CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF MECHANICAL ENGINEERING

GRADUATE THESIS

2018

AMIR MOHAMED AMIR ELHOSINY IBRAHIM

I declare that I work out the diploma (bachelor) thesis on my own under a supervision of the supervisor of the thesis and I cited all the materials and literature which I used in the work.

In Prague ……………… …………………

Name and Surname

BACHELOR'S THESIS ASSIGNMENT

I. Personal and study details

Student's name: **Elhosiny Ibrahim Amir Mohamed Amir** Personal ID number: **442081**

Faculty / Institute: **Faculty of Mechanical Engineering**

Department / Institute: **Department of Process Engineering**

Study program: **Bachelor of Mechanical Engineering**

Branch of study: **Power and Process Technology**

II. Bachelor's thesis details

Bachelor's thesis title in English:

Power characteristics of impellers

Bachelor's thesis title in Czech:

Příkonové charakteristiky míchadel

Guidelines:

Work out a literature search about mechanical mixing in non-baffled vessels. Focus especially on a description of power characteristics of impellers with regards to the effect of various parameters of system vessel-impeller (diameters ratio, position above vessel bottom). Try to find also some information about concentration profiles for chosen impellers, if a suspension is mixed in such vessel.
Determine experimentally a power characteristic of anchor agitator, pitched four-blade impeller and four-blade turbine. Try to compare the results with values obtained from the literature search. Carry out the experiments in different sizes of the vessels and describe the effect of the scale-up.

Bibliography / sources:

Name and workplace of bachelor's thesis supervisor:

Ing. Jiří Moravec, Ph.D., Department of Process Engineering FS

Name and workplace of second bachelor's thesis supervisor or consultant:

Date of bachelor's thesis assignment: **26.10.2017** Deadline for bachelor thesis submission: **05.01.2018**

Assignment valid until: ____________

Supervisor's signature | Head of department's signature | Dean's signature

III. Assignment receipt

The student acknowledges that the bachelor's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the bachelor's thesis, the author must state the names of consultants and include a list of references.

31.10.2017
Date of assignment receipt

Amir Ibrahim
Student's signature

Annotation sheet

Name: Amir Mohamed Amir

Surname: Elhosiny Ibrahim

Title Czech: Prikonocé charakteristiky míchadel

Title English: Power Characteristics of impellers

Scope of work: number of pages: 64

number of figures: 56

number of tables: 8

number of appendices:1

Academic year:2017/2018

Language: English

Department:Process Engineering

Specialization : Power and Process Technology

Supervisor: Jiri Moravec

Reviewer:

Tutor:

Submitter: : Czech Technical University Prague Faculty of Mechanical Engineering Department of process.

Annotation - Czech: Práce se zabývá experimentálním stanovením příkonových charakteristik mechanicky míchané nádoby s centrálním míchadlem a to pro různé typy míchadel, různá geometrická uspořádání míchaného systému a pro dvě různé kapaliny, vodu a glycerin.

Annotation - English: The thesis deals to experimentally evaluate power number dependence on Reynolds number for mechanically agitated systems with central mixing systems without baffles for various types of impellers, their geometrical set-up and for two different liquids, i.e. water and glycerine.

Keywords: Impellers; Mixing performance; Stirred vessel, Renolad Number, power number, Viscosity.

Utilization: Design of power for mixing equipment with the researched geometrical set-up.

Table of contents

Abstract

Liquid-liquid mixing is a key procedure to industries that is usually trying to accomplish mechanical agitation system. Liquid-liquid mixing execution done in mixed tank can be assessed Eventually tested for Different parameters, in particular base minimum fomentation speed, blending time, power consumption, circulation time, interfacial area. The vitality from claiming these liquid-liquid blending parameters, the estimation method will be discussed briefly. Enter parameters for example, impeller type, control number, stream pattern, number of impellers, furthermore scattered stage volume fraction, furthermore will physical properties about stages for example, such that viscosity and density, need aid reviewed. The correlation of Reylonld's number and power number and its effect on the system and the mixing process is mentioned in details in this paper.

Introduction

Mixing is very important in many industrial applications. It is physical operation in which there is a heterogeneous physical system and the intent is to make it more homogenous. The physical operation of mixing is essential for the success of a bio process. Mixing has a direct effect on mass and heat transfer, which are two key thermodynamic parameters. The equipment that we use to mix affects the agitation efficiency, power requirements, and operating costs.

Bad mixing would result in:
1. pH gradients
2. Temperature gradients
3. Compartmentalization
4. Nutrient gradients
5. Poor parameter control

In industrial mixing applications power consumption per unit volume is widely used for scale up, scale down and design. Although it's widely used, we can just define the dependence of power consumption on Impeller and tank geometry only in the most general terms. This is because it's hard sometimes to obtain accurate torque measurements on small scales.

Homogeneity and uniformity of the system is improved by one key process called mixing, and this mixing occurs when materials tend to move from one side to another in the vessel. (Rushton, 1956. The system is referred to as uniform based on gradient of properties such as concentration, viscosity, temperature (Paul et al., 2004). There are three main mixing operations gas-liquid, solid-liquid, and liquid-liquid mixing. Liquid-liquid mixing plays an important role in producing and increasing essential interfacial area to improve mass and heat transfer between phases (Paul et al., 2004). And according to van de Vusse, Liquid-liquid mixing is divided into miscible and immiscible liquid-liquid mixing. The term ‘‘blending’’ is used to describe miscible liquid mixing, while the term ‘‘mixing’’ is used for dispersions of immiscible liquids or the formation of emulsions (Rushton, 1956). The dispersion of immiscible liquids is used to mix water and hydrocarbons and acidic or alkaline solutions combined with organic liquids, and produce various types of emulsion products. Also, according to Paul,. Liquid-liquid mixing is applicable for special process objectives such as solvent extraction and removal or addition of heat. Generally, blending of miscible liquids happens slowly by molecular diffusion and natural convection. Thus, agitation systems can apply forced convection to obtain homogeneity more rapidly (Rushton, 1956). Tanks and vessels are the most accessible and universal equipment used in a wide range of process industries such as esterification and hydrolysis (Paul et al., 2004). Furthermore, inadequate understanding of mixing could result in undesirable product quality and increased production costs. Nevertheless, it is possible to waste large amounts of input energy through inappropriate system selection (Holland and Bragg, 1995). Mixing operations are often complex. They not only require understanding the fluid flow aspects, but also consideration of the mechanical equipment and power requirements.

Part 1: Literature review

This model was used as a study material at Dlian university of technology, Biomass course(Life.dlut.edu.cn). I will be explaining it as a typical design of mixing tanks. Figure(1) shows a representation of the tank.

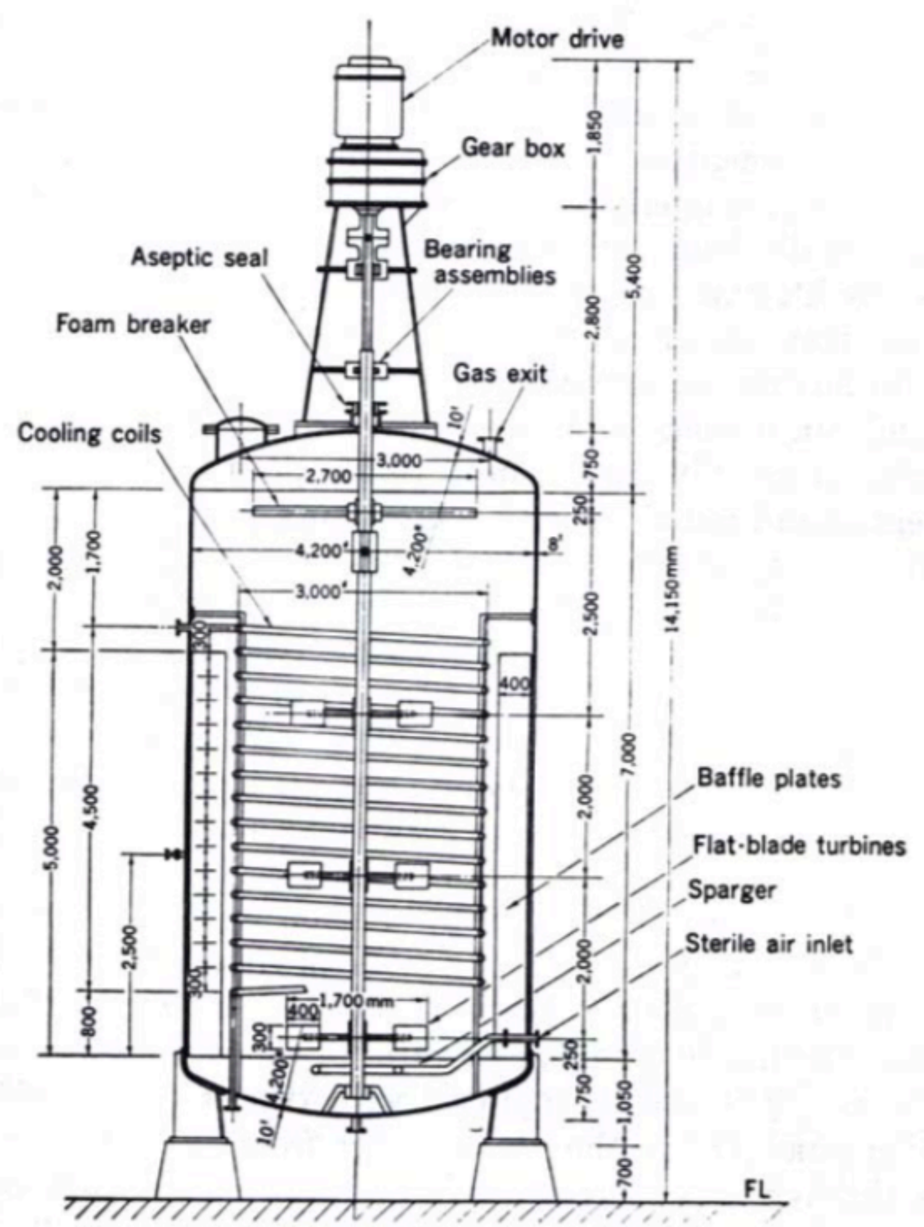


Figure 1. A standard tank with a working volume of 100 M3 and used for penicillin production

1. Mixing Equipment

Mixing takes place mostly in cylindrical stirred tanks; to eliminate sharp corners and pockets in which fluid would get stagnant, the design of the base better be rounded at the edges rather than angled. In a Mixer, there are several components such as: an impeller, shaft, shaft seal, gearbox, and a motor drive. Once the impeller starts rotating it pumps the liquid creating a regular flow thus mixing the particles. The depth of the liquid in the tank shouldn't exceed 1.0-1.25 times the tank diameter. Figure 2 below, shows a typical; configuration of stirred tank.

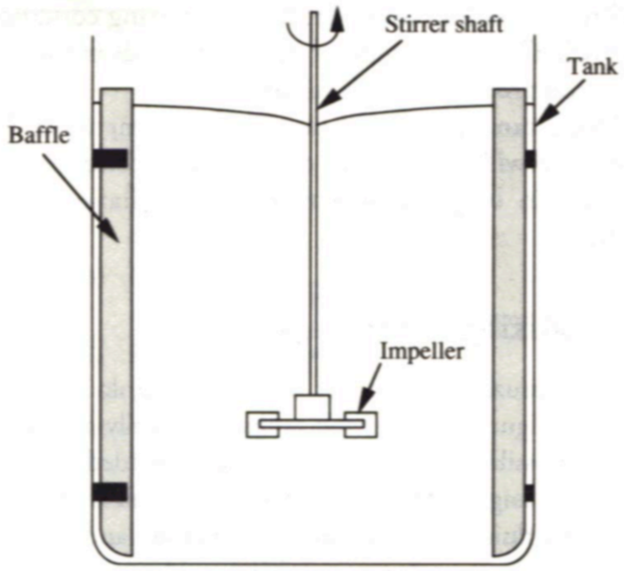


Figure 2. Typical configuration of a stirred tank

Baffles

Baffles are sometimes installed to help reduce vortexing of the liquid. Baffles as shown in figure (3) are vertical metal strips mounted on the wall of the vessel. They are attached to the wall by welding brackets. To prevent the liquid from swirling and forming vortex, two or four equally spaced baffles are usually sufficient depending on the task.

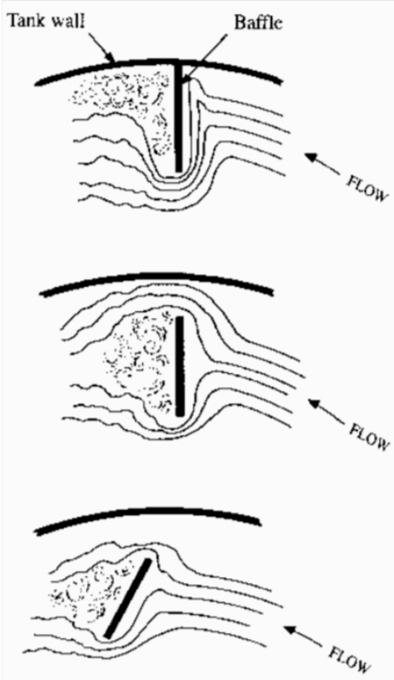


Figure 3. Baffle arrangements.

Stirrer shaft

The main function of the stirring shaft is to transmit the torque from the stirrer motor to the impeller; It also have more mechanical functions like resisting the bending force that is created by the impeller, limit lateral deflections and support the weight of the impeller. All these functions must be reached with the least vibration. Typically, the stirring shaft shown in (figure 4) passes through a motor that is placed on the top of the vessel but in some cases when mixing viscous fluids, the shaft is designed to enter through the base of the vessel to alleviate mechanical stresses. The main disadvantage of bottom entering stirrers is that there is a risk of fluid leaks due to failure of wearing of the seals.

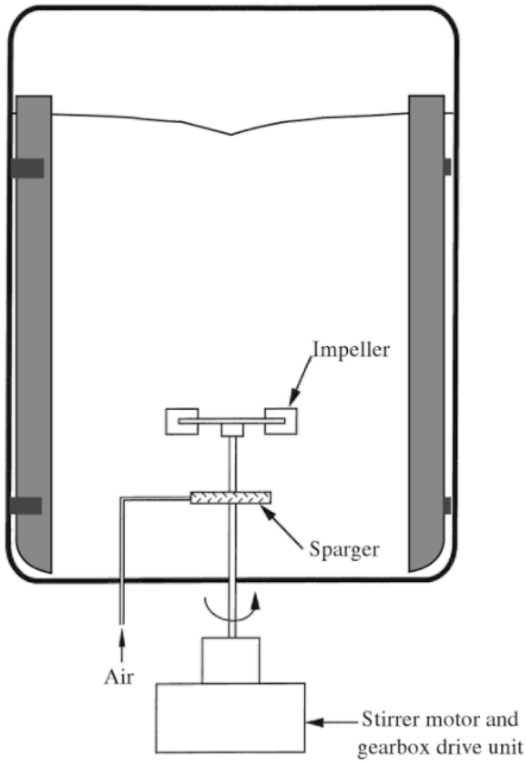


Figure 4. A Vessel with bottom entering stirrer.

Impellers

There are many varieties of impeller designs that are available for different mixing procedures as shown in figure (5). Impellers are picked based on their shear and fluid flow patterns. There are several factors for choosing an impeller including the viscosity if the liquid and how sensitive the system is to mechanical shear. Its recommended to use propellers and flat-blade turbines for low to medium viscosity liquids. 6- flat-blade disc-mounted turbine shown in Figure (6) is the most frequently used impeller in fermentation industry; this impeller is known as Rushton turbine.

