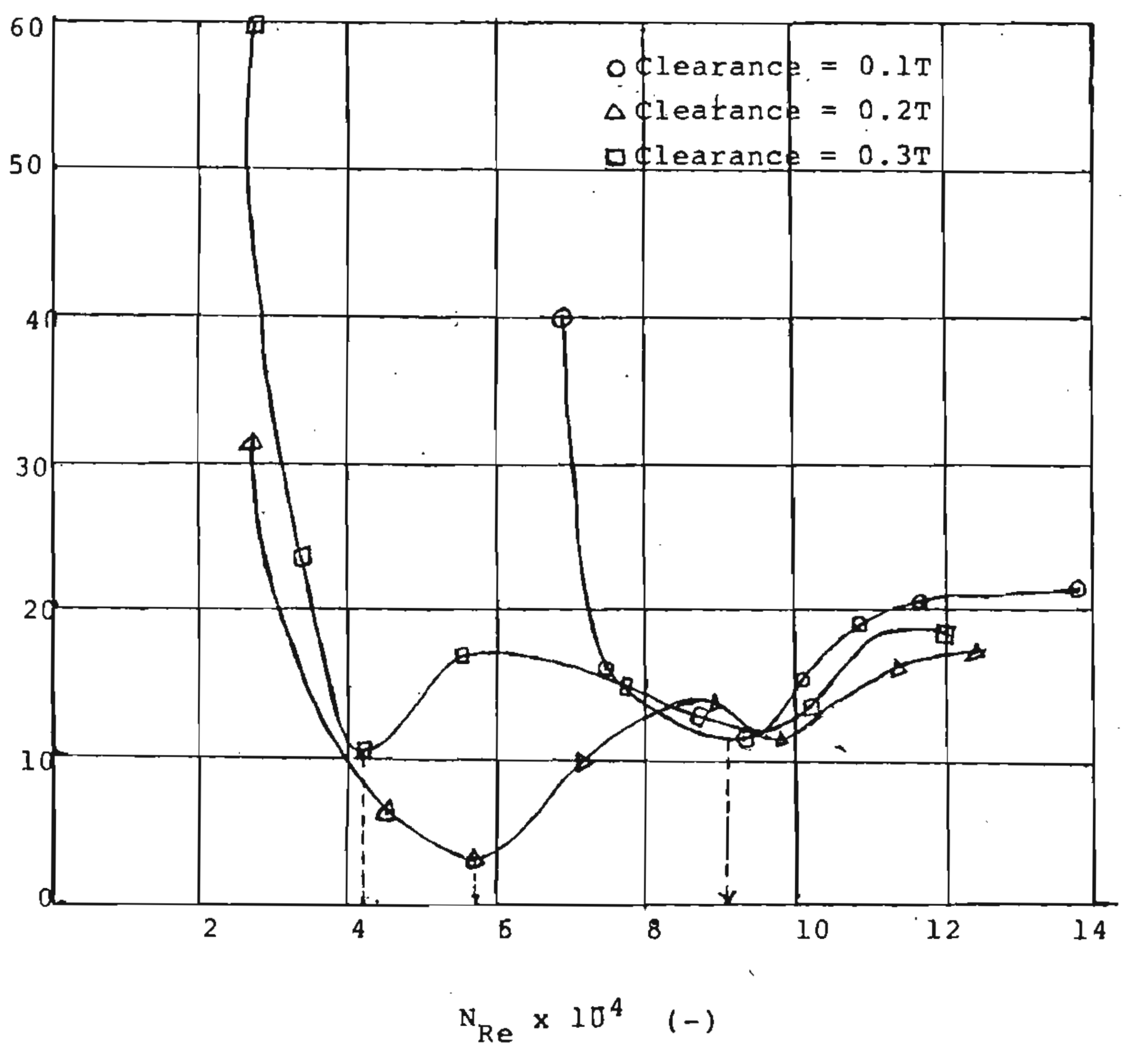


FIGURE - VIII

INE TYPE IMPELLER

rial - ILMENITE

icle size = 150 - 180 microns

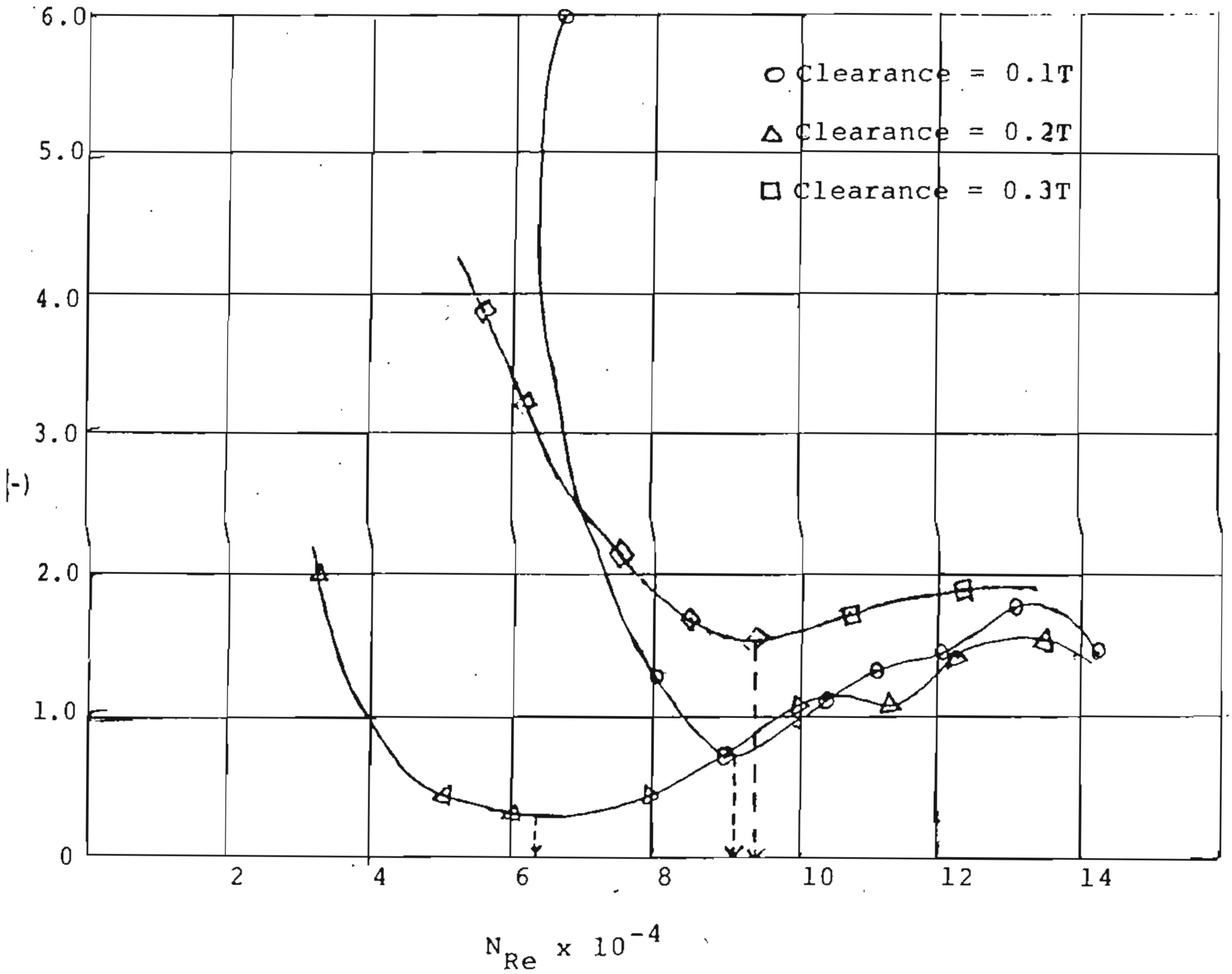
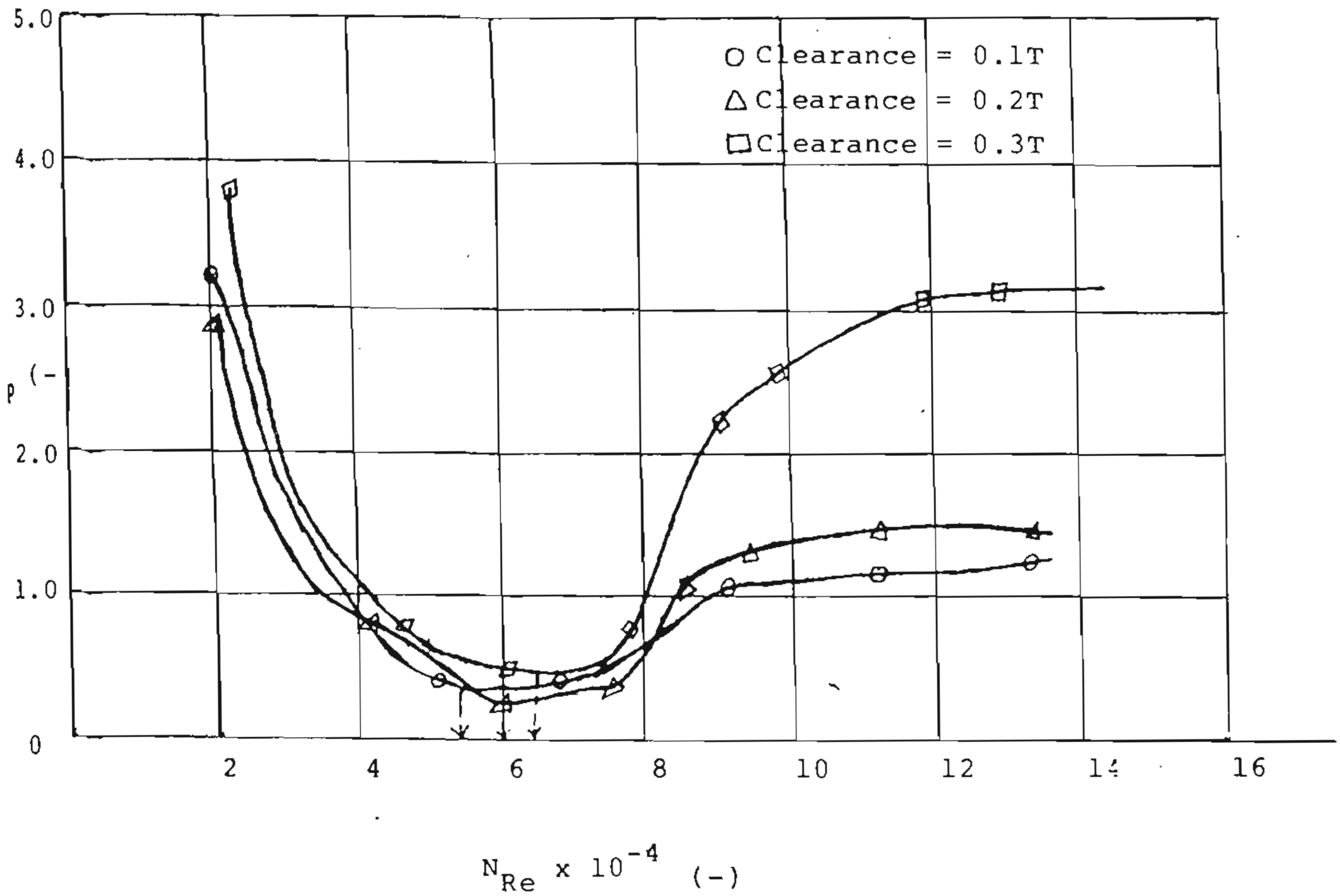