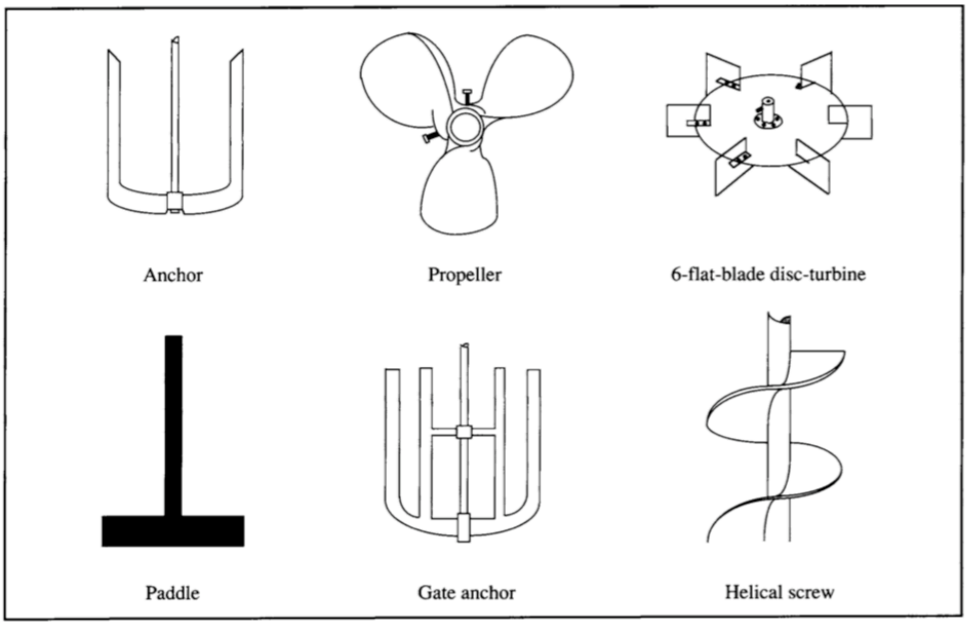


Figure 5. Impeller designs.

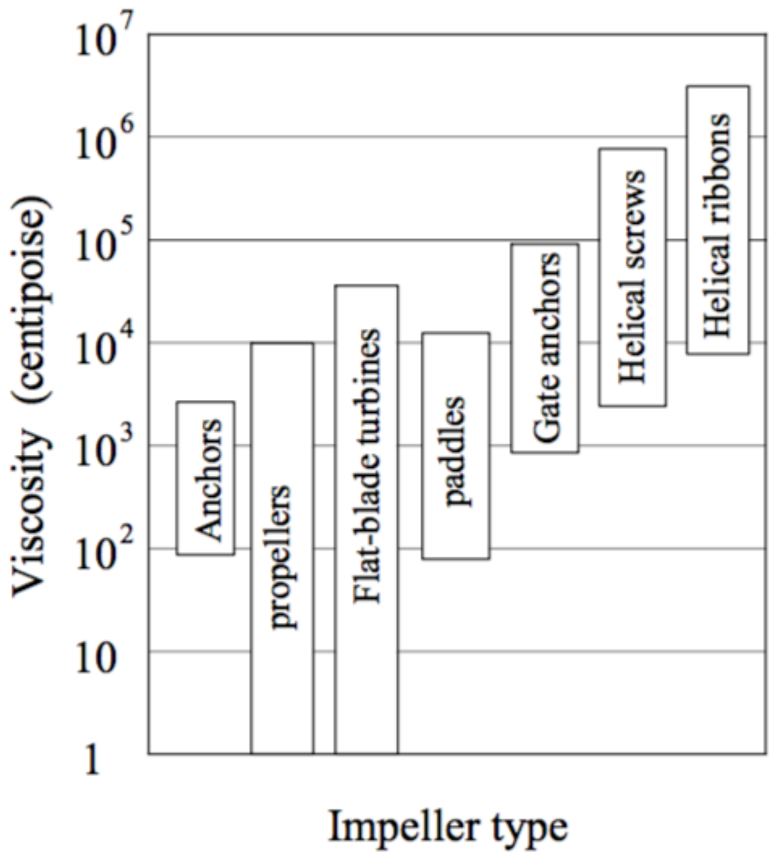


Figure 6.Viscosity ranges for different impellers.

2. Mechanism of Mixing

Poor performance in mixing can be caused different factors. One of them is large liquid circulation loops. For mixing to be successful, fluid coursed by the impeller must sweep the whole vessel in a sensible time. What's more, the speed of liquid leaving the impeller must be adequate to convey material into the most remote parts of the tank. Turbulence should likewise be produced in the fluid; Mixing is sure to be poor unless there is a turbulent stream in the vessel. These are the essential factors in blending, which can be portrayed as a mix of three physical procedures: circulation, scattering and dissemination.

Distribution is the procedure whereby materials are transported to all locales of the vessel by bulk circulation currents. In mixing, distribution is really important, however it can be moderately slow. The size of the circulation flows is big in large tanks and the time taken to cross them is long; this and how regular the fluid pumping at the impeller hinders quick mixing. Therefore, distribution is the slowest step in mixing.

But if the rotational speed of the impeller is adequately high, turbulence is superimposed on the process of distribution. Turbulence stream happens when the fluid stops traveling along streamlines but moves inconsistently in cross currents.

3. Flow Patterns in Agitated Tanks

The flow pattern is the direction of the velocity vectors through an agitated vessel. The direction and the magnitude of velocity is important to predict how the fluid respond to the impeller. As shown in figure (7)

The flow pattern in an agitated tank depends on these main points:

- impeller design
- the properties of the fluid,
- the size and geometric proportions of the vessel, baffles and agitator.

Impellers can be classified as Axial flow impellers and Radial flow impellers:

Axial-flow impellers

The flow pattern produced by typical axial flow impeller produces an excellent top to bottom motion when the agitator is center mounted so it's mainly used when we have solid particles in the solution, and this movement in flow discourages these particles to lay at the bottom.

Radial-flow impellers

Radial-flow impellers have blades which are parallel to the vertical axis of the stirrer shaft and tank.

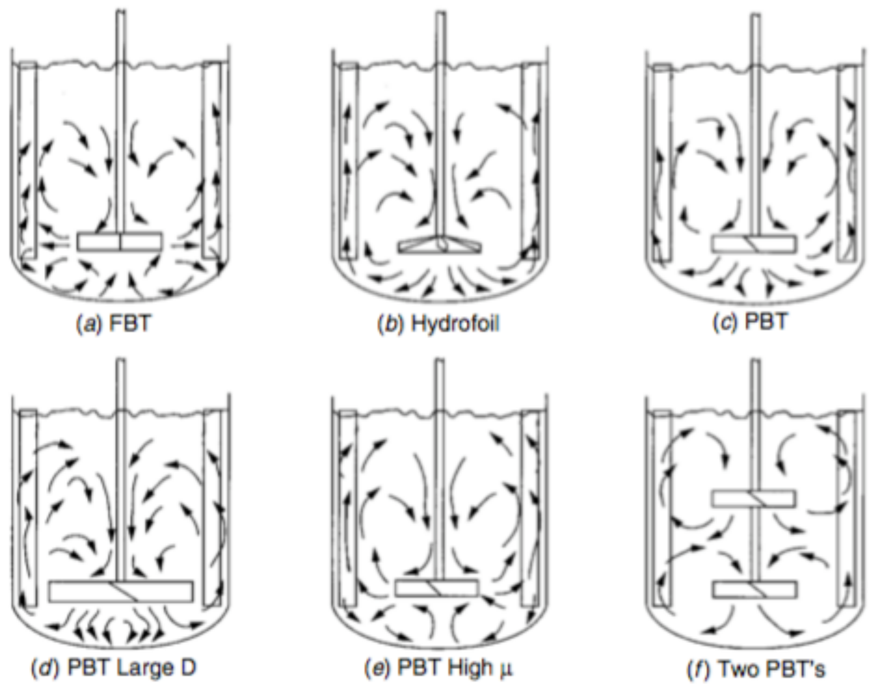


Figure 7.Flow patterns with different impellers, impeller diameter, and liquid viscosity.

Circular flow of liquid around the shaft is disadvantageous because sometimes when the impeller speed is high the vortex reaches the impeller allowing surrounding gas to be drawn into the fluid adding a lot of stress on the stirring shaft and the bearings. To avoid this, we usually introduce baffles which interrupts this circular flow and creates turbulence. This holds for both axial and radial impellers.

4. Power Requirements for Mixing

The earliest studies we have on power consumptions date back to the beginnings of the 1940s; The study by Rushton et al. is yet considered the first definitive in the field. Rushton et al. used dimensional analysis to develop several dimensionless groups, one of them is the Power Number N_p

The power that is consumed by an agitator mainly depends on the stirrer speed, the geometry of the vessel and the impeller, and the physical properties of the fluid such as density and viscosity. The power required for a given stirrer speed depends on the resistance of the fluid to rotation speed of the impeller. The relationship between these variable is often expressed in dimensionless number such as the impeller Reynolds number (Re) and the power number (Np).The Equations are shown bellow. The electric power consumed by the motor is greater than the mixing power by an amount that depends on the efficiency. This is mainly happening because there is always friction in the stirrer motor gear box and the seals which reduces the amount of energy transmitted to the fluid.

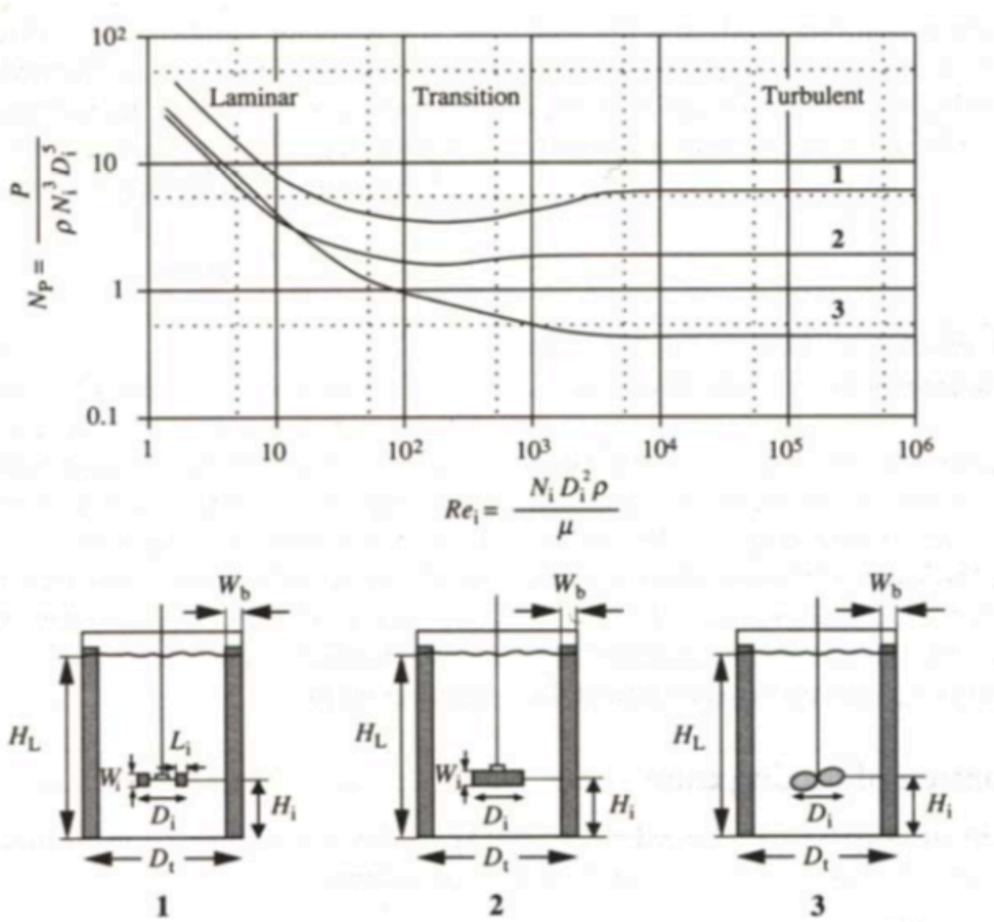
$$P = 2 * \pi * Ni * M \text{........(1)}$$

$$Re = \frac{Ni * D^2 * \rho}{\mu} \text{..............(2)}$$

$$Np = \frac{P}{\rho * Ni^3 * Di^5} \text{............(3)}$$

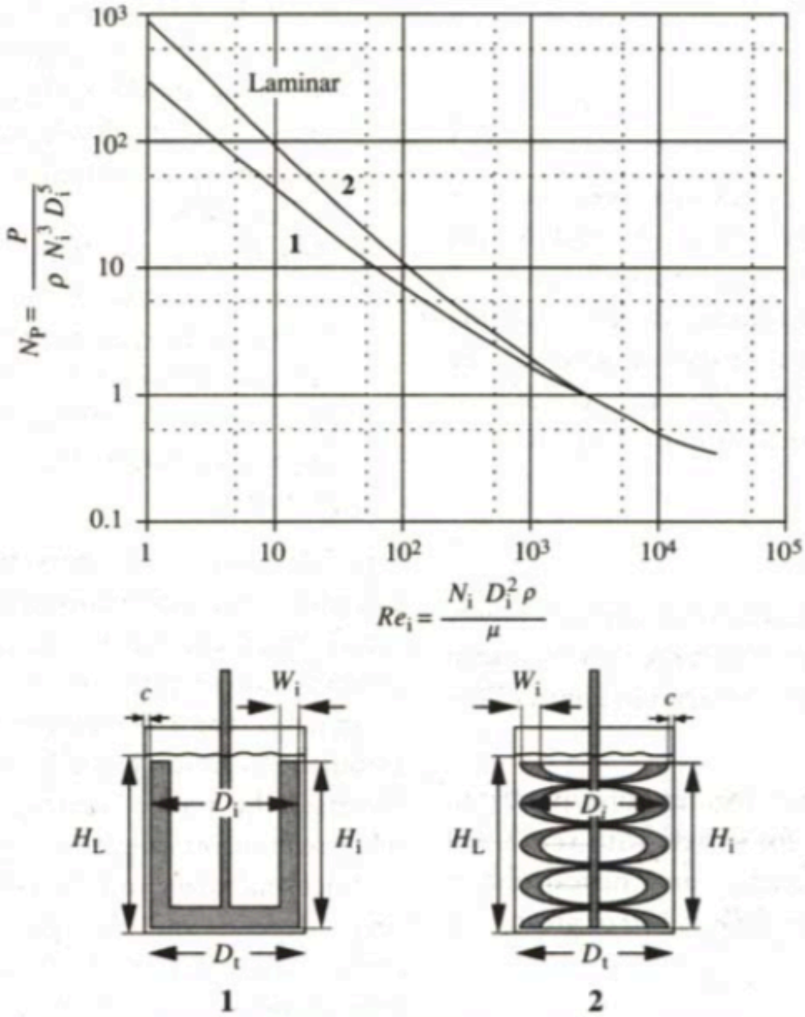
Equations 1, 2 and 3

Processes in mixers occur either under laminar or turbulent flow conditions; It depends on the Reynolds number of the impeller. process is laminar For Reynolds numbers below about 10; At Reynolds numbers higher than about 10^4 , fully turbulent conditions are achieved, and between these 2 regimes the flow is transitional. Figures (8,9, and 10) relates impeller size, power number, and Reynold number.