FIGURE - IX

TURBINE TYPE IMPELLER

Material - SAND

Particle size = 300 - 355 microns



<u>FIGURE - X</u>

PITCH BLADEDTURBINE

Material - SAND

Particle size = 300 - 355 microns

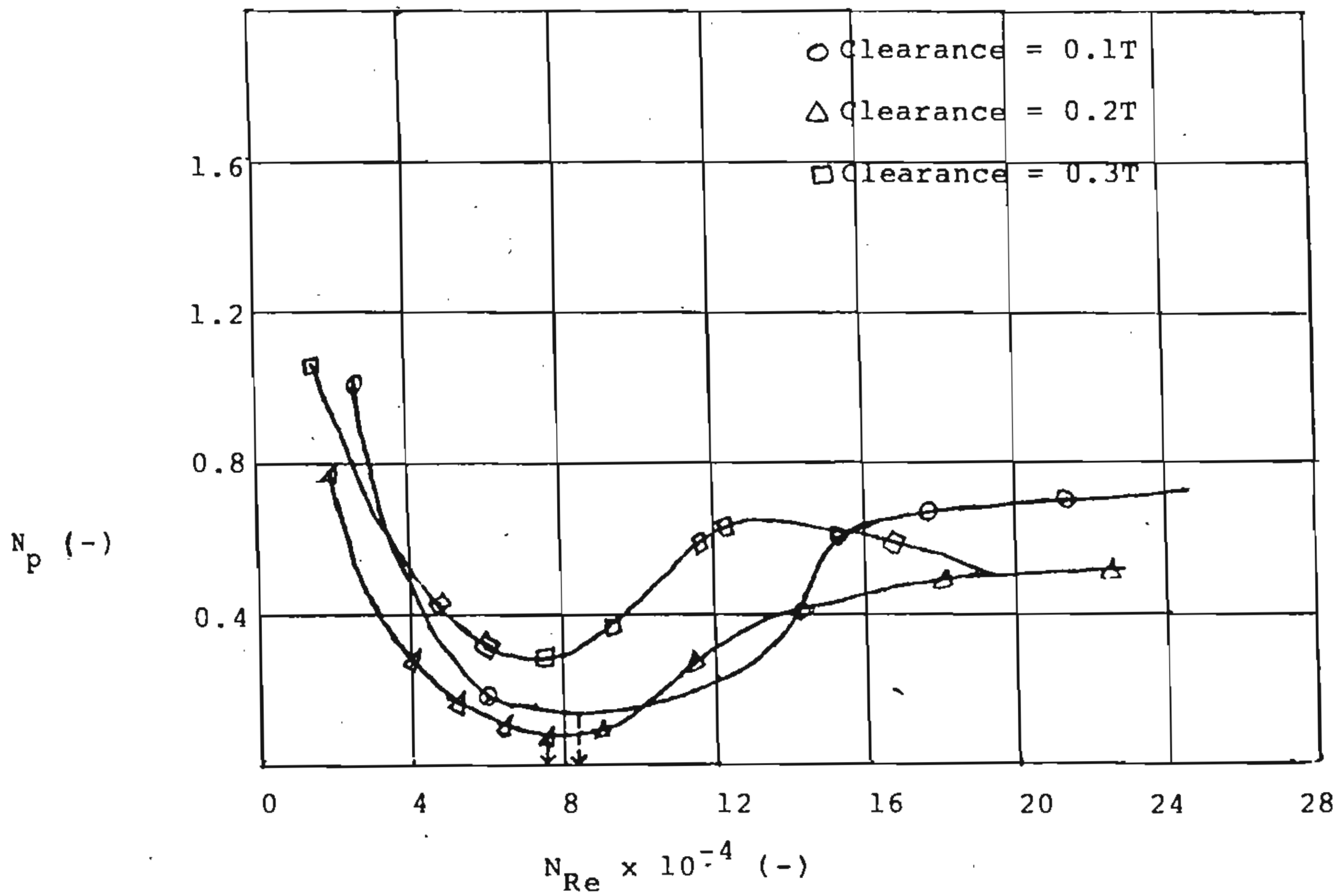


FIGURE - XI

ITCH BLADED TURBINE

aterial - ILMENITE

article size = 150 - 180 microns

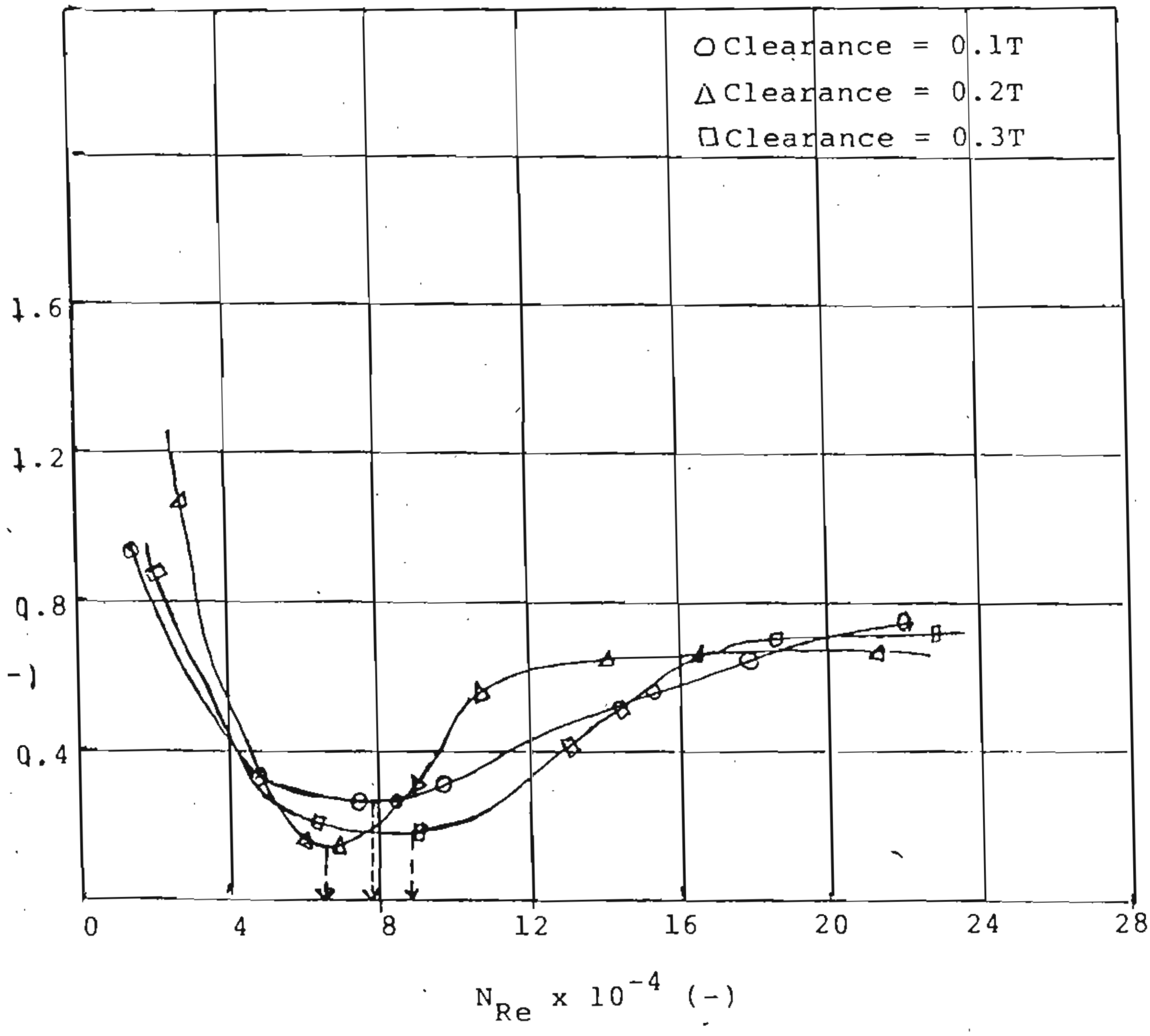


FIGURE - XII

PITCH BLADED TURBINE

Material - ILMENITE

Particle size = 105 - 150 microns

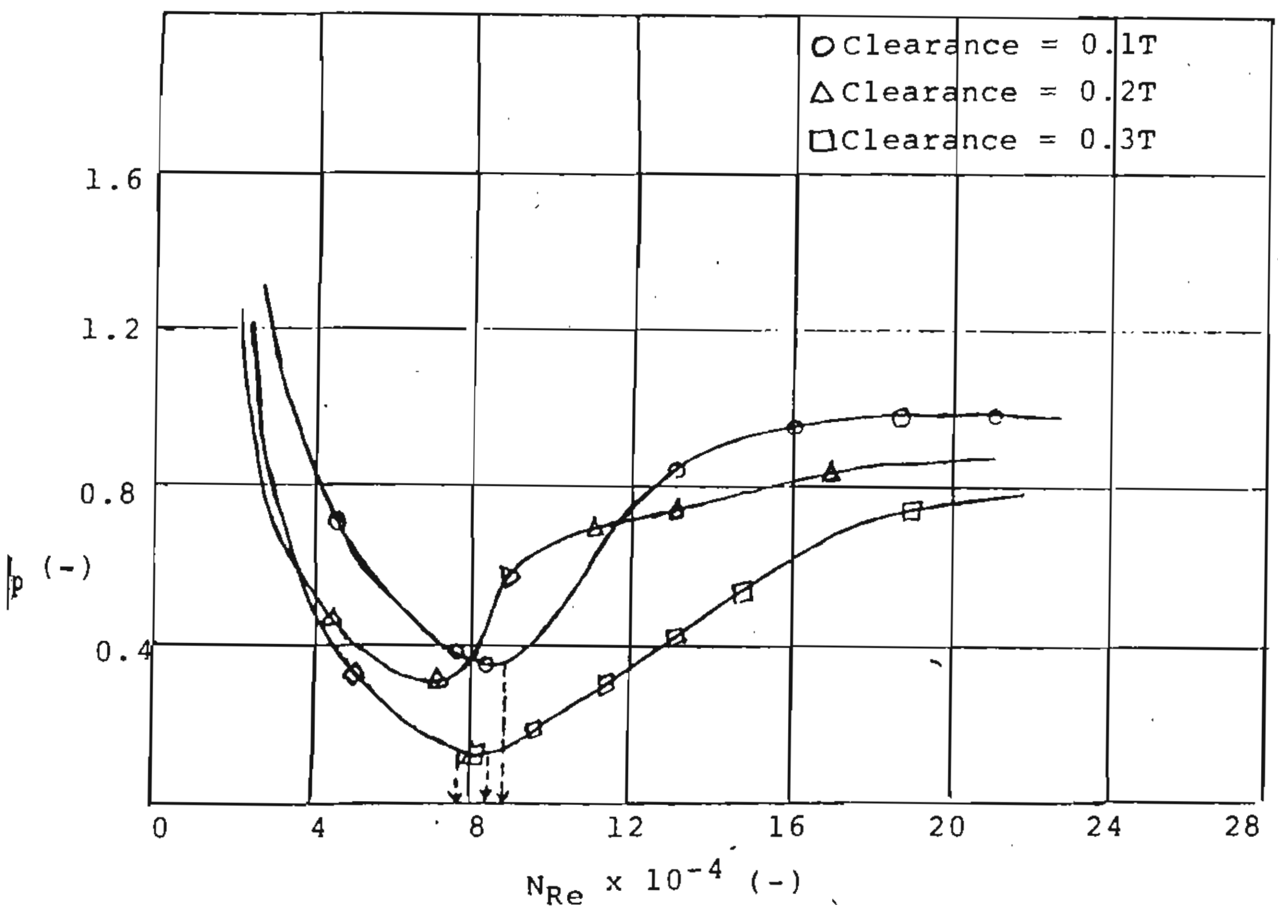
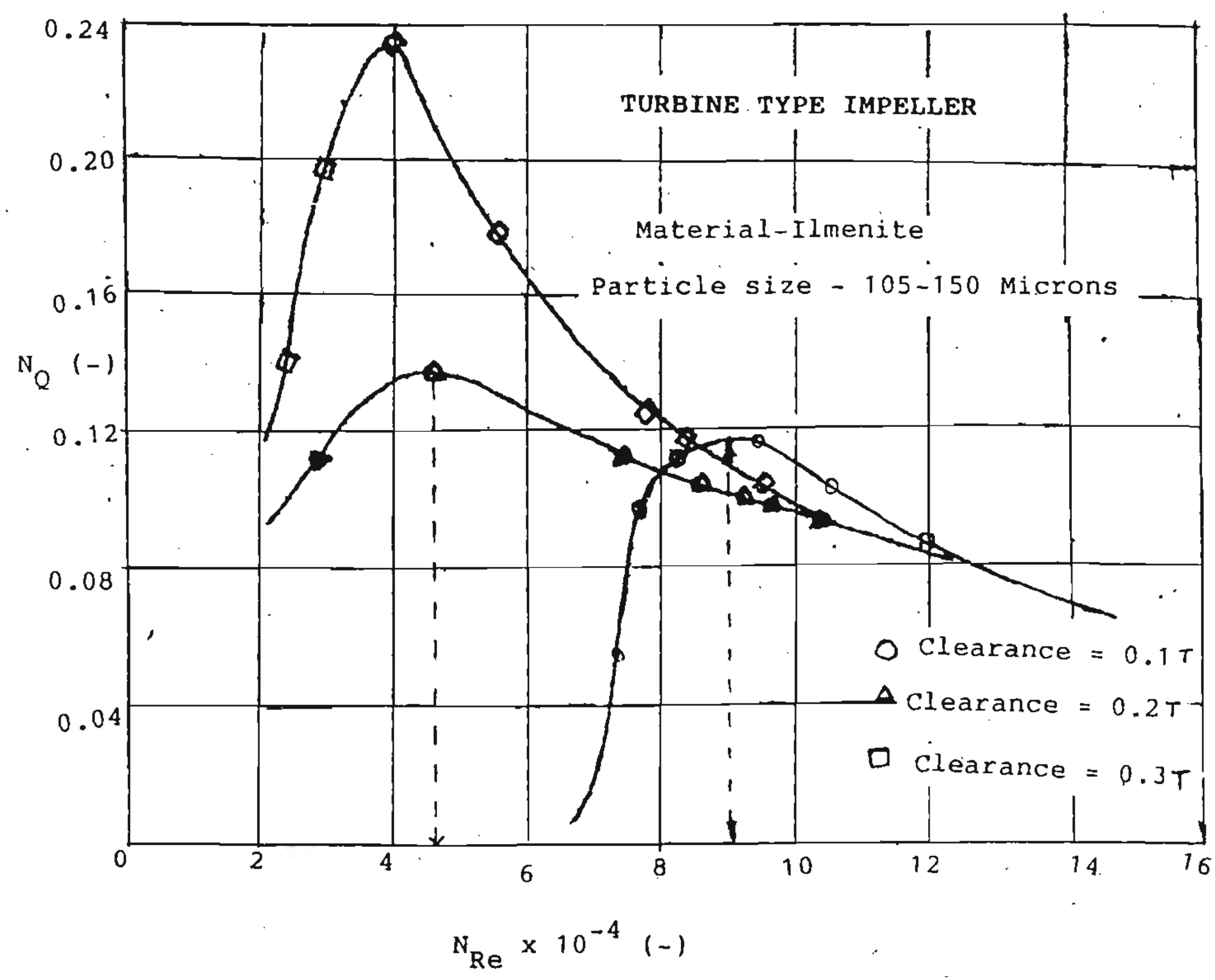


FIGURE-13



TURBINE TYPE IMPELLER
Material-Ilmenite
Particle size - 105-150 Microns
Clearance = 0.1T
Clearance = 0.2T
Clearance = 0.3T
0.24
0.20
0.16
0.12
0.08
0.04
N_Q (-)
0
2
4
6
8
10
12
14
16
$N_{Re} \times 10^{-4}$ (-)