Impeller	D_t/D_i	H_L/D_i	H_i/D_i	Baffles	
				W_b/D_t	Number
1. Rushton turbine $W_i/D_i = 0.2$, $L_i/D_i = 0.25$	3	3	1	0.1	4
2. Paddle $W_i/D_i = 0.25$	3	3	1	0.1	4
3. Marine propeller Pitch = D_i	3	3	1	0.1	4

Figure 8. Correlation between power number and Reynolds number for Rushton turbine, paddle and marine propeller without sparging



Impeller	D_t/D_i	c/D_i	H_i/D_i	W_i/D_i
1. Anchor	1.02	0.01	1	0.1
2. Helical ribbon	1.02	0.01	1	0.1

Figure 9. Correlation between power number and Reynolds number for anchor and helical-ribbon impeller without sparging

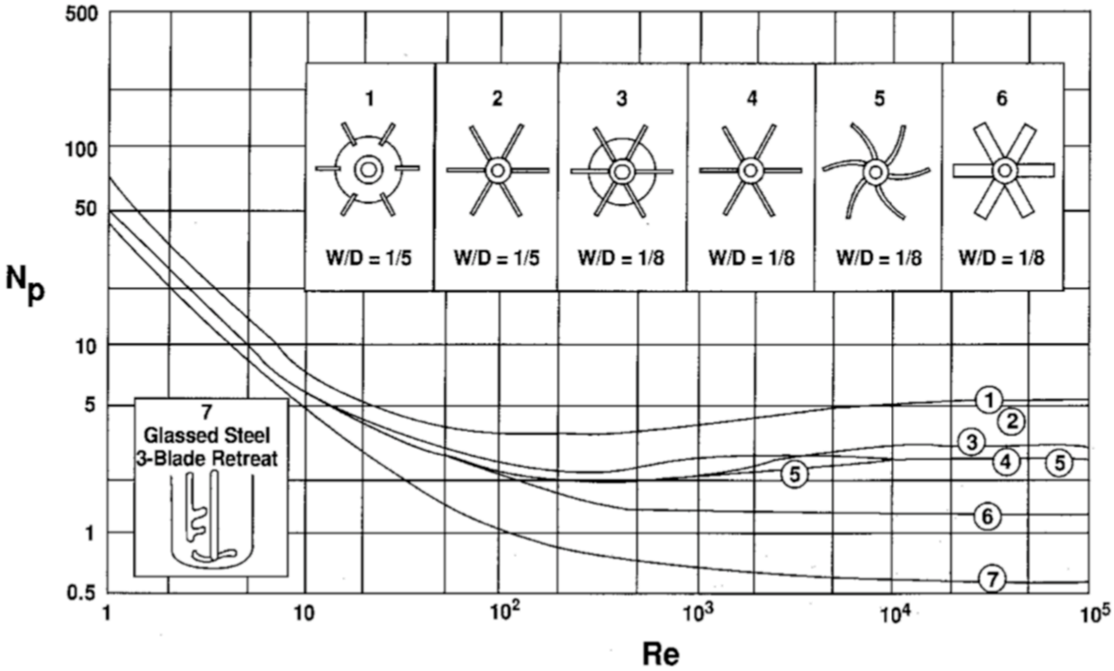


Figure 10. Power number versus impeller Reynolds number for seven different impellers. (Modified from Rushton et al., 1950.)

5. Assessing Mixing Effectiveness

Mixing time is a helpful parameter for evaluating efficiency of mixing and is applied to portray bulk stream in fermenters. The mixing time t_m is the time required to accomplish a given level of homogeneity beginning from the totally segregated state. It can be aquired by infusing a tracer into the vessel and following its focus at a settled point in the tank. Tracers in like manner utilize acids, bases and salt solutions (concentrated);detectors are pH probs and conductivity cells. Mixing time can likewise be dicta*. Concentration response after tracer is injected into a stirred tank is shown in figure(11).*

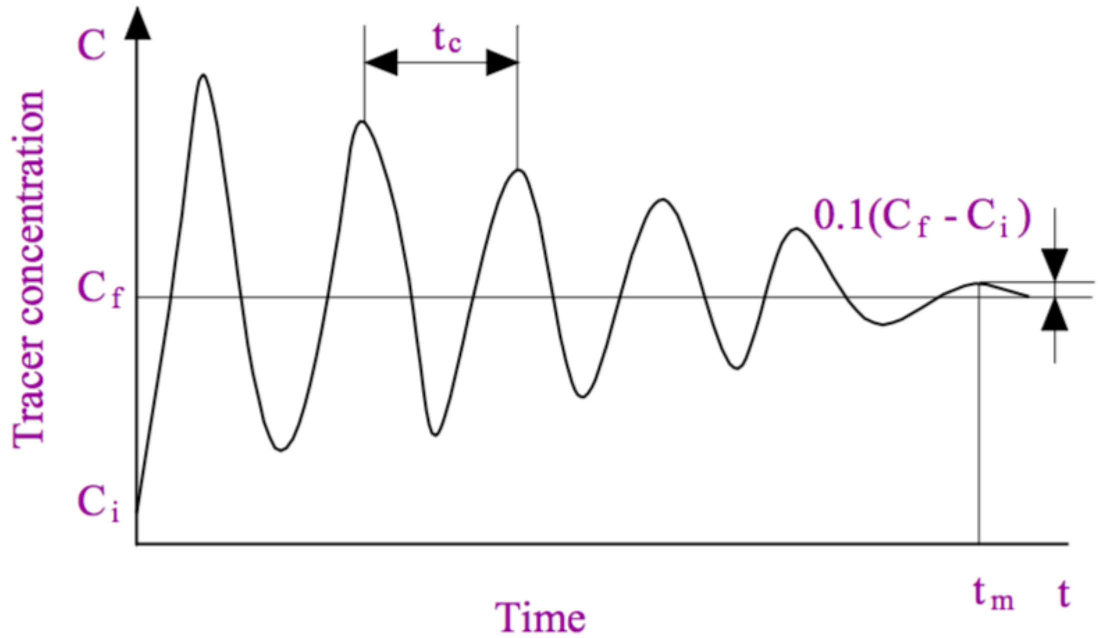


Figure 11. Concentration response after tracer is injected into a stirred tank

6. Effect of Rheological Properties on Mixing

For mixing to be effective turbulent conditions should be achieved. Impeller's Reynolds number represents how intense the turbulence is; Once it falls bellow criteria the turbulence is damped and therefore mixing time increases in a significant way. Re decreases indirectly proportional to the increase in viscosity; That's why non-turbulent conditions and poor mixing always result during mixing high viscous fluids. You can solve this by increasing the impeller speed but this would require increasing the power consumption. When we want to measure rheological properties of fluids using impellers, we have to be in the laminar (creeping) regime of the flow, so that power number would depend on Re ,and thus the viscosity can be determined.

7. Improving Mixing

In some cases, it's not possible to reduce the time of mixing by raising the input power into the stirrer. So instead of increasing the stirrer speed there are other various techniques to improve fluid circulation. We can improve the mixing in our system by installing baffles; This routine is for stirrer fermenters, and it produces greater turbulence. For efficient mixing, we should place the impeller below the geometric center of the vessel. The impeller in standard designs is located with a distance about one impeller diameter or one-third the tank diameter above the bottom of the tank.

Mixing is eased when the currents above the impeller are bigger that those below; Basically, the fluid particles would leave the impeller at the same time but takes different periods of time to return and exchange material. When upper and lower circulation loops are asynchronous, the rate of distribution throughout the vessel increases.

To improve mixing we can also use multiple impellers as shown in figure(12), but you must add in consideration that this will require an increase in the power input. Bioreactors are usually tall cylindrical vessels with liquid depth that is greater than the tank diameter. This design results in a higher hydrostatic pressure at the bottom of the vessel, and gives the rising air bubbles a longer contact time with the liquid. To achieve mixing effectively in tall fermenters, it requires the use of more than one impeller.

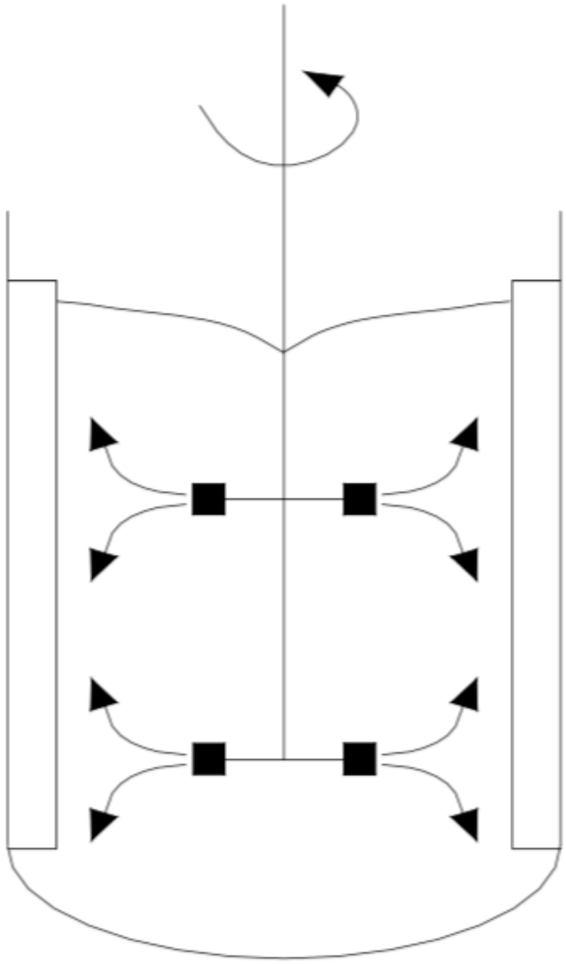


Figure 12. Multiple impellers in a tall fermenter

Objective:

The general approach of this experiment is to find the correlation of Reylonld's number and power number and its effect on the system and the mixing process. Also, the effect of impeller type, control number, stream pattern, number of impellers, volume fraction, and some physical properties, such that viscosity and density on the mixing process.
The goal of my work is to determine power characteristics of anchor agitator, pitched four-blade impeller and four-blade turbine, and then compare these results to the values I provide through Literature search. Therefore, to describe effects of geometrical parameters on mixing processes.

Part 2: Experiments

1. Methods and Equipment

The experiments were carried out in 3 Vessels with different diameters. There were used 3 different types of impellers in each vessel. (4RT , 4PBT and Anchor) as shown in the table 1.
Experiments were done using water and glycerin separately; the aim is to be able to measure in wider range of Reynolds numbers since the higher viscosity liquid needs higher torque (power) at the same speed. The depth of the liquid in the tank is equals to 1.0 times the tank diameter. Reynolds numbers were investigated covering the range from low transitional to fully turbulent flow. The geometry of used equipment(impellers , vessels) is shown in figures (13, 14) respectively.

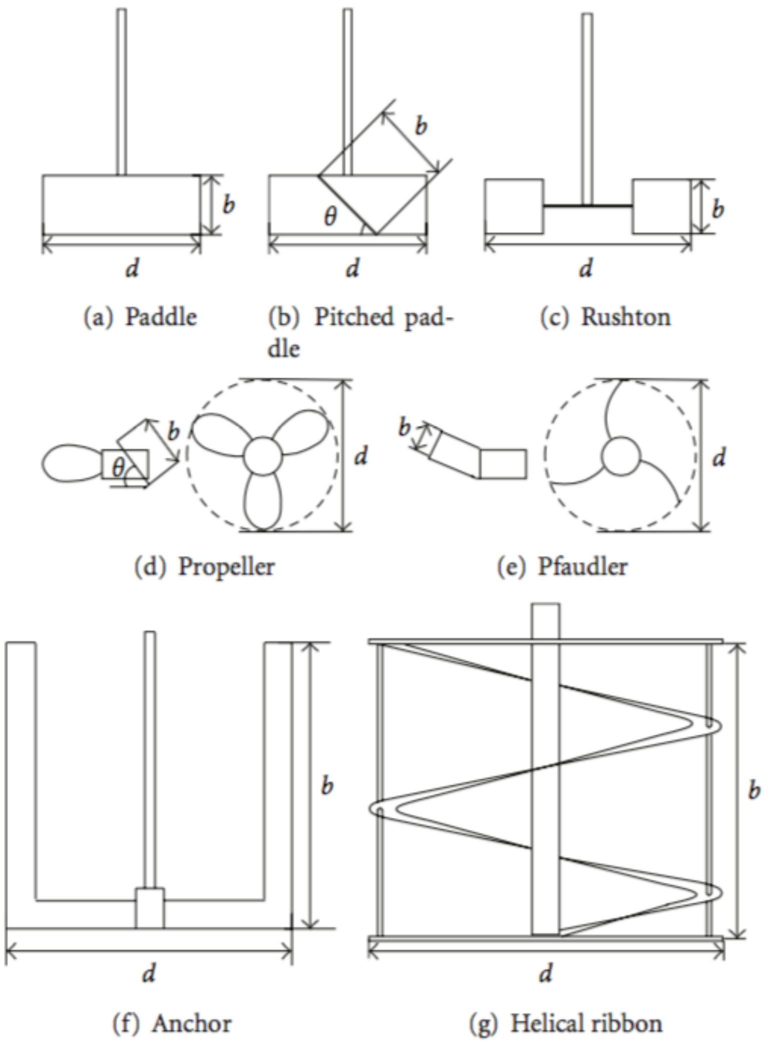


Figure 13. Geometry of mixing impellers

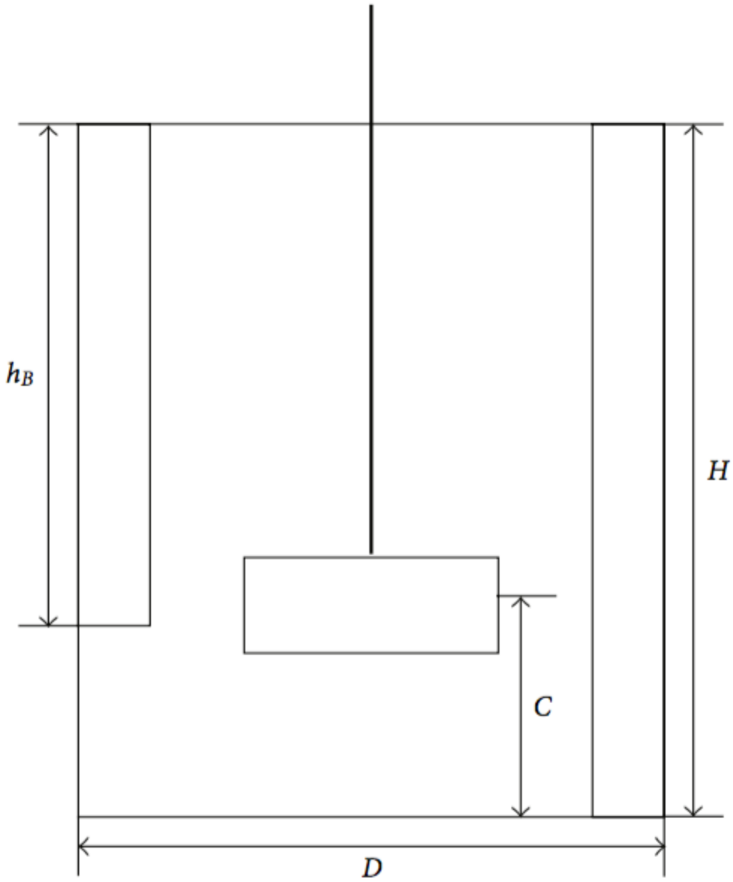


Figure 14. Geometry of mixing vessel

Vessels

The three vessels used have Diameters of 70 , 100 , 140 mm. The depth of the fluid in the tank is equals to 1.0 times the tank diameter. Pictures of the vessels used. fig(15)

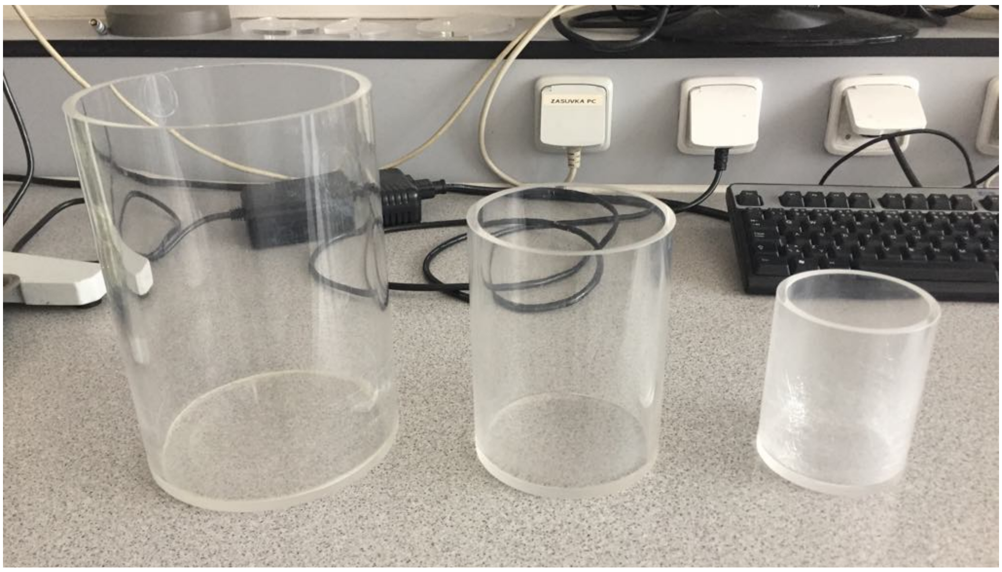


Figure 15.Vessels used in experiments with Dv=70,100,140

Impellers

Pictures Of impellers 4RT, 4PBT and Anchor are given in Figure.(16). Their dimensions are given in details in Table (1). In water, Experiments were done twice in each vessel for impellers 4Rt and 4PBT; impellers were located one time at an off-bottom clearance $C=0.5D_{imp}$,and another time at $C=D_{imp}$ .On the other hand, Anchor impeller was located with clearance $C=0.055D_{imp}$.