<u>FIGURE - XIV</u>

TURBINE TYPE IMPELLER

Material - SAND

Particle size = 300 - 355 microns

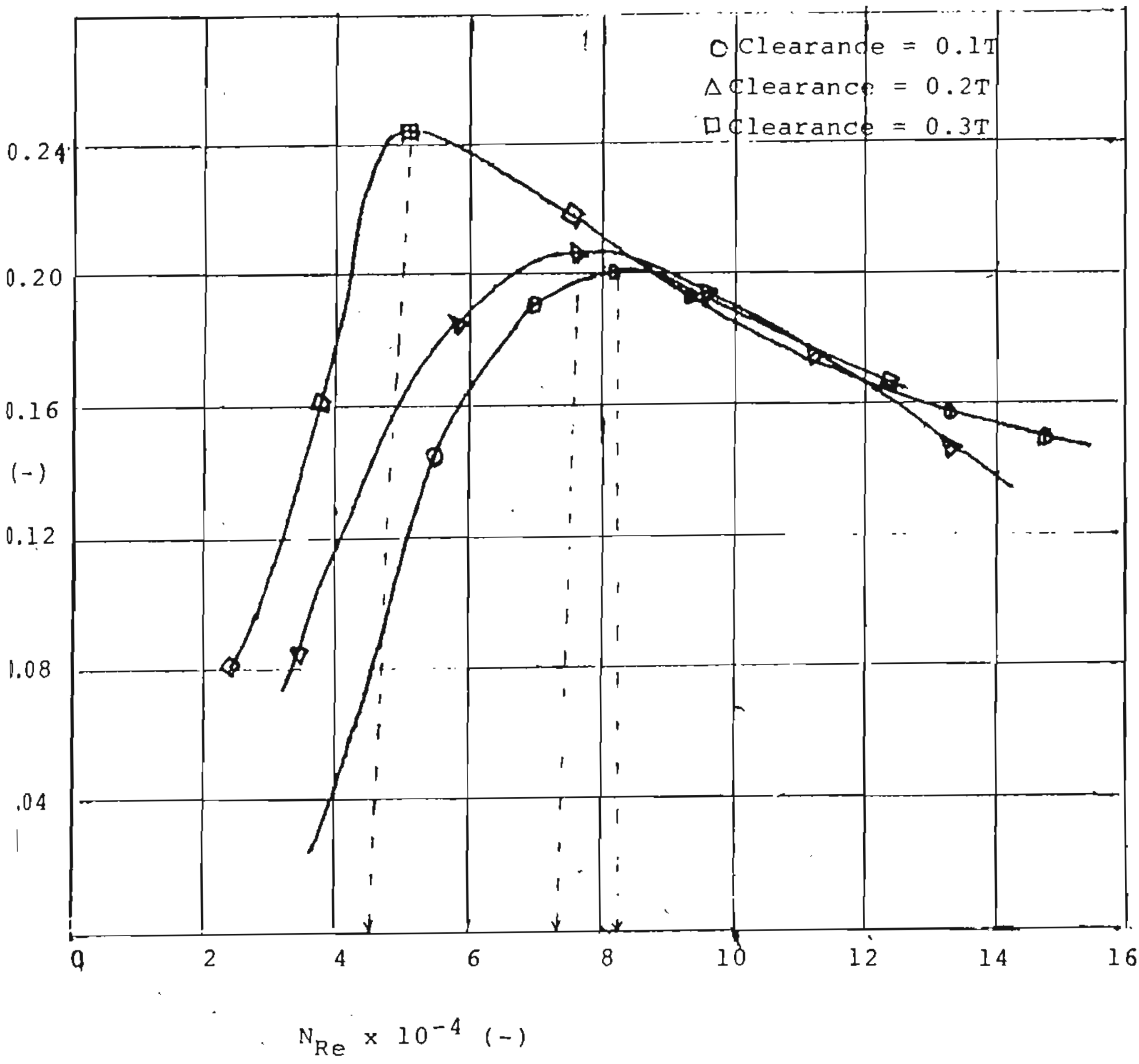


FIGURE - XV

PITCH BLADED TURBINE
Material - SAND
Particle size = 300 - 355 microns

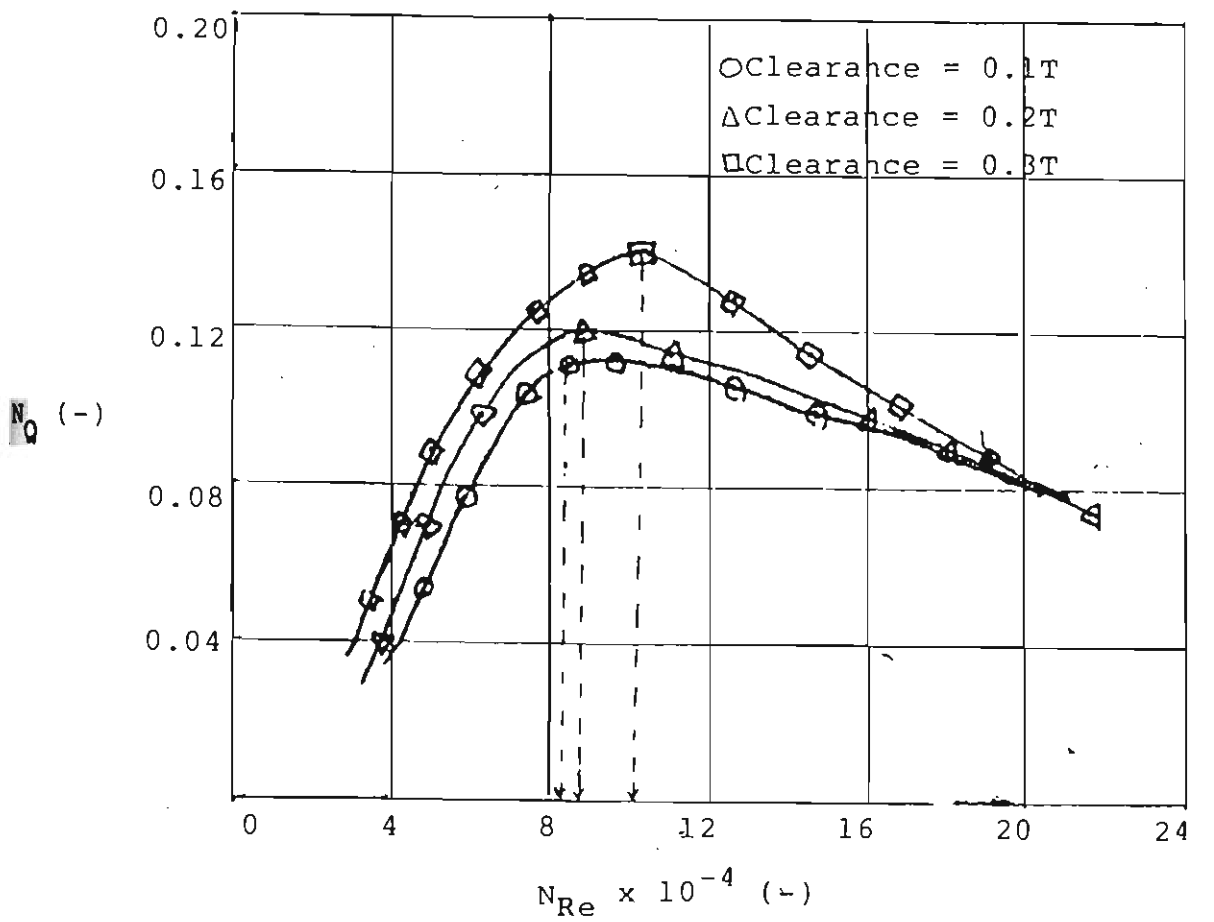
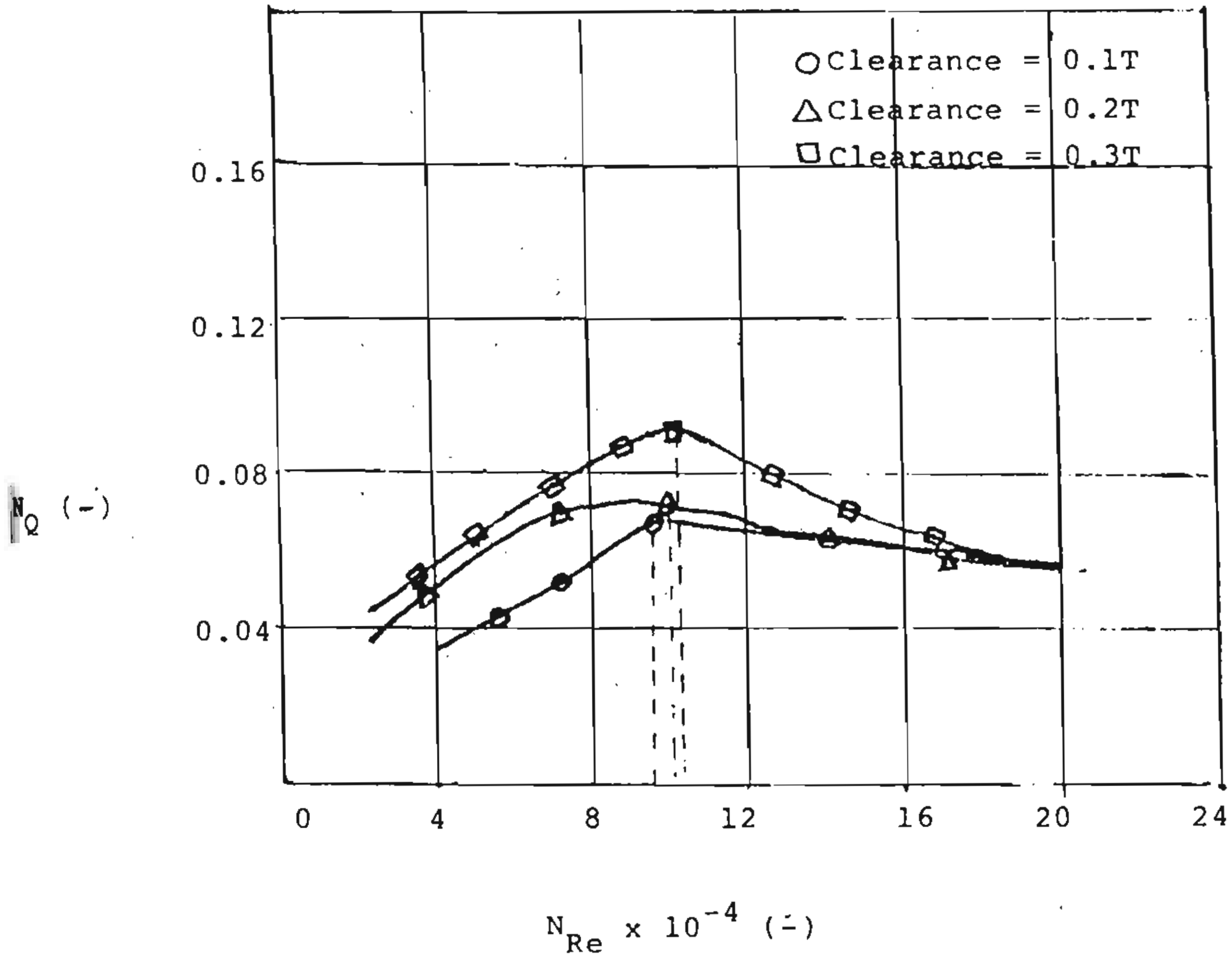


FIGURE - XVI

PITCH BLADED TURBINE

Material - ILMENITE

Particle size = 150 - 180 microns



<u>FIGURE - XVII</u>

PITCH BLADED TURBINE

Material - ILMENITE

Particle size = 105 - 150 microns

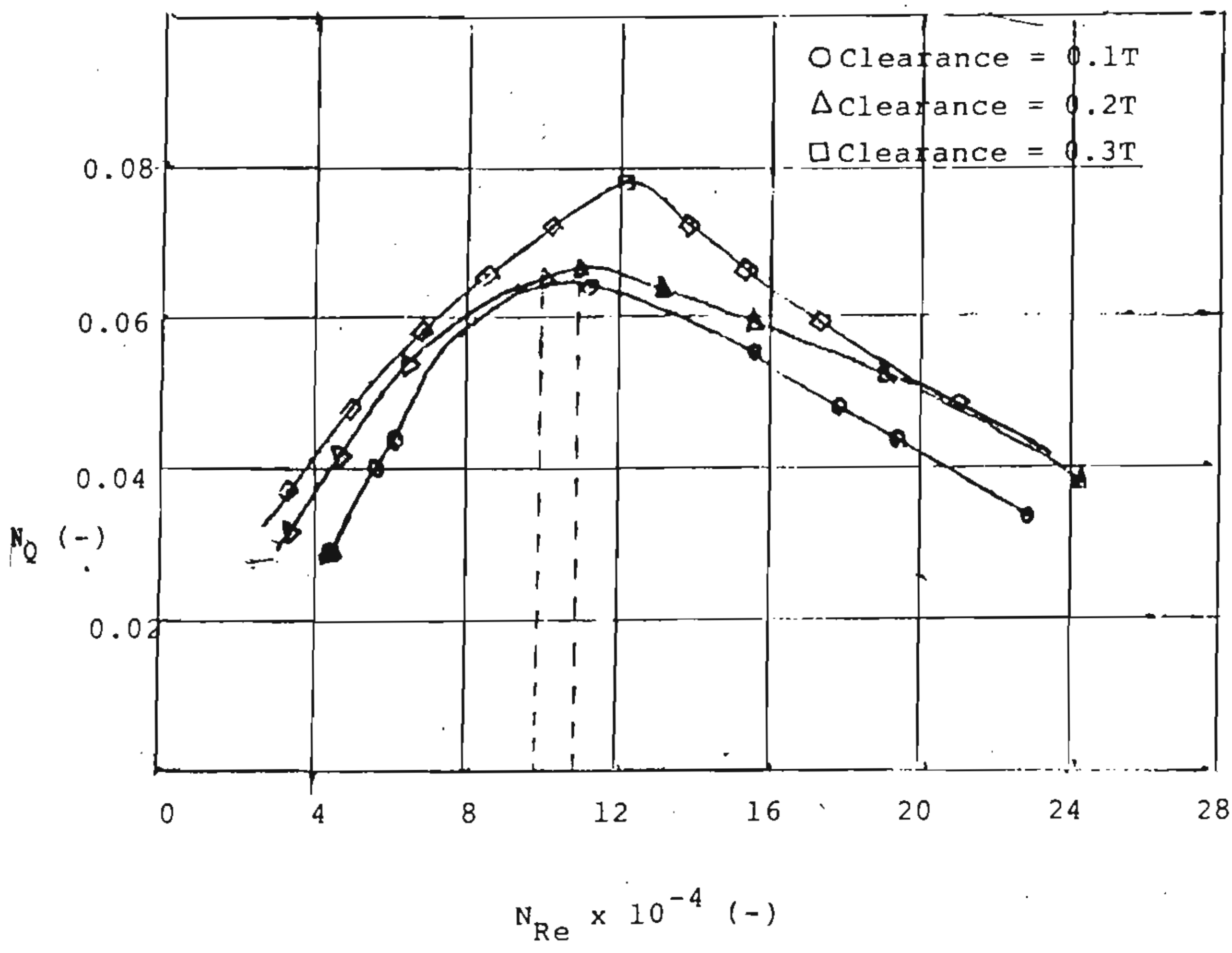
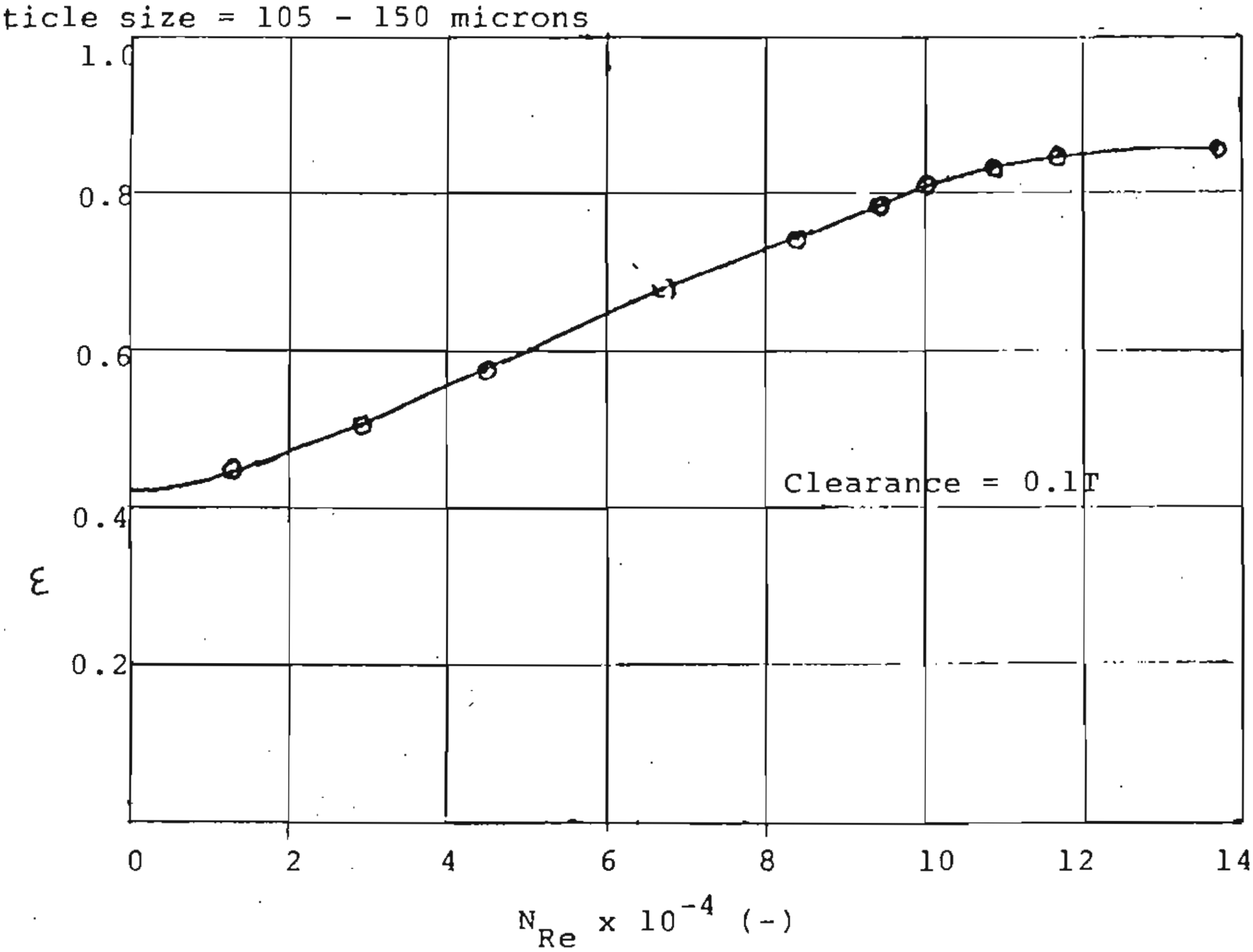