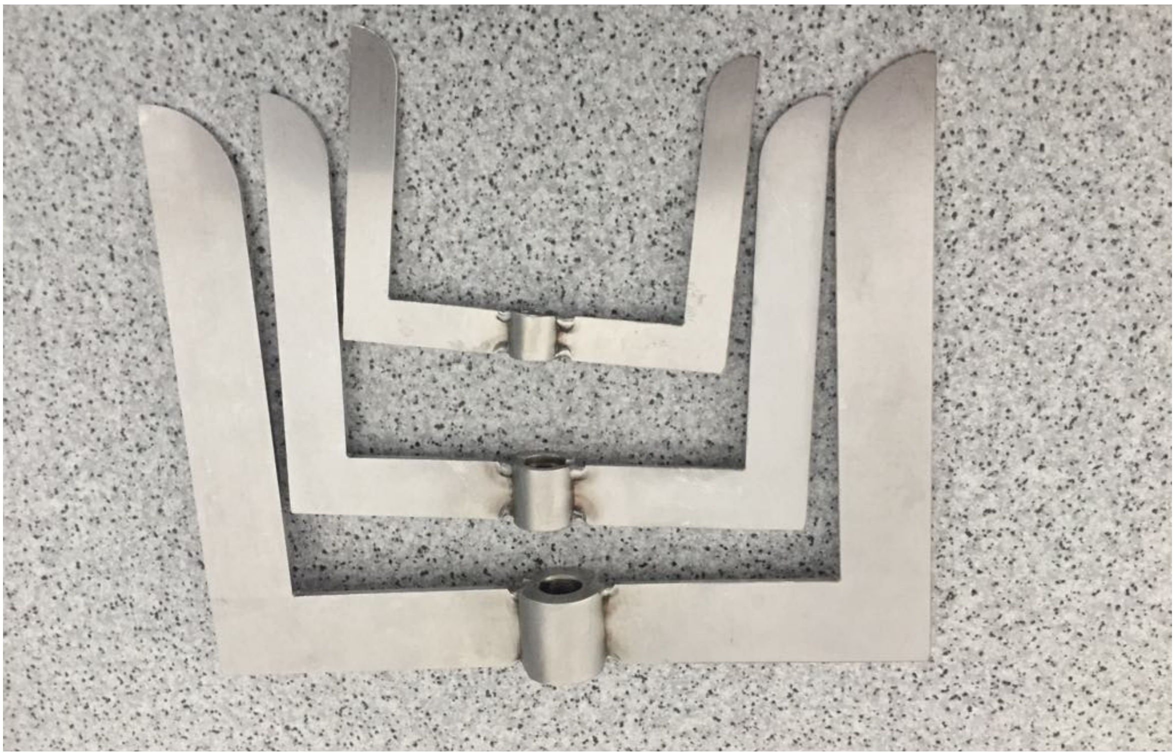


Figure 16. The Impellers used in the experiment

		Dv		
		70	100	140
Impeller	4RT	35,3	49,1	69,75
	4PBT	35	50	70
	Anchor	63,4	90,2	126

Table 1. Dimensions of impeller in each vessel

Viscometer

The Viscometer used for the tests is RheoTec RC20 as shown in fig(17) . Its maximum torque is 50 mNm and maximum rotations is 800 rpm.

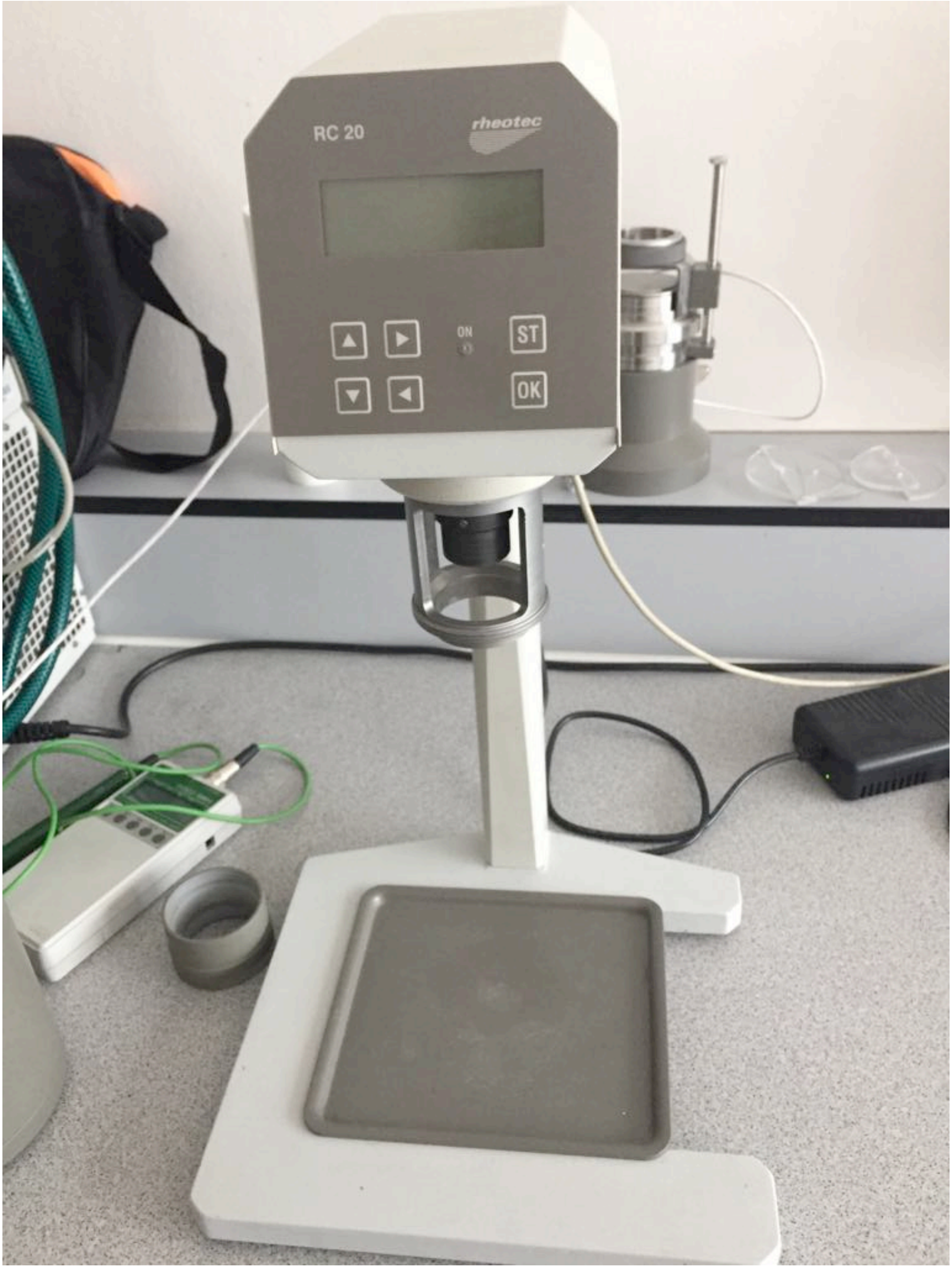


Figure 17. Viscometer

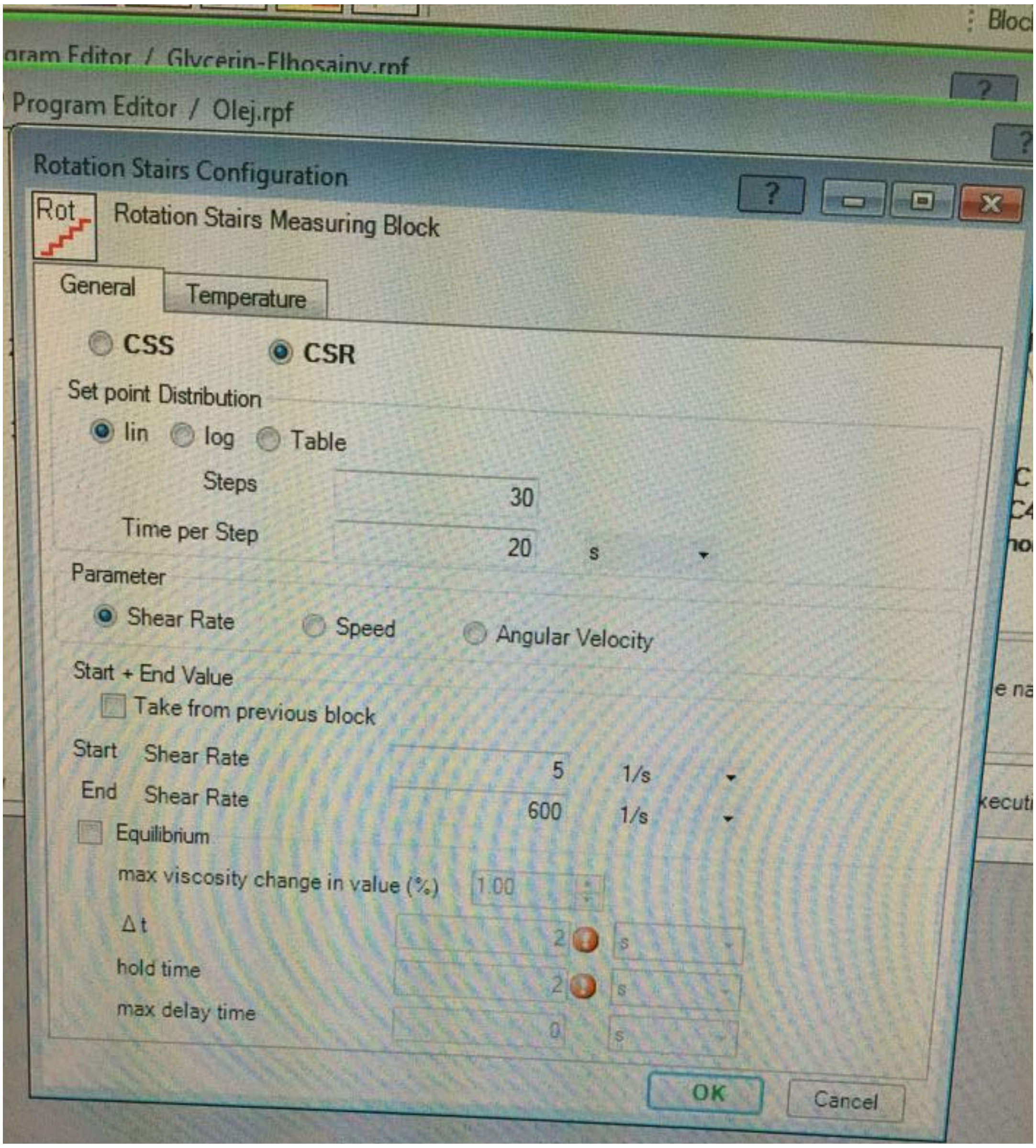
2. The torque measurements

Torque measurements were taken over a wide range of RPM for each tested impeller. To ensure that steady state measurements were reached the dynamics had to be closely watched.

Data is collected through the software RheoWin(18) . Before each experiments you have to set some parameters in the program like how many steps do you need in which speed changes gradually in each step, the time during each step, starting Speed, Maximum Speed as shown in Fig.(19) Each experiment for each impeller starts at step no. 1 with the starting speed set depending on the impeller and time during each step is set to 20 seconds. After each step the velocity increases till it reaches step no. 30 with maximum speed (Set depending on the impeller). Then it starts reducing again gradually till it Reaches Starting Speed again. Starting and ending speeds, shown in table (2), are checked manually and separately before each experiment so that we are sure it’s the sufficient speed for the impeller concerning torque limits and vortex formation.

All the data are recorded after each step then exported in an excel sheet later and used to analyze readings and make various calculations to detect the power characteristics of each impeller in each vessel tables (6,7,8). Vortex was also measure during each experiment in which I monitored when it starts and take measurements of the height of the vortex at step no. 30 (maximum speed) as shown in Fig(25). I also made some charts showing in which step did the vortex start and end as shown in fig.(24)

Viscosities and Densities were selected according to the standard tables of Water and Glycerin within given temperatures measured during the experiments, as shown in Tables (2-5)


Program Editor / Olej.rpf
Rotation Stairs Configuration
Rot
Rotation Stairs Measuring Block
General
Temperature
CSS
CSR
Set point Distribution
lin
log
Table
Steps
30
Time per Step
20
s
Parameter
Shear Rate
Speed
Angular Velocity
Start + End Value
Take from previous block
Start
Shear Rate
5
1/s
End
Shear Rate
600
1/s
Equilibrium
max viscosity change in value (%)
1.00
Δt
2
hold time
2
max delay time
0
OK
Cancel

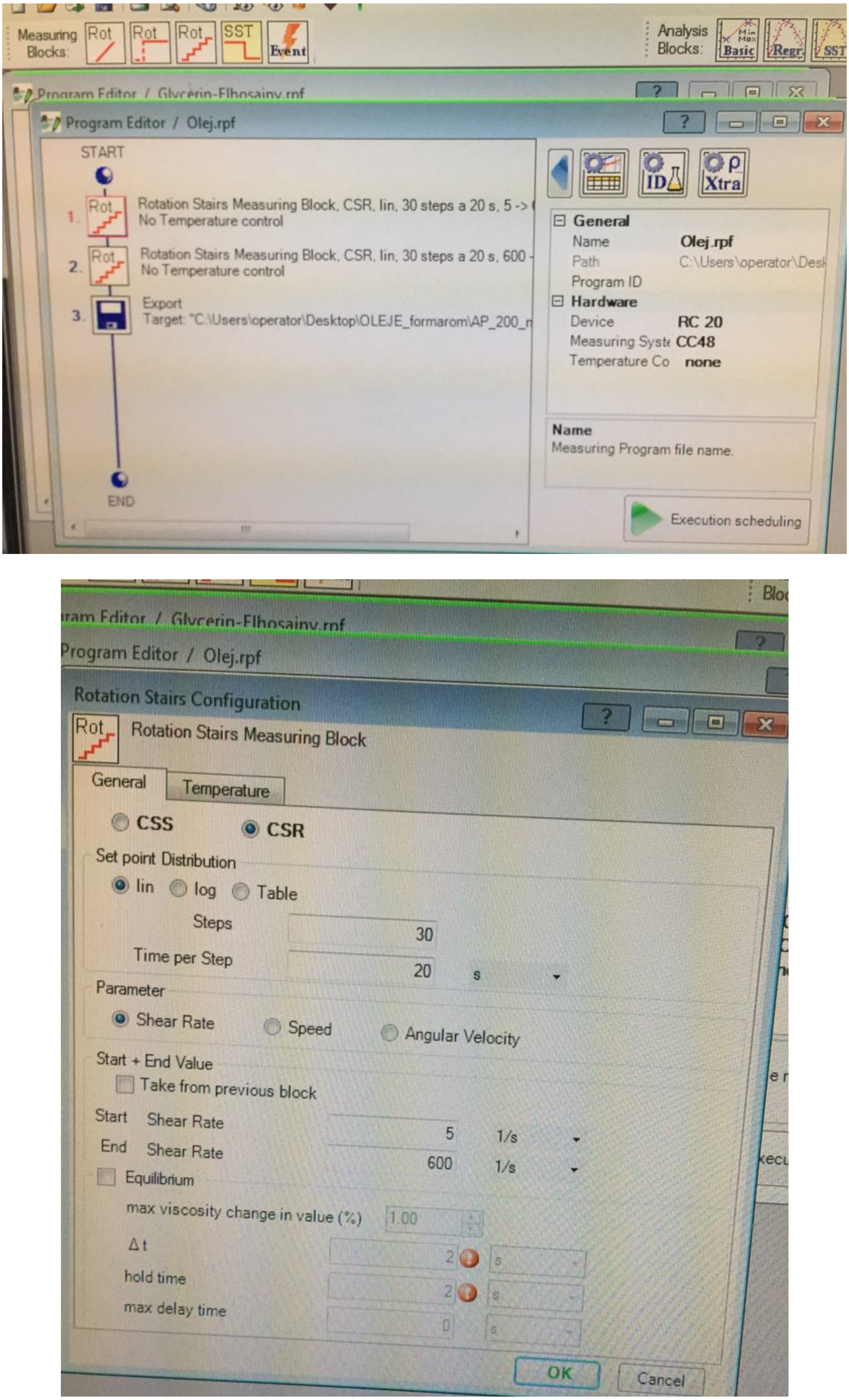


Figure 18. Setting parameters for experiments on RheoWin software.