FIGURE - XVIII

TURBINE TYPE IMPELLER

Material - ILMENITE

Particle size = 105 - 150 microns



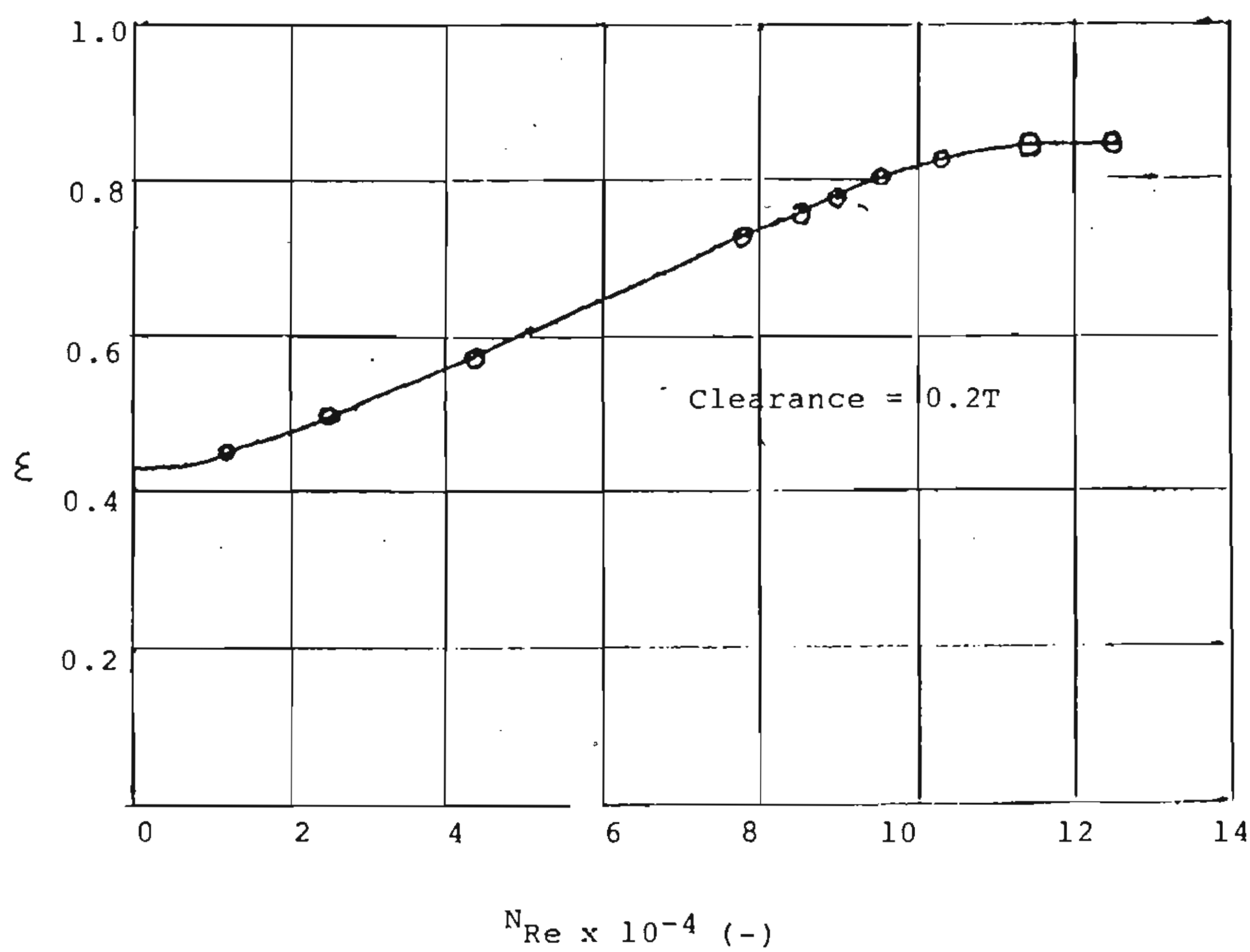


FIGURE - XIX

TURBINE TYPE IMPELLER
Material - ILMENITE
Particle size = 105 - 150 microns

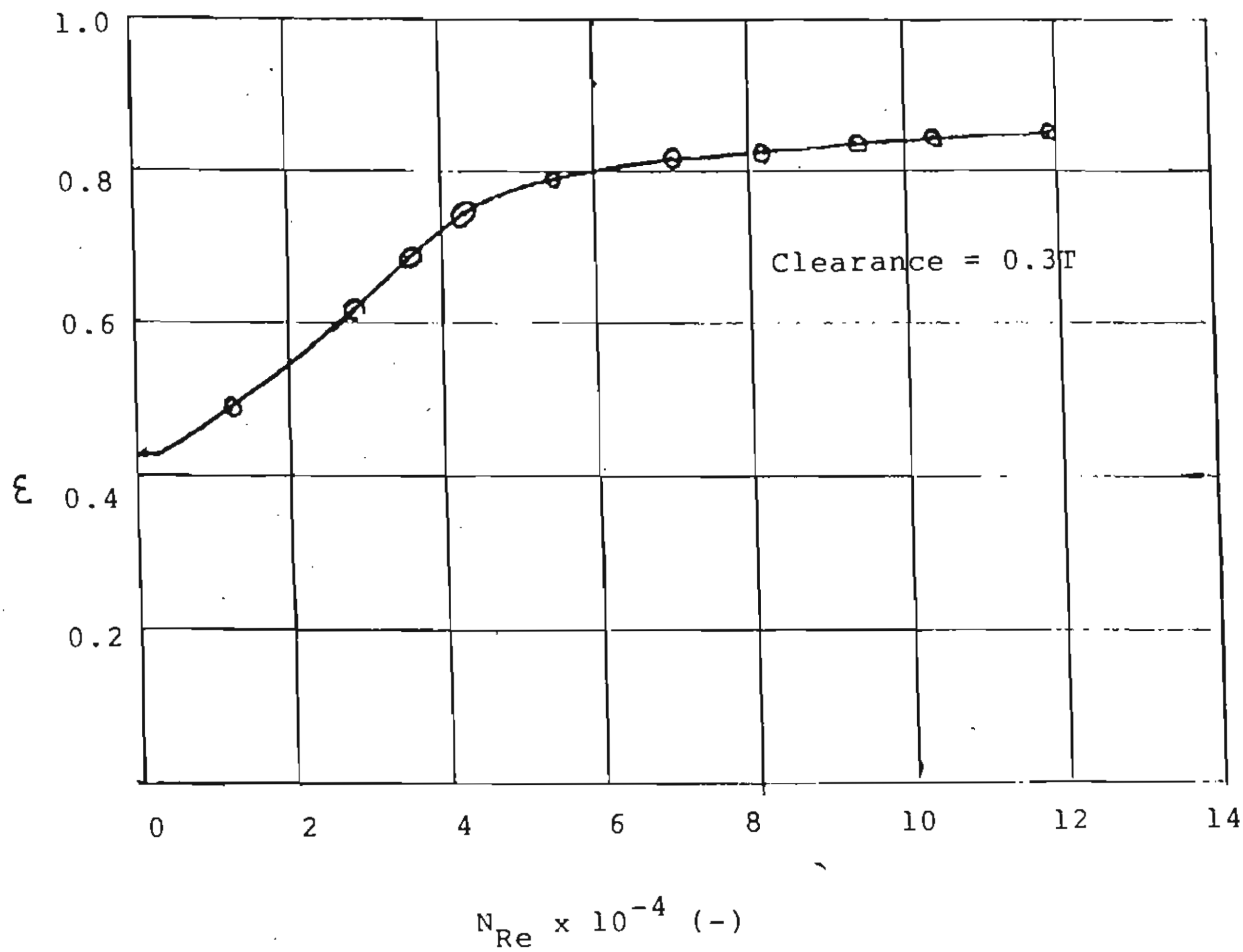
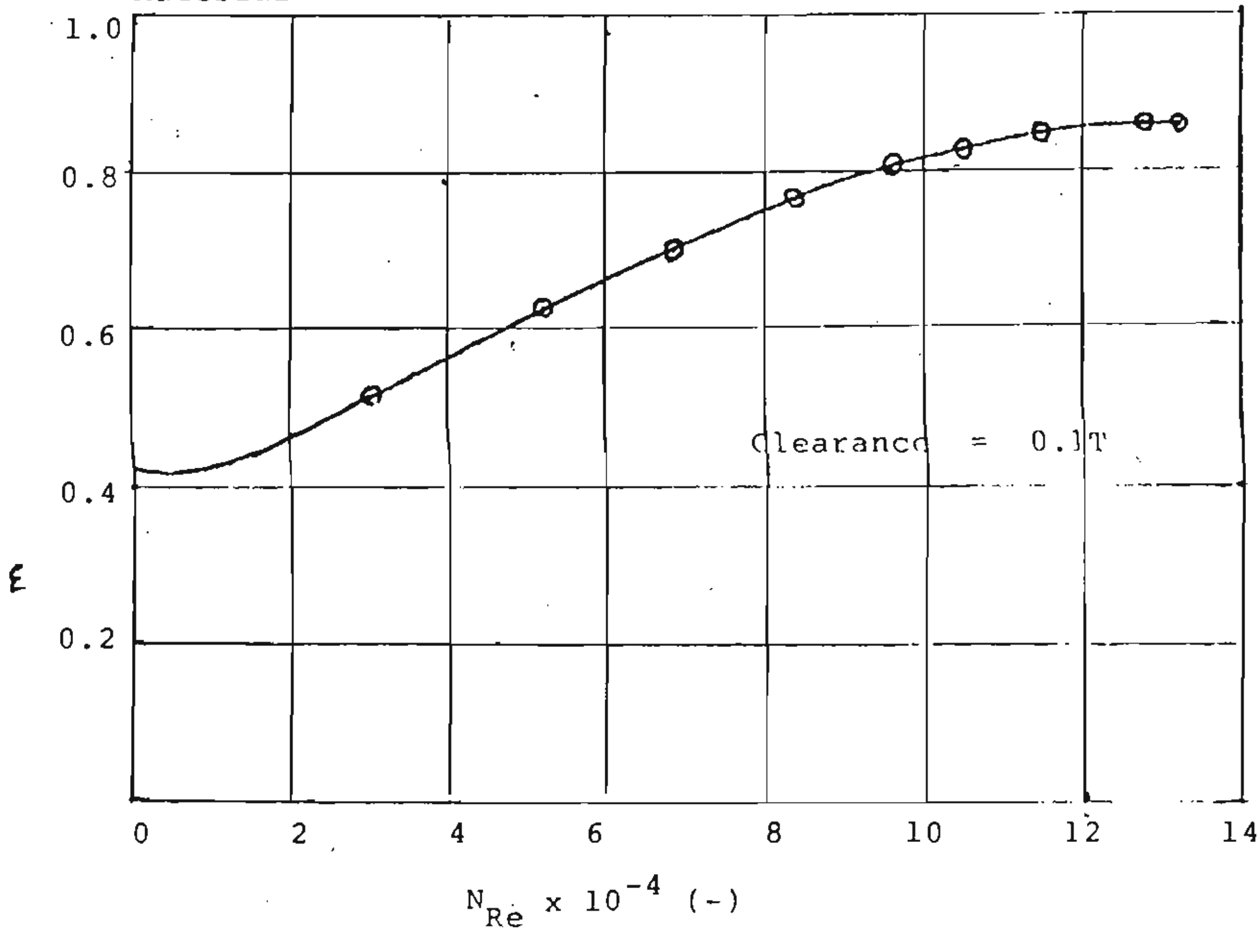