3. Viscosity and temperature tables

	Dv	70		100		140	
Impeller		Temperature	Viscosity	Temperature	Viscosity	Temperature	Viscosity
4RT	Initial	20,3	0,6179	20,1	0,6261	20,6	0,6101
	Final	20,5	0,6133	20,5	0,6133	20,7	0,6069
4PBT	Initial	20,4	0,6165	20,4	0,6165	20,7	0,6069
	Final	20,6	0,6101	20,7	0,6037	20,8	0,6037
Anchor	Initial	20,5	0,6133	20,8	0,6037	20,5	0,6133
	Final	20,7	0,6069	21,2	0,5909	20,6	0,6101

Table 2. Viscosity values chosen from the standard tables of Glycerin viscosity according to the temperature values obtained from experiments for several impellers in 3 different Vessels Dv=70,100,140

	Dv	70		100		140	
Impeller		Temperature	Viscosity	Temperature	Viscosity	Temperature	Viscosity
4RT	Initial	28,3	0,0008297	26,4	0,000865	18,4	0,001041
	Final	27,5	0,000844	26,2	0,000869	18,2	0,001046
4PBT	Initial	27,3	0,000848	27,3	0,000848	27,4	0,000846
	Final	25,7	0,000878	26,8	0,000857	27,2	0,0008497

Table 3. . Viscosity values chosen from the standard tables of water viscosity according to the temperature values obtained from experiments for several impellers in 3 different Vessels Dv=70,100,140

	Dv	70		100		140	
Impeller		Temperature	Viscosity	Temperature	Viscosity	Temperature	Viscosity
4RT	Initial	26,3	0,0008667	26,2	0,000869	18,3	0,0010437
	Final	26,2	0,000869	26,1	0,000871	18,2	0,0010462
4PBT	Initial	26,7	0,000859	26,8	0,000857	27,2	0,0008497
	Final	26,5	0,000863	26,6	0,000871	27,5	0,000844

Table 4. . Viscosity values chosen from the standard tables of water viscosity according to the temperature values obtained from experiments for several impellers in 3 different Vessels Dv=70,100,140

	Dv	70		100		140	
Impeller		Temperature	Viscosity	Temperature	Viscosity	Temperature	Viscosity
Anchor	Initial	18,7	0,001034	18,7	0,001034	18,4	0,001041
	Final	18,8	0,001031	18,8	0,001031	18,5	0,0010386

Table 5 . Viscosity values chosen from the standard tables of water viscosity according to the temperature values obtained from experiments for several impellers in 3 different Vessels Dv=70,100,140

Part 3: Results and discussion of practical part

At this stage I have the values of speed , density, viscosity , torque and diameter of the impeller; As you can see in tables (6) and (7),(8) , the software extract the results to an excel sheet which I added more parameters like density and viscosity.So now i can calculate the Reynold's number and power then power number using the equations (1,2,3). After obtaining results for Re and Np I made a graph for each experiment to explain their relation, as show in Fgures (19-48) . Values of torque less than 0.2 mNm were neglected for more precise results. Measured vortexes during experiments are plotted on charts Fig(25). Reynolds number which is referred to sometimes as the impeller's Reynolds numbers. At High Reynolds number, the power number tends to be independent of the impeller Reynolds number and dependent only on the geometry. The Reynolds number increases with the square of the vessel size for the same rotational speed. While power number is contestant and independent of the Reynolds number in baffled systems in Reynolds number above 10^3-10^4, depending on the impeller. Results of this correlation of Re and Np is shown in figures (50-56) in which I have chosen three random values of impellers diameter which means vessel size as well. Each vessel with had a constant speed of impeller for the particular value chosen, then to be resulted is how Re and Np change respectively.

Angular Vel	BlockIndex	BlockNumb	BU	Compliance	Count (in 1)	Deflection .	Deformatio	Delta Defle	Density (in	Experiment	Increments
0	0	1	13,44	5240,5869	0	136269,72	6691,1814	136269,72	1	20,21875	173503,99
0	0	1	19,622	7554,8373	1	286806,2	14082,897	150536,49	1	40,4375	191669,01
0	0	1	23,57	9900,1035	2	451460,2	22167,817	164654	1	60,640625	209643,98
0	0	1	26,824	12143,689	3	630223,1	30945,519	178762,9	1	80,859375	227607,99
0	0	1	30,892	13771,815	4	823109,03	40416,697	192885,93	1	101,07813	245590
0	0	1	34,23	15554,413	5	1030103,1	50580,619	206994,04	1	121,29688	263553
0	0	1	38,396	16760,014	6	1245032	61134,163	214928,93	1	141,54688	273656,01
0	0	1	42,45	17943,418	7	1473679,5	72361,321	228647,46	1	161,75	291122,99
0	0	1	47,704	18668,677	8	1723012,7	84604,204	249333,28	1	181,96875	317460,99
0	0	1	52,366	19606,895	9	1986453,4	97539,793	263440,62	1	202,1875	335423,02
0	0	1	57,038	20515,943	10	2263997,4	111167,89	277544,01	1	222,39063	353380,01
0	0	1	62,484	21140,35	11	2555648,7	125488,7	291651,3	1	242,60938	371341,97
0	0	1	67,872	21790,411	12	2861384,5	140501,09	305735,85	1	262,82813	389274,98
0	0	1	74,344	22117,066	13	3181219,1	156205,76	319834,58	1	283,04688	407226,04
0	0	1	81,154	22387,942	14	3515153,2	172602,75	333934,06	1	303,26563	425178,05
0	0	1	86,778	22960,006	15	3854799,4	189280,22	339646,23	1	323,5	432451,01
0	0	1	94,344	23055,422	16	4208307,9	206638,37	353508,49	1	343,71875	450100,99
0	0	1	100,556	23521,226	17	4576021,9	224694,04	367714	1	363,92188	468188
0	0	1	107,182	23949,463	18	4966355,4	243860,38	390333,47	1	384,15625	496988,01
0	0	1	115,156	24106,412	19	5370804	263719,81	404448,64	1	404,375	514960
0	0	1	123,512	24227,093	20	5789360,7	284271,99	418556,73	1	424,57813	532922,98
0	0	1	130,646	24616,094	21	6222077,5	305519,45	432716,73	1	444,8125	550952,05
0	0	1	137,994	24979,478	22	6669046	327466,72	446968,52	1	465,04688	569098
0	0	1	147,014	25067,914	23	7130123,4	350106,76	461077,4	1	485,26563	587061,98
0	0	1	156,57	25053,686	24	7589275,8	372652,29	459152,43	1	505,5	584611,03
0	0	1	164,634	25312,604	25	8062625,8	395894,95	473350,03	1	525,70313	602687,98
0	0	1	174,546	25319,6	26	8550409,2	419846,32	487783,31	1	545,92188	621065
0	0	1	183,278	25525,212	27	9051068,3	444429,93	500659,12	1	566,125	637458,99
0	0	1	193,962	25489,766	28	9565389,4	469684,37	514321,1	1	586,34375	654853,96
0	0	1	204,256	25586,229	29	10111166	496483,38	545777,07	1	606,5625	694904,95
0	1	2	175,384	31336,281	30	10633043	522108,82	521876,67	1	626,90625	664474,01
0	1	2	188,888	30519,742	31	11153351	547657,25	520308,23	1	647,125	662477,02
0	1	2	180,058	33470,502	32	11659899	572530,01	506548,02	1	667,34375	644956,97
0	1	2	170,214	36901,685	33	12152388	596712,43	492488,65	1	687,54688	627056,03
0	1	2	160,014	40798,345	34	12630504	620189,1	478115,82	1	707,76563	608755,97
0	1	2	152,124	44491,345	35	13094636	642979,13	464131,88	1	728	590951,06
0	1	2	143,052	48978,359	36	13555587	665612,97	460950,97	1	748,23438	586901
0	1	2	133,57	54184,449	37	14002441	687554,6	446853,89	1	768,45313	568952,04
0	1	2	125,498	59451,823	38	14435178	708803,07	432737,1	1	788,67188	550977,99
0	1	2	118,72	64668,609	39	14853800	729358,44	418621,93	1	808,875	533006
0	1	2	109,246	72190,508	40	15258288	749219,8	404487,89	1	829,10938	515009,98
0	1	2	102,162	79171,765	41	15648758	768392,86	390470,13	1	849,32813	497162,01
0	1	2	94,83	87296,356	42	16016293	786439,77	367535,73	1	869,5625	467961,03
0	1	2	88,15	95988,851	43	16370550	803834,63	354256,24	1	889,78125	451053,05
0	1	2	82,45	104754,89	44	16710334	820518,89	339784,46	1	909,98438	432627,01
0	1	2	75,056	117374,76	45	17044343	836919,59	334009,41	1	930,20313	425273,99
0	1	2	70,11	128013,47	46	17364240	852627,3	319896,6	1	950,42188	407305
0	1	2	63,64	143511,63	47	17670035	867642,59	305794,78	1	970,65625	389350,01
0	1	2	57,654	161026,85	48	17961718	881964,97	291683,51	1	990,875	371382,98
0	1	2	52,574	179315,09	49	18239293	895594,57	277574,63	1	1011,0781	353418,99
0	1	2	48,06	198990,64	50	18502762	908531,55	263468,87	1	1031,2813	335458,99
0	1	2	43,058	225100,99	51	18752165	920777,87	249403,18	1	1051,4844	317549,99
0	1	2	37,978	258306,07	52	18979591	931945,06	227426,19	1	1071,7188	289568,02
0	1	2	34,262	289546,7	53	19193381	942442,64	213789,32	1	1091,9375	272205,02
0	1	2	29,026	345464,95	54	19400429	952609,23	207048,25	1	1112,1406	263622,02
0	1	2	26,29	385210,72	55	19593368	962083,03	192939,33	1	1132,375	245657,99
0	1	2	22,432	455581,84	56	19772180	970863,12	178811,6	1	1152,5938	227670
0	1	2	19,316	533482,14	57	19936882	978950,39	164701,94	1	1172,7969	209705,02
0	1	2	15,672	662491,76	58	20087461	986344,23	150579,68	1	1193,0156	191724
0	1	2	12,74	820495,19	59	20223933	993045,32	136471,58	1	1213,2344	173761,01

Table 6 Values obtained from the experiment for impeller 4PBT in Vessel Dv=100 (1)

s	Kinematic V	LoopIndex (	MPointID	Number (in	Rounds	Shear Rate	Shear Stres	Speed (in 1/	Temperatur	Temperatur	Time (in s)	Torque (in mN	Viscosity (in
9	2.48283223	0	12094	1	22	514,25142	1,2768	100,01	1000	0	20	0,336	0,0024828
1	3.28550267	0	12095	2	46	567,36828	1,86409	110,34	1000	0	40	0,49055	0,0032855
8	3.608110489	0	12096	3	73	620,58798	2,23915	120,69	1000	0	60	0,58925	0,0036081
9	3.782198624	0	12097	4	101	673,75626	2,54828	131,03	1000	0	80	0,6706	0,0037822
0	4.03691478	0	12098	5	131	726,97596	2,93474	141,38	1000	0	100	0,7723	0,0040369
3	4.168267652	0	12099	6	164	780,14424	3,25185	151,72	1000	0	120	0,85575	0,0041683
1	4.37698324	0	12100	7	198	833,36394	3,64762	162,07	1000	0	140	0,9599	0,004377
9	4.54890404	0	12101	8	234	886,53222	4,03275	172,41	1000	0	160	1,06125	0,0045489
9	4.822421645	0	12102	9	273	939,75192	4,53188	182,76	1000	0	180	1,1926	0,0048224
2	5.010241507	0	12103	10	315	992,9202	4,97477	193,1	1000	0	200	1,30915	0,0050102
1	5.179622725	0	12104	11	359	1046,1399	5,41861	203,45	1000	0	220	1,42595	0,0051796
7	5.399741499	0	12105	12	406	1099,3082	5,93598	213,79	1000	0	240	1,5621	0,0053997
8	5.594519761	0	12106	13	455	1152,5279	6,44784	224,14	1000	0	260	1,6968	0,0055945
4	5.857761046	0	12107	14	506	1205,6962	7,06268	234,48	1000	0	280	1,8586	0,0058578
5	6.124023252	0	12108	15	559	1258,9159	7,70963	244,83	1000	0	300	2,02885	0,006124
1	6.28306504	0	12109	16	613	1312,0841	8,24391	255,17	1000	0	320	2,16945	0,0062831
9	6.56460469	0	12110	17	670	1365,3038	8,96268	265,52	1000	0	340	2,3586	0,0065646
8	6.73458425	0	12111	18	728	1418,4721	9,55282	275,86	1000	0	360	2,5139	0,0067346
1	6.918765098	0	12112	19	790	1471,6918	10,18229	286,21	1000	0	380	2,67955	0,0069188
0	7.17431061	0	12113	20	855	1524,8601	10,93982	296,55	1000	0	400	2,8789	0,0071743
8	7.43539078	0	12114	21	922	1578,0798	11,73364	306,9	1000	0	420	3,0878	0,0074354
5	7.608511637	0	12115	22	991	1631,2481	12,41137	317,24	1000	0	440	3,26615	0,0076085
8	7.78253532	0	12116	23	1062	1684,4678	13,10943	327,59	1000	0	460	3,44985	0,0077825
8	8.037546136	0	12117	24	1136	1737,6361	13,96633	337,93	1000	0	480	3,67535	0,0080375
3	8.305610274	0	12118	25	1209	1790,8558	14,87415	348,28	1000	0	500	3,91425	0,0083056
8	8.481575977	0	12119	26	1284	1844,024	15,64023	358,62	1000	0	520	4,11585	0,0084816
5	8.73997876	0	12120	27	1362	1897,2437	16,58187	368,97	1000	0	540	4,36365	0,00874
9	8.927041989	0	12121	28	1442	1950,412	17,41141	379,31	1000	0	560	4,58195	0,008927
6	9.196495451	0	12122	29	1524	2003,6317	18,42639	389,66	1000	0	580	4,84905	0,0091965
5	9.43422792	0	12123	30	1611	2056,8	19,40432	400	1000	0	600	5,1064	0,0094342
1	8.127501423	0	12124	1	1694	2050,0126	16,66148	398,68	1000	0	620	4,84905	0,0081275
2	8.955917307	0	12125	2	1776	2003,6317	17,94436	389,66	1000	0	640	4,7222	0,0089559
7	8.77020333	0	12126	3	1857	1950,412	17,10551	379,31	1000	0	660	4,50145	0,0087702
3	8.52306409	0	12127	4	1935	1897,2437	16,17033	368,97	1000	0	680	4,25535	0,0085231
7	8.24356389	0	12128	5	2011	1844,024	15,20133	358,62	1000	0	700	4,00035	0,0082436
6	8.069762134	0	12129	6	2084	1790,8558	14,45178	348,28	1000	0	720	3,8031	0,0080698
1	7.82093576	0	12130	7	2157	1737,6361	13,58994	337,93	1000	0	740	3,5763	0,0078209
4	7.533032184	0	12131	8	2228	1684,4678	12,68915	327,59	1000	0	760	3,33925	0,007533
9	7.30870438	0	12132	9	2297	1631,2481	11,92231	317,24	1000	0	780	3,13745	0,0073087
6	7.146913609	0	12133	10	2363	1578,0798	11,2784	306,9	1000	0	800	2,968	0,0071469
8	6.806112901	0	12134	11	2427	1524,8601	10,37837	296,55	1000	0	820	2,73115	0,0068061
1	6.594716276	0	12135	12	2489	1471,6918	9,70539	286,21	1000	0	840	2,55405	0,0065947
3	6.351094161	0	12136	13	2547	1418,4721	9,00885	275,86	1000	0	860	2,37075	0,0063511
5	6.133616382	0	12137	14	2603	1365,3038	8,37425	265,52	1000	0	880	2,20375	0,0061336
1	5.96970099	0	12138	15	2657	1312,0841	7,83275	255,17	1000	0	900	2,06125	0,0059697
9	5.66385747	0	12139	16	2710	1258,9159	7,13032	244,83	1000	0	920	1,8764	0,0056639
5	5.524152950	0	12140	17	2761	1205,6962	6,66045	234,48	1000	0	940	1,75275	0,0055242
1	5.24568655	0	12141	18	2809	1152,5279	6,0458	224,14	1000	0	960	1,591	0,0052457
8	4.98234262	0	12142	19	2856	1099,3082	5,47713	213,79	1000	0	980	1,44135	0,0049823
9	4.77424673	0	12143	20	2901	1046,1399	4,99453	203,45	1000	0	1000	1,31435	0,0047742
9	4.59825472	0	12144	21	2943	992,9202	4,5657	193,1	1000	0	1020	1,2015	0,0045983
9	4.352755139	0	12145	22	2983	939,75192	4,09051	182,76	1000	0	1040	1,07645	0,0043528
2	4.06968852	0	12146	23	3019	886,53222	3,60791	172,41	1000	0	1060	0,94945	0,0040697
2	3.90572455	0	12147	24	3053	833,36394	3,25489	162,07	1000	0	1080	0,85655	0,0039057
2	3.53456432	0	12148	25	3086	780,14424	2,75747	151,72	1000	0	1100	0,72565	0,0035346
9	3.435533136	0	12149	26	3117	726,97596	2,49755	141,38	1000	0	1120	0,65725	0,0034355
0	3.162924230	0	12150	27	3146	673,75626	2,13104	131,03	1000	0	1140	0,5608	0,0031629
2	2.95690548	0	12151	28	3172	620,58798	1,83502	120,69	1000	0	1160	0,4829	0,0029569
4	2.624115680	0	12152	29	3195	567,36828	1,48884	110,34	1000	0	1180	0,3918	0,0026241
1	2.35375340	0	12153	30	3217	514,2	1,2103	100	1000	0	1200	0,3185	0,0023538

Table 7. Values obtained from the experiment for impeller 4PBT in Vessel Dv=100 (2).

Viscosity	Speed	Torque	Dimp	Density	p	Re	Np
0.000848	1.6676667	0.00008134	0.035	1000	0.0008519	2409.070362	3.497076185
0.0008485	2.0115	0.00010915	0.035	1000	0.0013788	2904.022262	3.225544874
0.000849	2.3563333	0.0001362	0.035	1000	0.0020155	3399.824157	2.933074375
0.0008495	2.7011667	0.00016705	0.035	1000	0.0028337	3895.032537	2.737556798
0.00085	3.046	0.0002127	0.035	1000	0.0040687	4389.6485	2.7411141
0.0008505	3.3908333	0.00026295	0.035	1000	0.0055994	4883.673	2.7345112
0.0008511	3.7356667	0.0003114	0.035	1000	0.0073054	5377.1072	2.6680981
0.0008516	4.0805	0.00037045	0.035	1000	0.009493	5869.9522	2.6602488
0.0008521	4.4253333	0.00044935	0.035	1000	0.0124879	6362.2089	2.7435456
0.0008526	4.7701667	0.0005041	0.035	1000	0.0151011	6853.8785	2.648921
0.0008531	5.115	0.00058465	0.035	1000	0.0187802	7344.962	2.671924
0.0008536	5.4598333	0.00066045	0.035	1000	0.0226453	7835.4604	2.6491137
0.0008541	5.8046667	0.00074465	0.035	1000	0.027145	8325.3747	2.6425125
0.0008546	6.1495	0.00082915	0.035	1000	0.0320208	8814.7061	2.6216392
0.0008551	6.4943333	0.00092845	0.035	1000	0.0378663	9303.4556	2.6321388
0.0008556	6.839	0.0010355	0.035	1000	0.0444736	9791.3855	2.6471851
0.0008561	7.1838333	0.0011519	0.035	1000	0.0519674	10278.974	2.6688349
0.0008566	7.5286667	0.0012614	0.035	1000	0.059639	10765.984	2.6609463
0.0008572	7.8735	0.00138475	0.035	1000	0.0684698	11252.417	2.6708847
0.0008577	8.2183333	0.00151885	0.035	1000	0.0783896	11738.272	2.6888514
0.0008582	8.5631667	0.001637	0.035	1000	0.0880324	12223.552	2.6693118
0.0008587	8.908	0.0017835	0.035	1000	0.099773	12708.257	2.6873988
0.0008592	9.2528333	0.00193075	0.035	1000	0.1121916	13192.388	2.6964724
0.0008597	9.5976667	0.00206465	0.035	1000	0.1244434	13675.946	2.6799984
0.0008602	9.9425	0.00222085	0.035	1000	0.1386674	14158.933	2.6862563
0.0008607	10.287333	0.00241165	0.035	1000	0.1558033	14641.35	2.7247589
0.0008612	10.632167	0.0025767	0.035	1000	0.1720463	15123.196	2.7254595
0.0008617	10.977	0.0027128	0.035	1000	0.1870084	15604.474	2.6919679
0.0008622	11.321833	0.00282275	0.035	1000	0.2007007	16085.184	2.6330453
0.0008627	11.666667	0.00289715	0.035	1000	0.2122645	16565.328	2.545053
0.0008633	11.643667	0.0022713	0.035	1000	0.1660825	16522.933	2.0031543
0.0008638	11.321833	0.00275425	0.035	1000	0.1958302	16056.778	2.5691488
0.0008643	10.977	0.00262725	0.035	1000	0.181111	15558.571	2.6070748
0.0008648	10.632167	0.0024813	0.035	1000	0.1656764	15060.951	2.6245518
0.0008653	10.287333	0.00231755	0.035	1000	0.1497241	14563.916	2.6184417
0.0008658	9.9425	0.00214455	0.035	1000	0.1339033	14067.464	2.5939667
0.0008663	9.5976667	0.00200285	0.035	1000	0.1207185	13571.595	2.5997795
0.0008668	9.2528333	0.0018239	0.035	1000	0.1059828	13076.308	2.5472465
0.0008673	8.908	0.0017167	0.035	1000	0.096036	12581.601	2.5867438
0.0008678	8.5631667	0.0015857	0.035	1000	0.0852737	12087.475	2.5856614
0.0008683	8.2183333	0.0014362	0.035	1000	0.0741239	11593.926	2.5425344
0.0008688	7.8735	0.00131245	0.035	1000	0.0648949	11100.956	2.5314335
0.0008694	7.5286667	0.0012031	0.035	1000	0.0568826	10608.562	2.5379614
0.0008699	7.1838333	0.00110505	0.035	1000	0.0498537	10116.744	2.5602882
0.0008704	6.839	0.0009996	0.035	1000	0.0429317	9625.501	2.5554092
0.0008709	6.4943333	0.00089295	0.035	1000	0.0364184	9135.0656	2.531497
0.0008714	6.1495	0.00078325	0.035	1000	0.0302482	8644.9683	2.4765107
0.0008719	5.8046667	0.0007029	0.035	1000	0.025623	8155.4427	2.4943558
0.0008724	5.4598333	0.0006278	0.035	1000	0.0215259	7666.4877	2.5181521
0.0008729	5.115	0.0005371	0.035	1000	0.0172528	7178.1023	2.4546145
0.0008734	4.7701667	0.00046945	0.035	1000	0.0140631	6690.2856	2.4668438
0.0008739	4.4253333	0.00040365	0.035	1000	0.0112179	6203.0365	2.4645203
0.0008744	4.0805	0.0003382	0.035	1000	0.0086666	5716.354	2.4286574
0.0008749	3.7356667	0.00026965	0.035	1000	0.006326	5230.2373	2.310381
0.0008755	3.3908333	0.00022355	0.035	1000	0.0047604	4744.6852	2.3247765
0.000876	3.046	0.00018265	0.035	1000	0.0034939	4259.6968	2.353852801
0.0008765	2.7011667	0.00013365	0.035	1000	0.0022671	3775.271133	2.190209315
0.000877	2.3563333	0.0001007	0.035	1000	0.0014901	3291.407206	2.168579953
0.0008775	2.0115	0.0000686	0.035	1000	0.0008666	2808.104043	2.027232051
0.000878	1.6666667	0.00008134	0.035	1000	0.0008514	2325.360668	3.501273936

Table 8. Excel calculations for impeller 4PBT in Vessel Dv=100

Figure 19. Variation of power number with Reynolds number for Impeller 4RT in water (Dv=70, C=0.5Dimp)

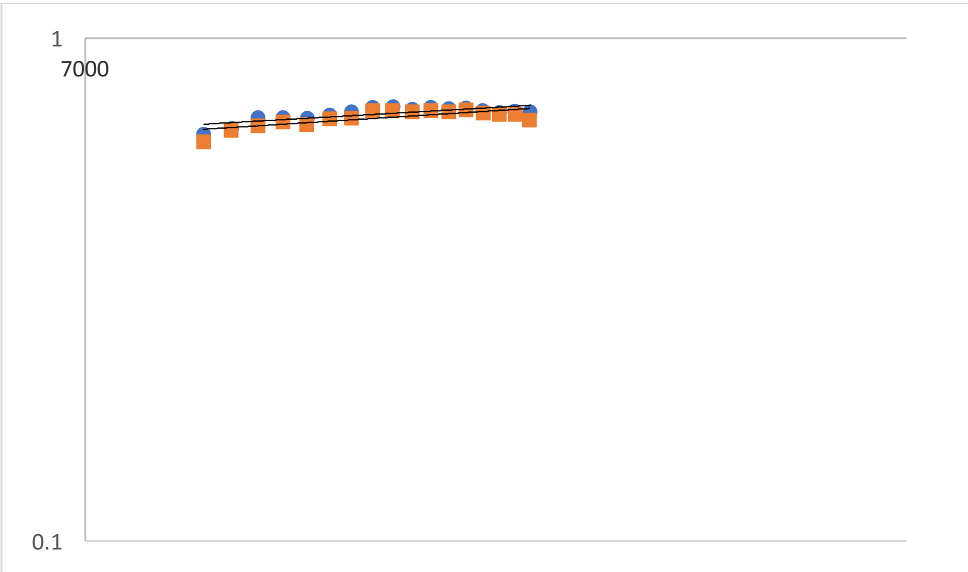


Figure 20. Variation of power number with Reynolds number for Impeller 4RT in water (Dv=70, C=Dimp)

Figure 21. Variation of power number with Reynolds number for Impeller 4PBT in water (Dv=70, C=0.5Dimp)

Figure 22. Variation of power number with Reynolds number for Impeller 4PBT in water (Dv=70, C=Dimp)

C

Figure 23. Variation of power number with Reynolds number for Impeller Anchor in water (Dv=70, C=0.055Dimp)

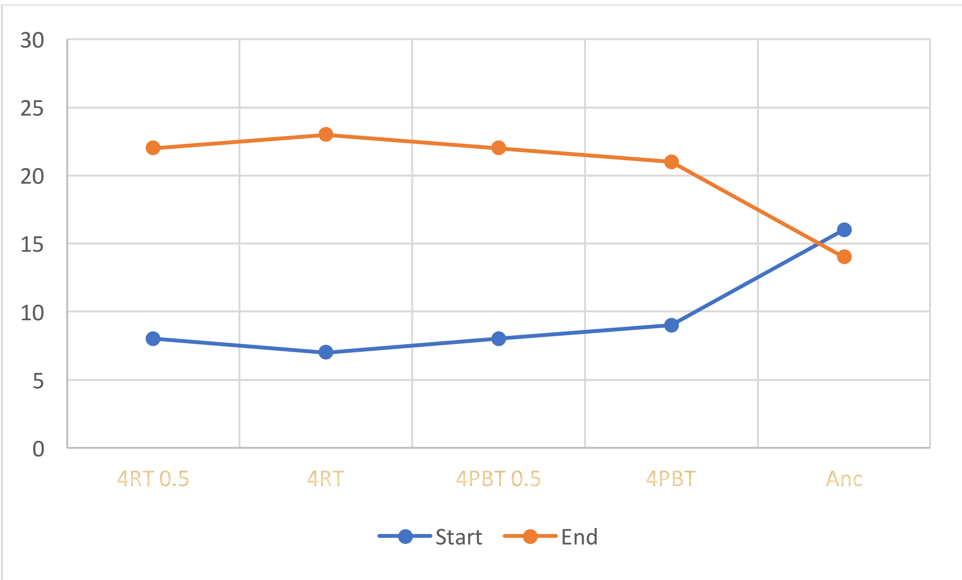


Figure 24. Step number in which vortex starts and ends for these given impellers in vessel Dv=70

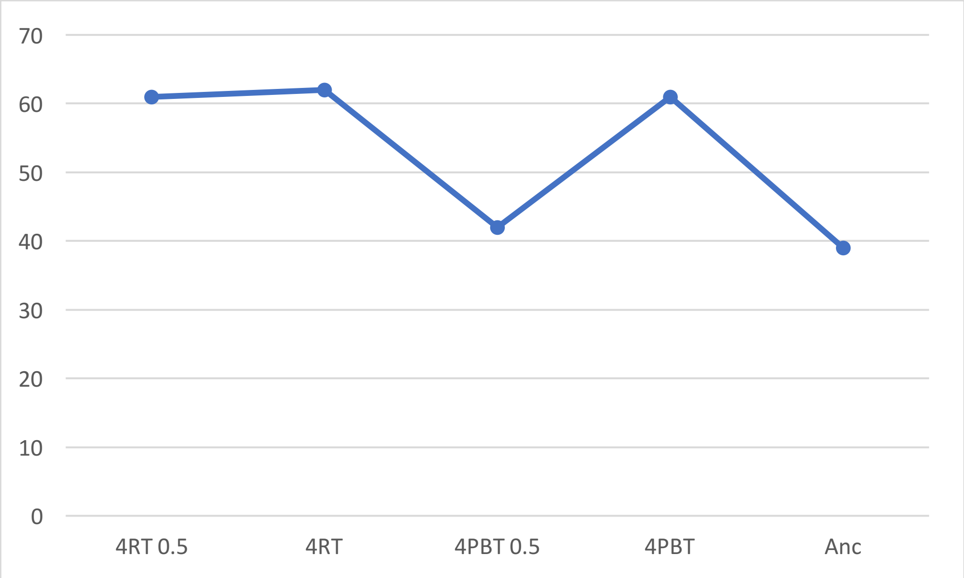


Figure 25. Vortex length in mm at Max point for these given impellers in Vessel Dv=70

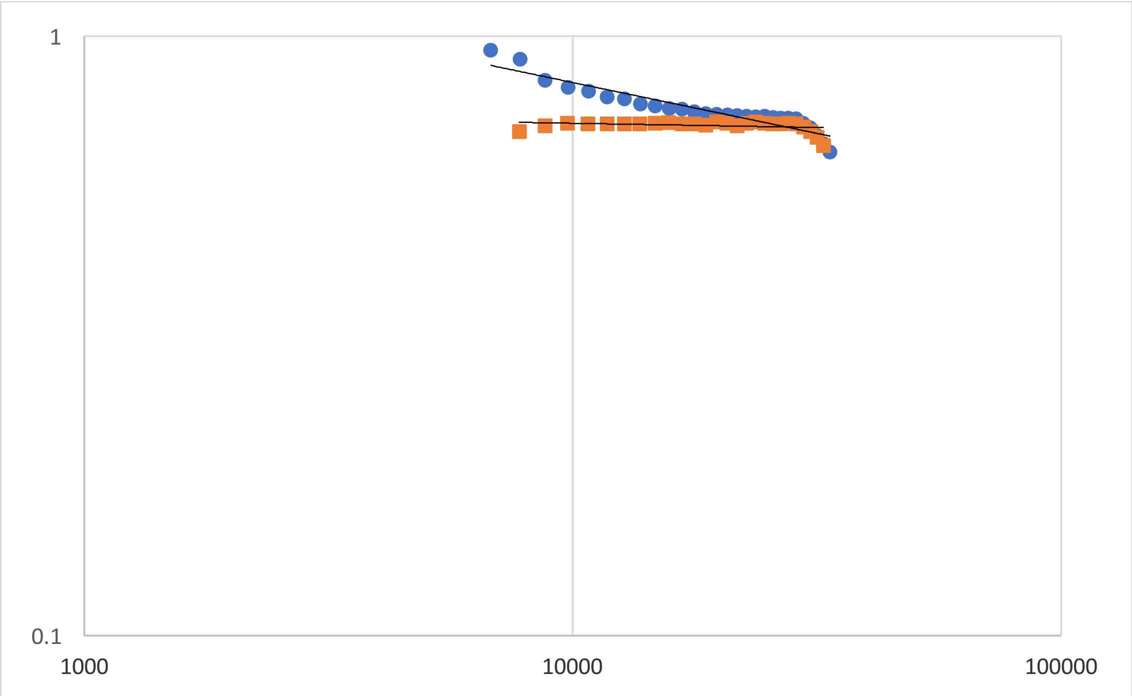


Figure 26. Variation of power number with Reynolds number for Impeller 4RT in water (Dv=100, C=0.5Dimp)