FIGURE - XX

TURBINE TYPE IMPELLER

Material - ILMENITE   Particle size = 150 - 180 microns



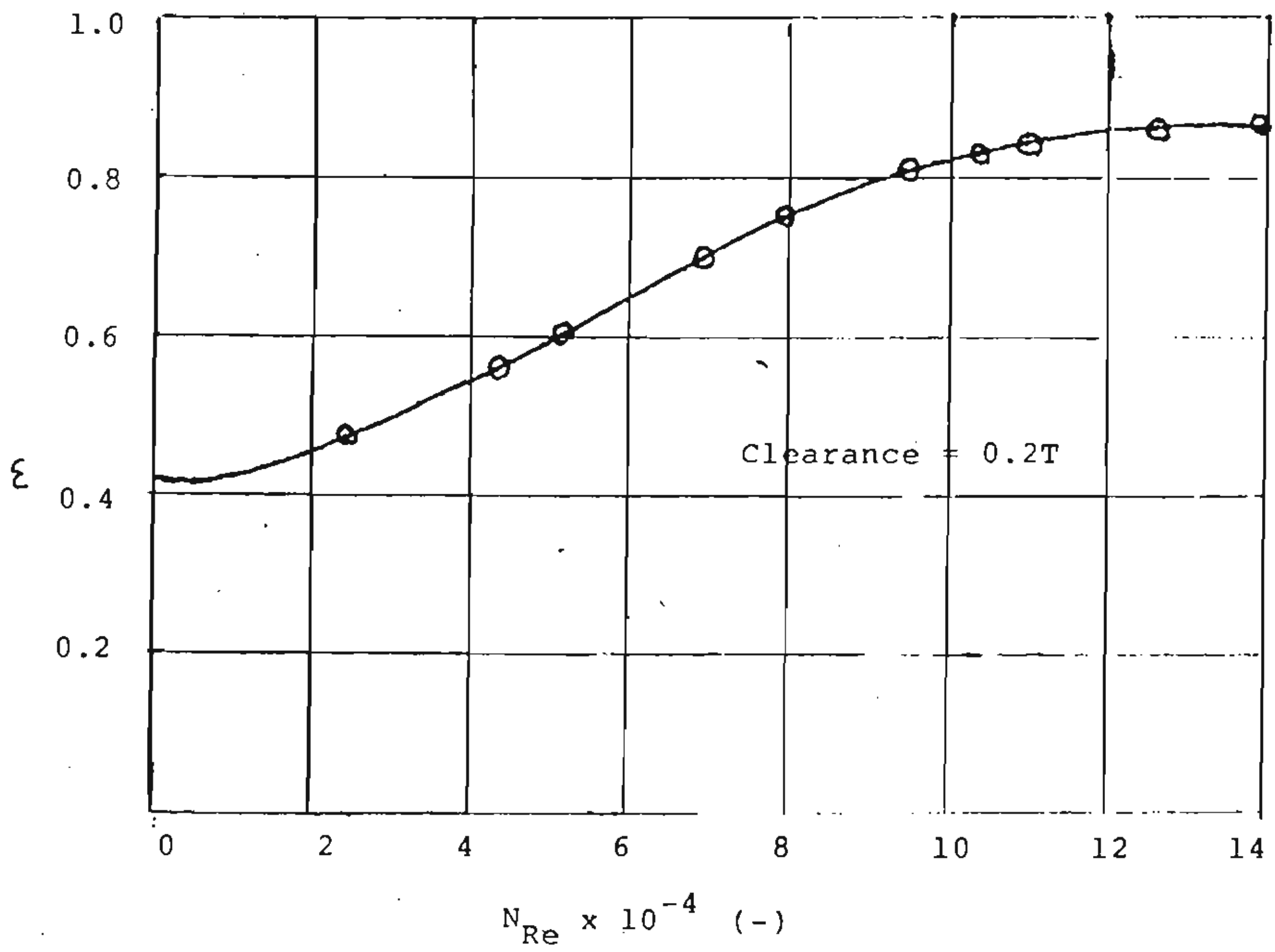
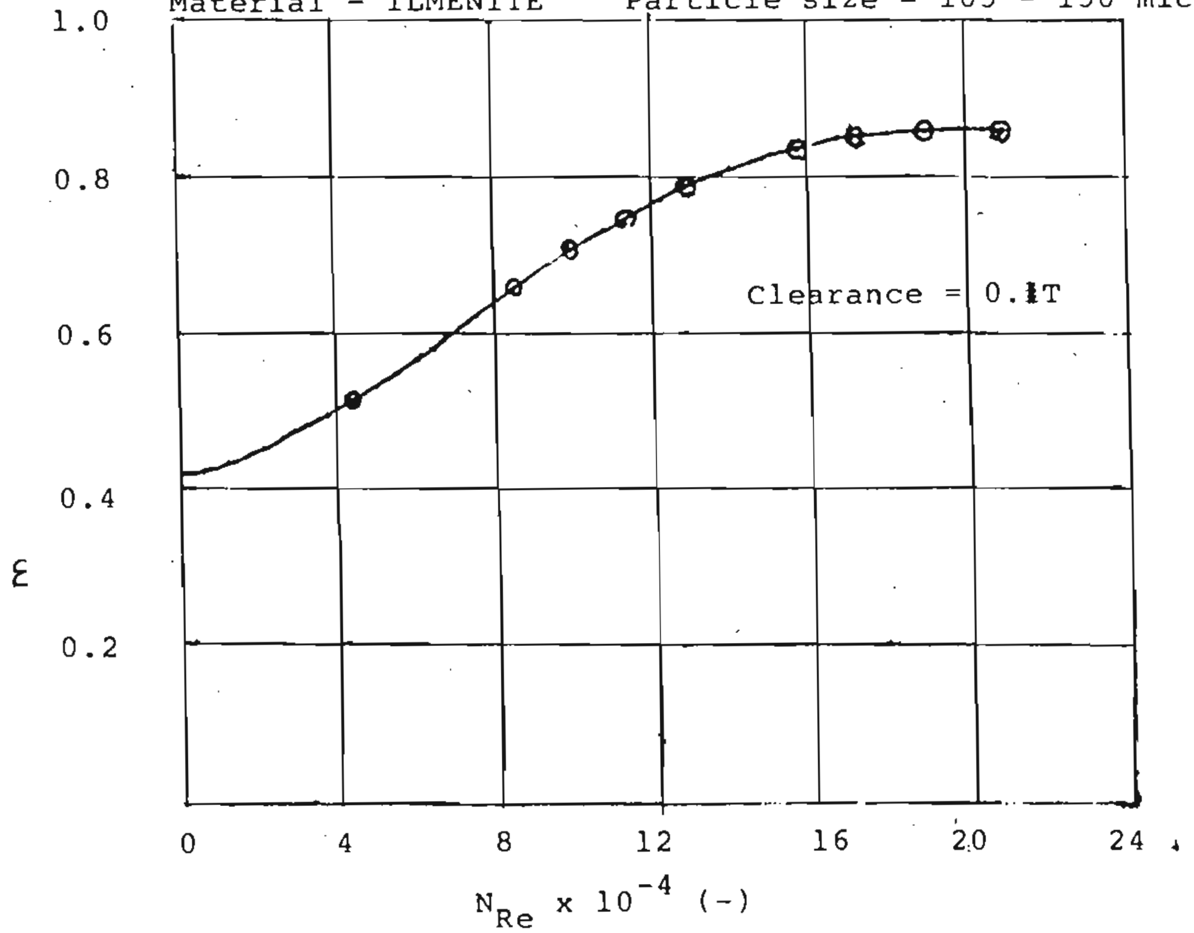