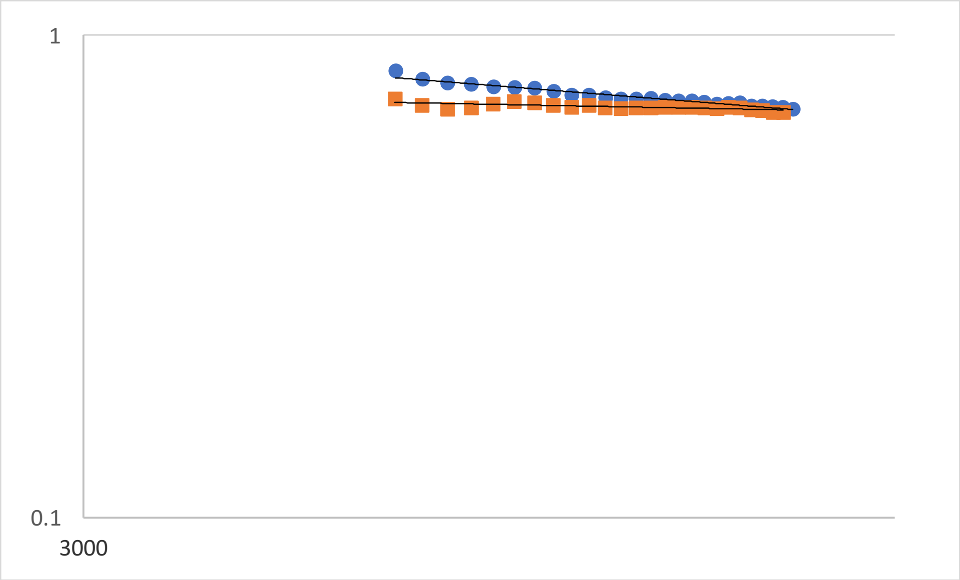


Figure 27. Variation of power number with Reynolds number for Impeller 4RT in water (Dv=100, C=Dimp)

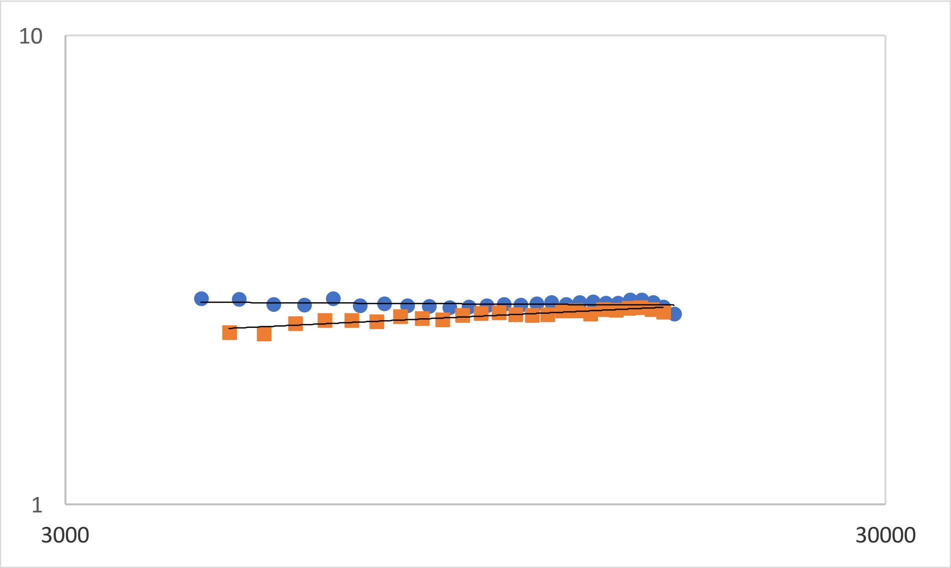


Figure 28.Variation of power number with Reynolds number for Impeller 4PBT in water (Dv=100, C=0.5Dimp)

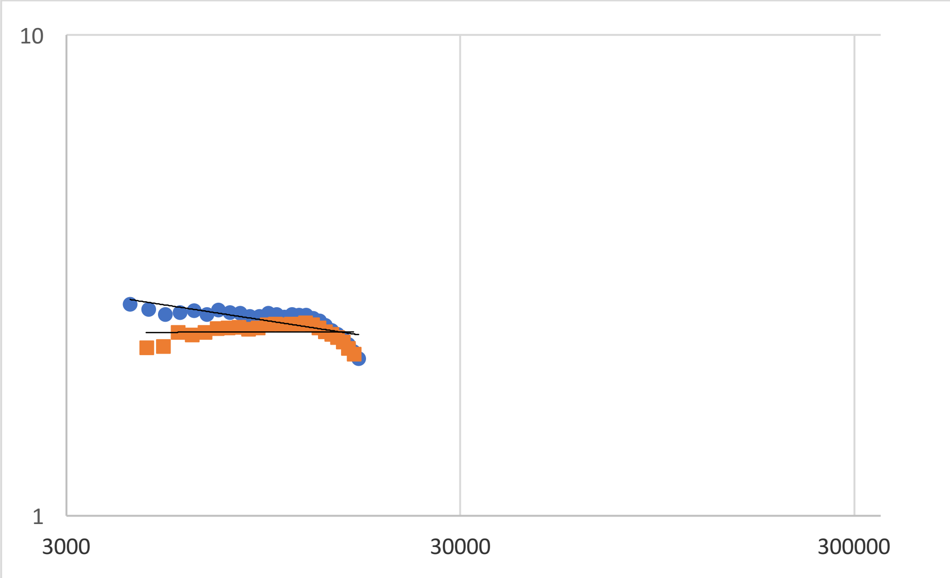


Figure 29. Variation of power number with Reynolds number for Impeller 4PBT in water (Dv=100, C=Dimp)

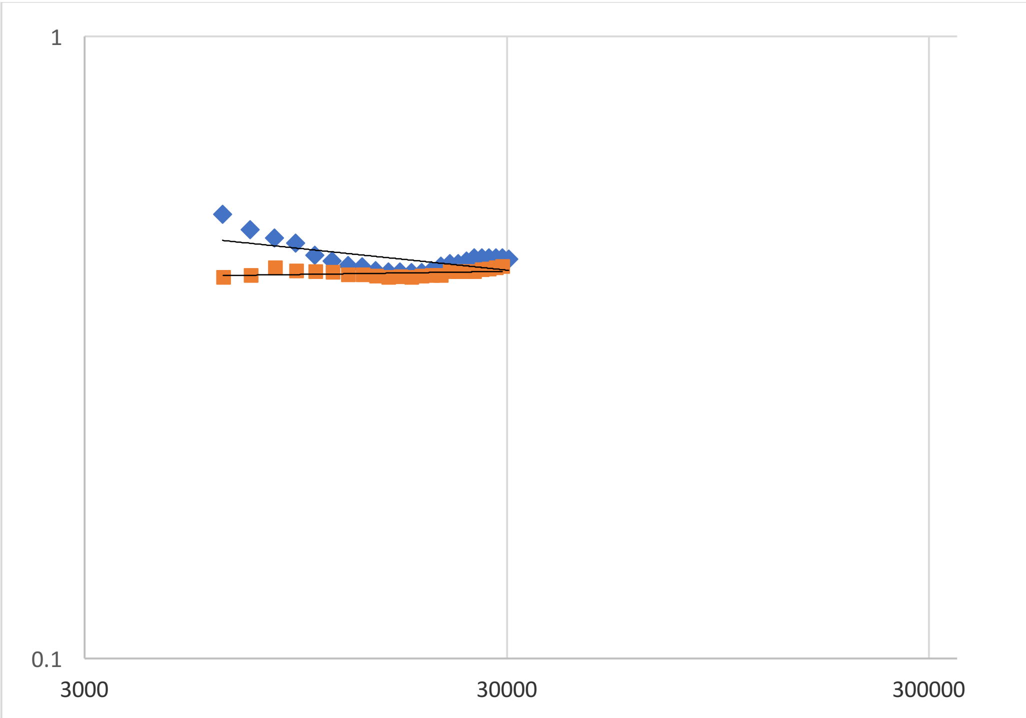


Figure 30. Variation of power number with Reynolds number for Impeller Anchor in water (Dv=100, C=0.055Dimp)

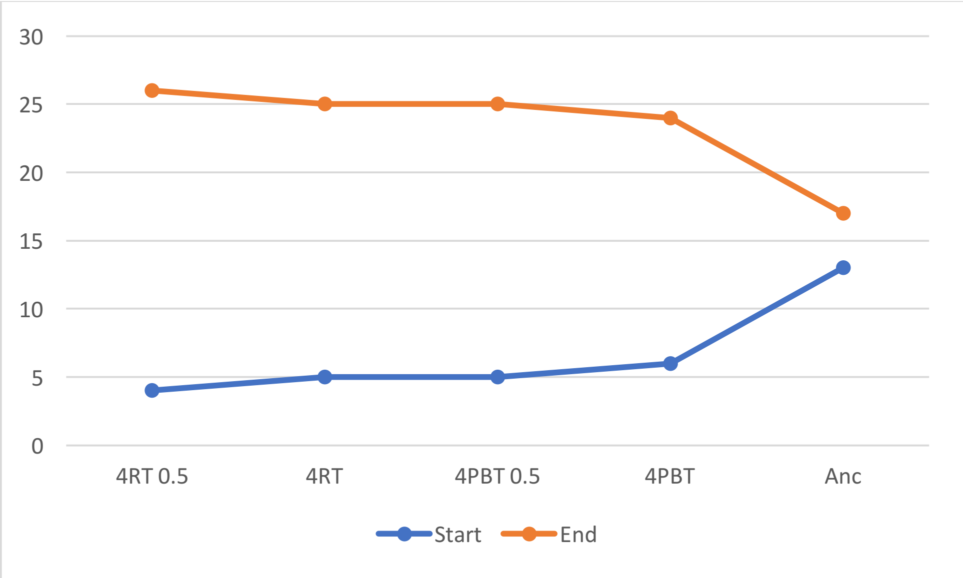


Figure 31. Step number in which vortex starts and ends for these given impellers in vessel Dv=100

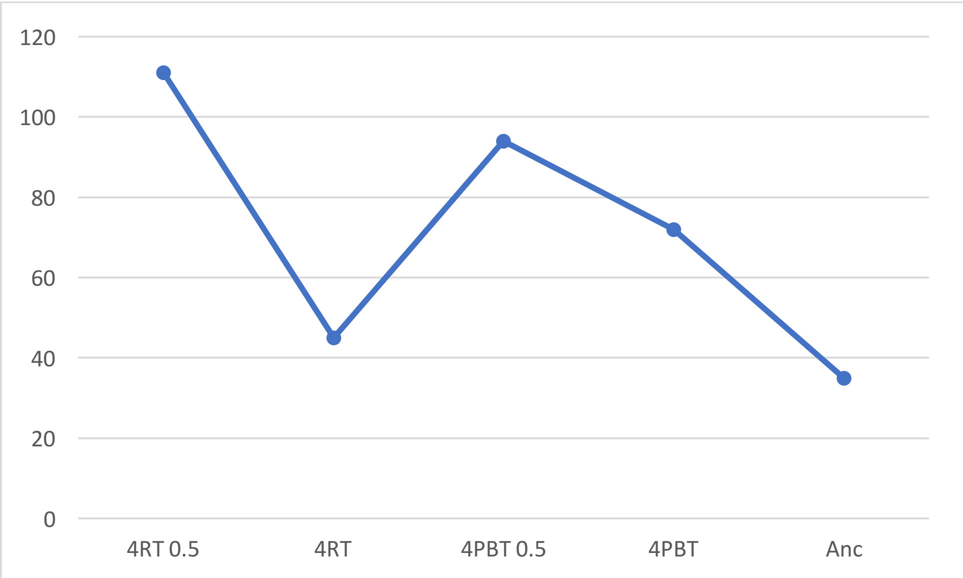


Figure 32. Vortex length in mm at Max point for these given impellers in Vessel Dv=100

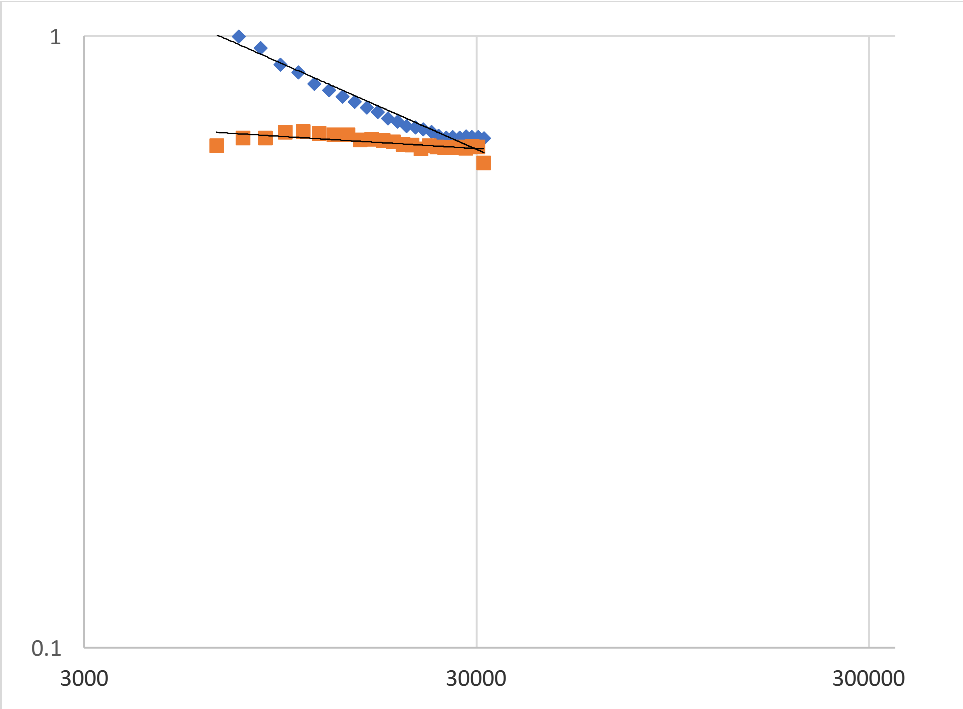


Figure 33. Variation of power number with Reynolds number for Impeller 4RT in water (Dv=140, C=0.5Dimp)