FIGURE - XXI

PITCH BLADED TURBINE

Material - ILMENITE   Particle size = 105 - 150 microns



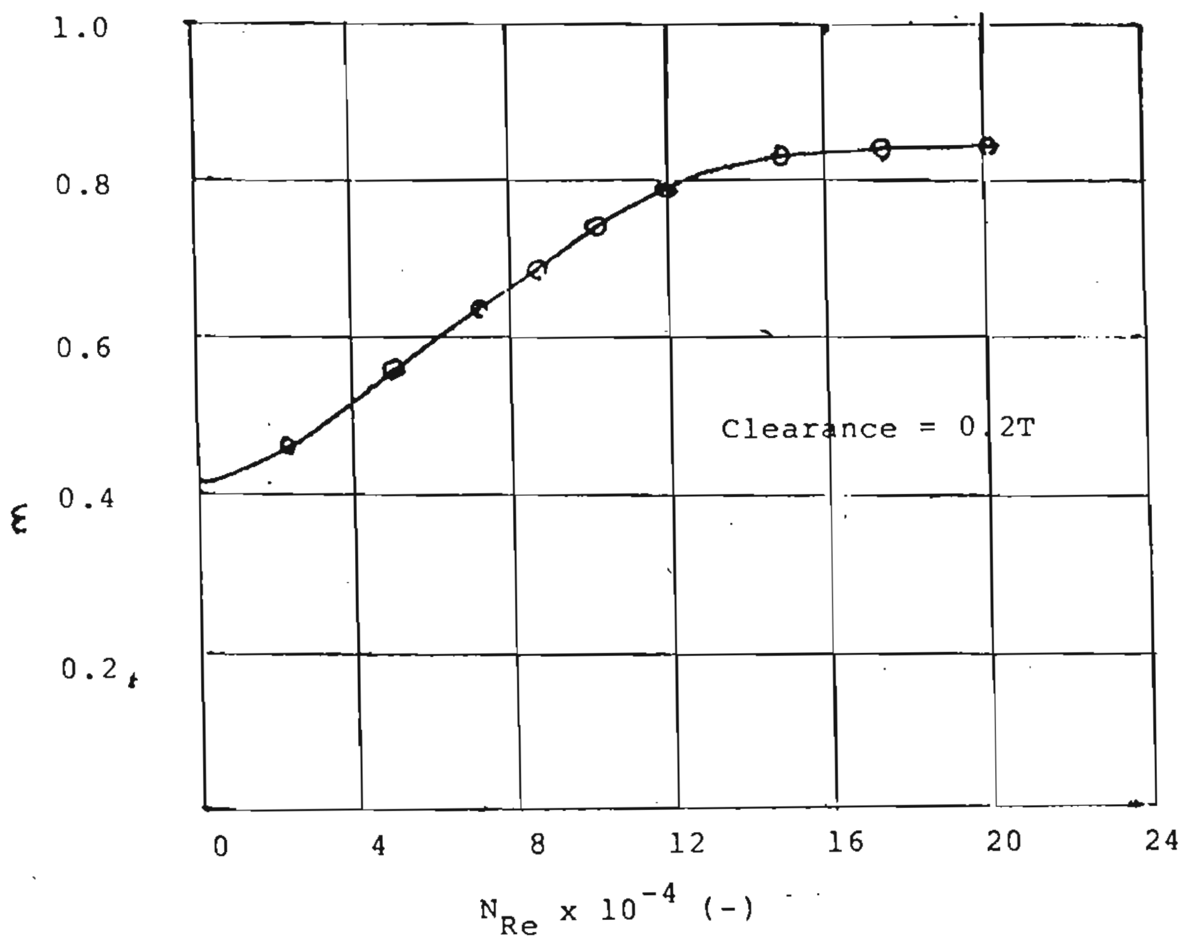


FIGURE - XXII

PITCH BLADED TURBINE

Material - ILMENITE

Particle size = 150 - 180 microns

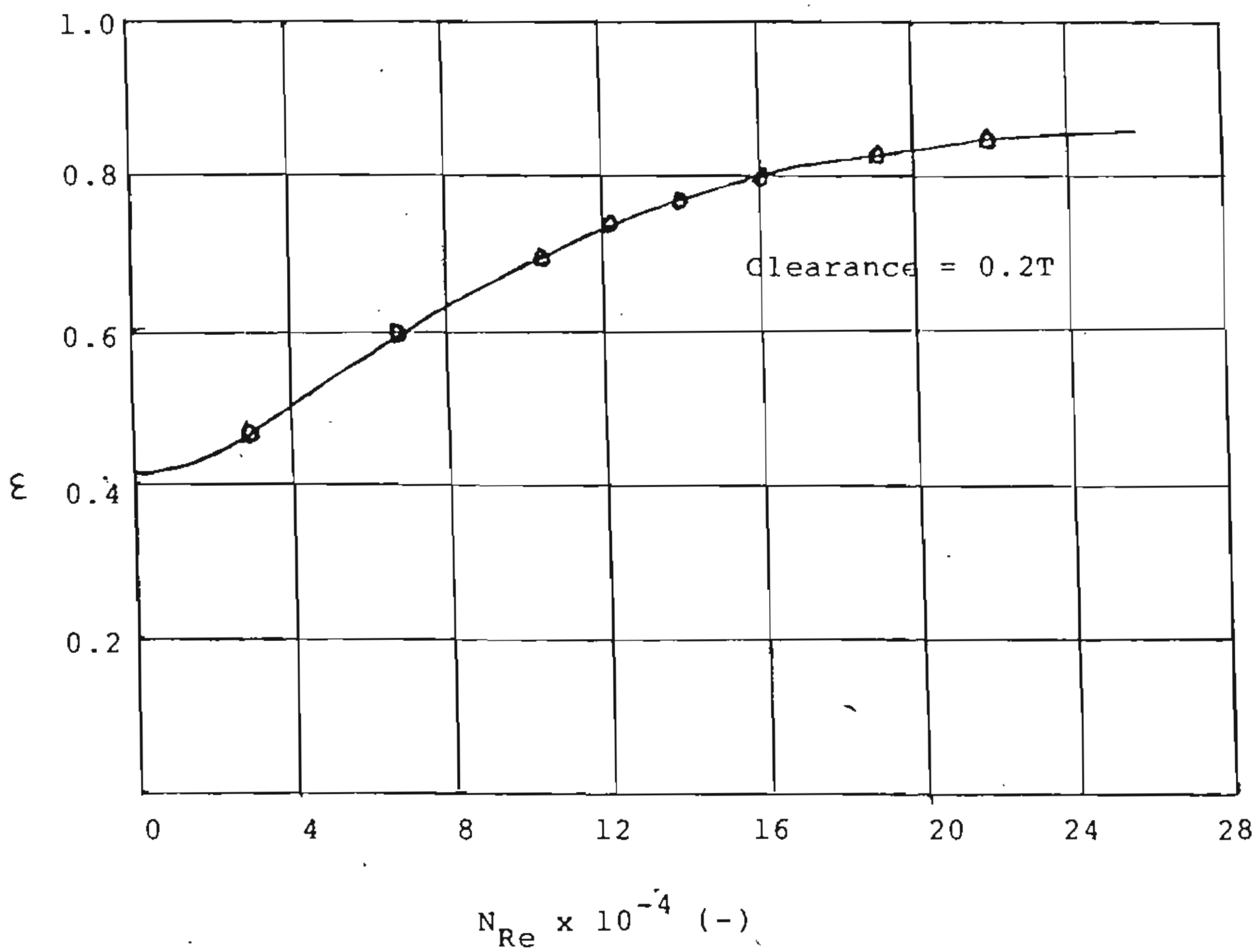


FIGURE - XXIII

TURBINE TYPE IMPELLER

Material - SAND

Particle size = 300 - 355 microns