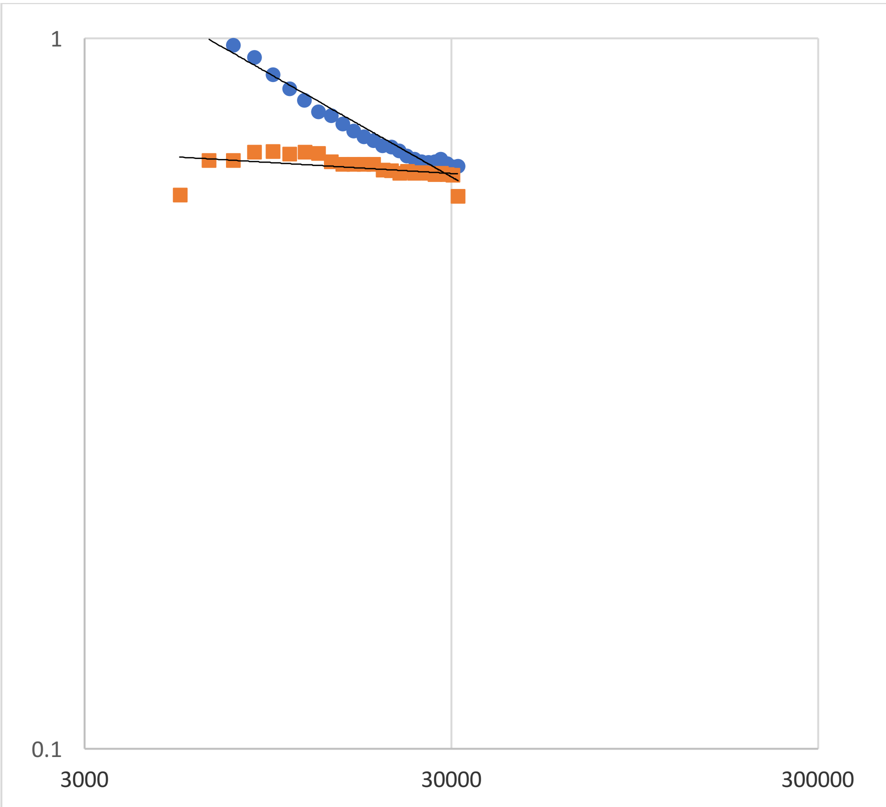


Figure 34. Variation of power number with Reynolds number for Impeller 4RT in water (Dv=140, C=Dimp)

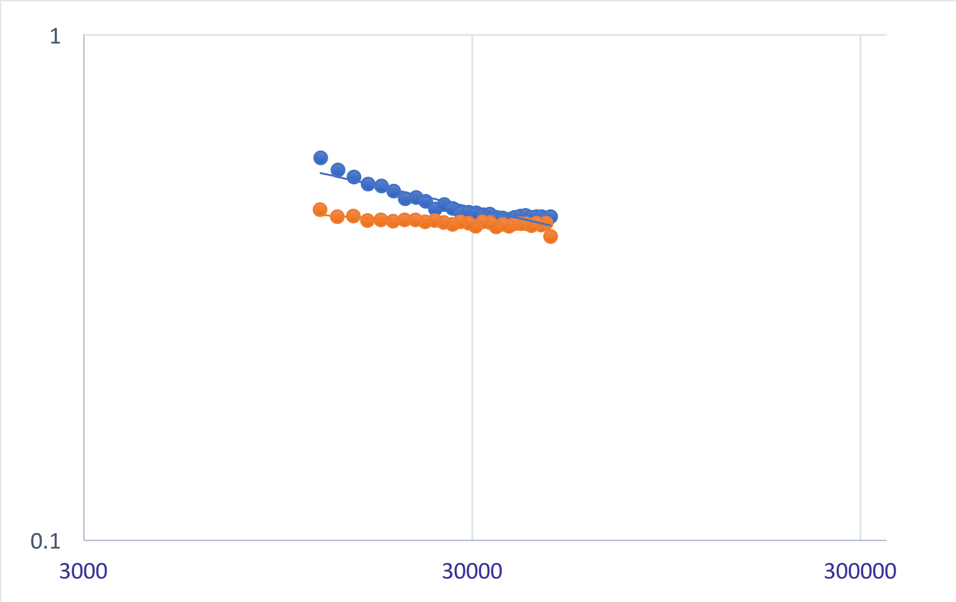


Figure 35. Variation of power number with Reynolds number for Impeller 4PBT in water (Dv=140, C=0.5Dimp)

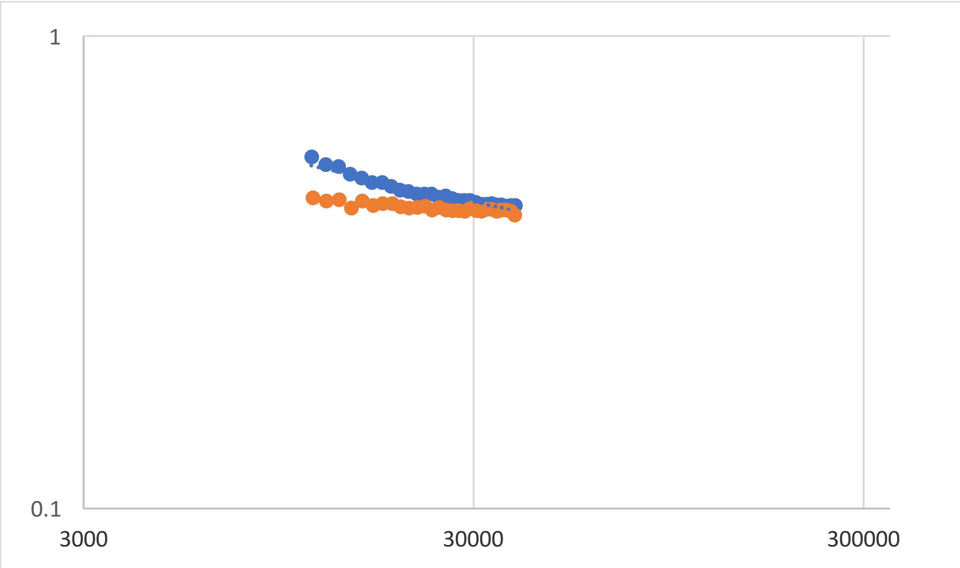


Figure 36. Variation of power number with Reynolds number for Impeller 4PBT in water (Dv=140, C=Dimp)

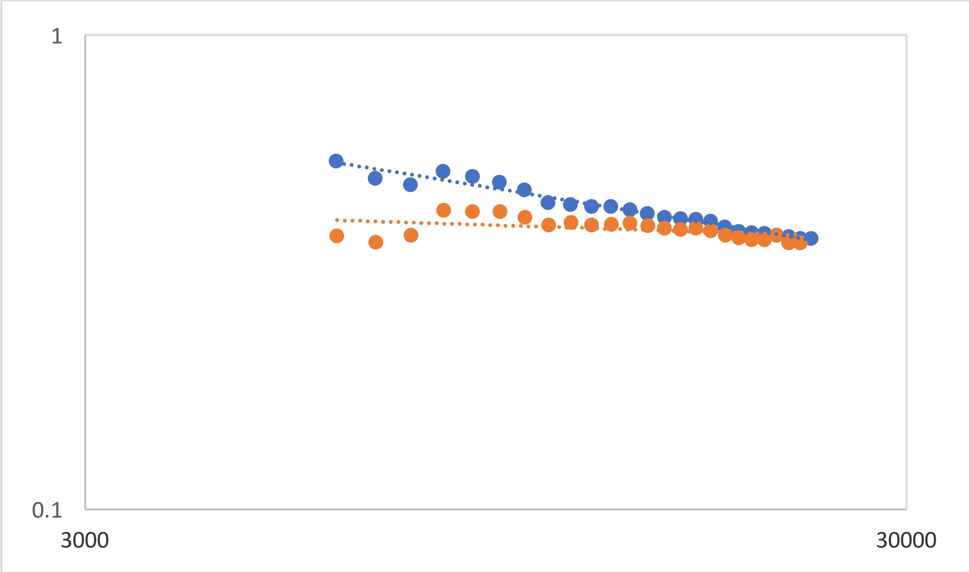


Figure 37. Variation of power number with Reynolds number for Impeller Anchor in water (Dv=140, C=0.055Dimp)

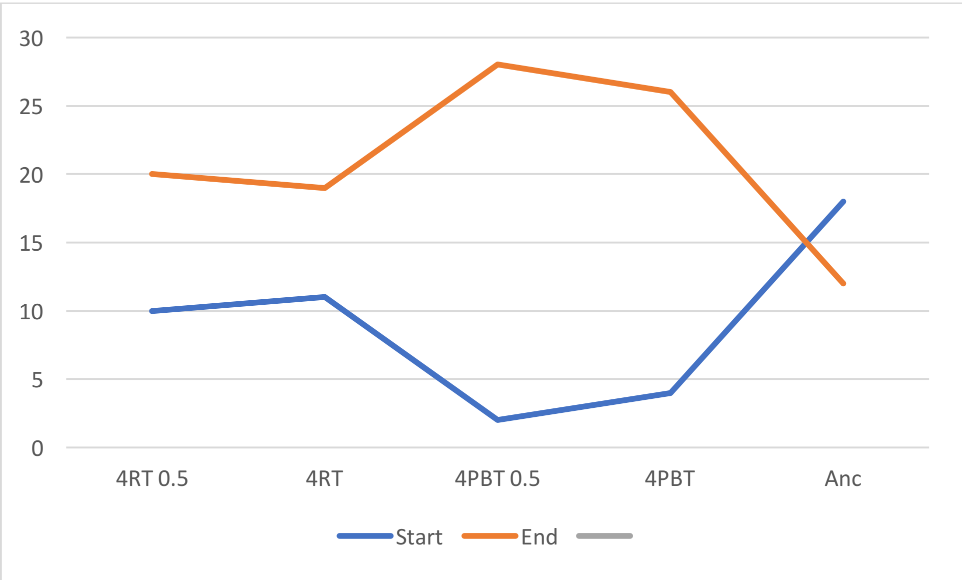


Figure 38. Step number in which vortex starts and ends for these given impellers in vessel Dv=140

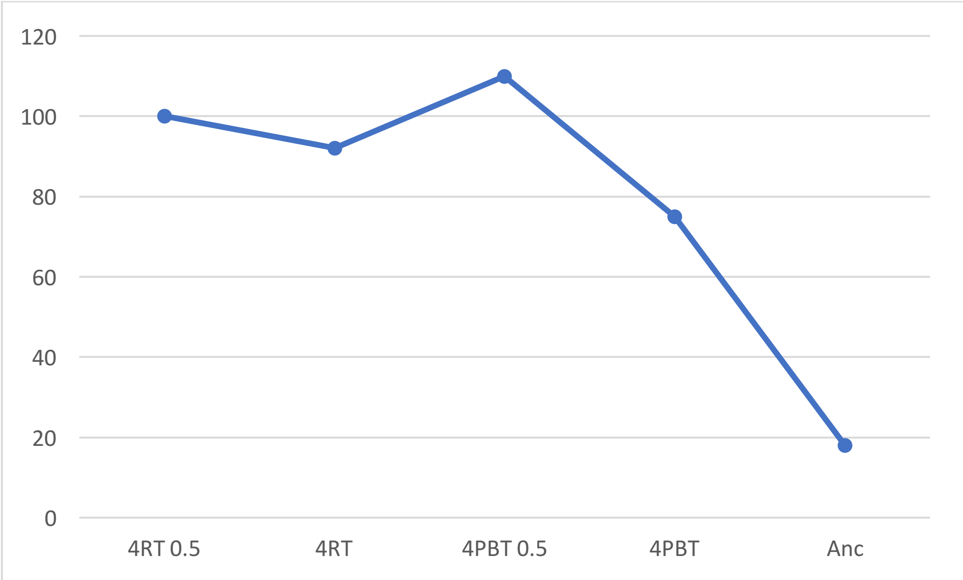


Figure 39. Vortex length in mm at Max point for these given impellers in Vessel Dv=140

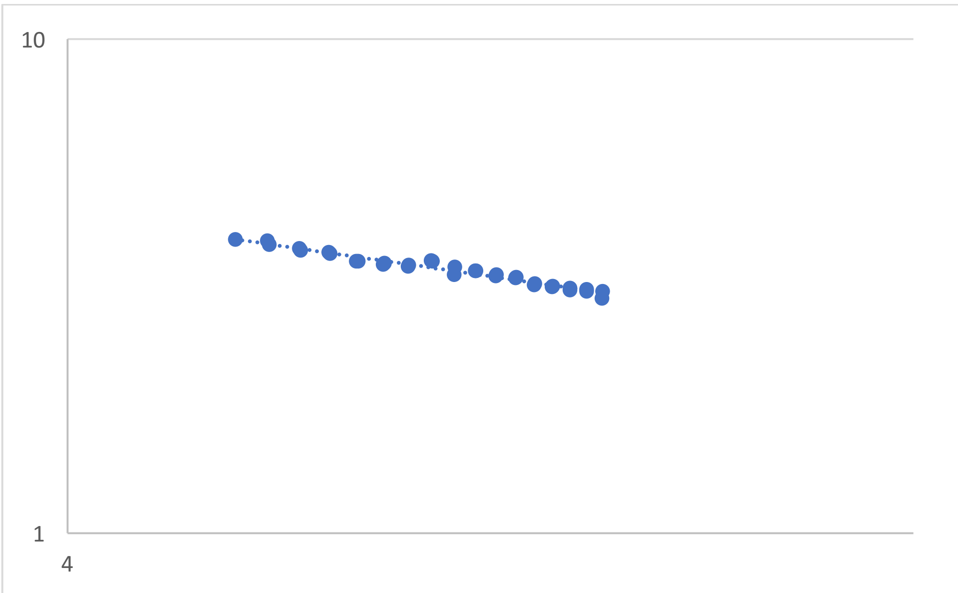


Figure 40. Variation of power number with Reynolds number for Impeller 4RT in Glycerine (Dv=70, C=0.5Dimp)

Figure 41. Variation of power number with Reynolds number for Impeller 4BTT in Glycerine (Dv=70, C=0.5Dimp)

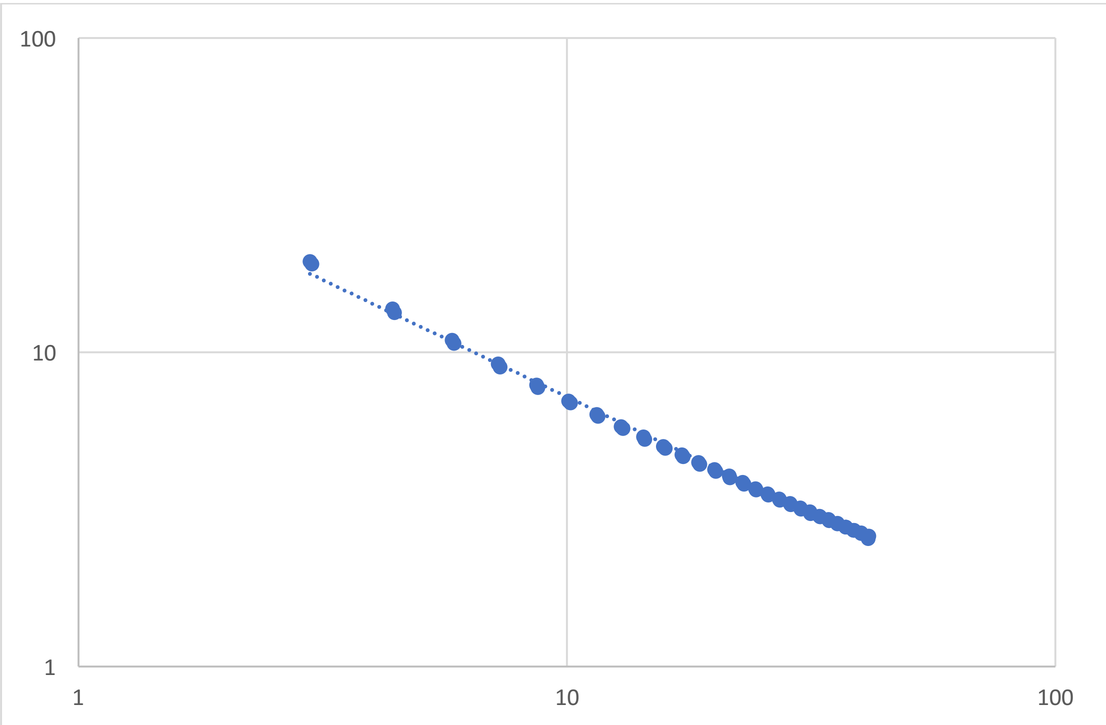


Figure 42. Variation of power number with Reynolds number for Impeller Anchor in Glycerine (Dv=70, C=0.055Dimp)

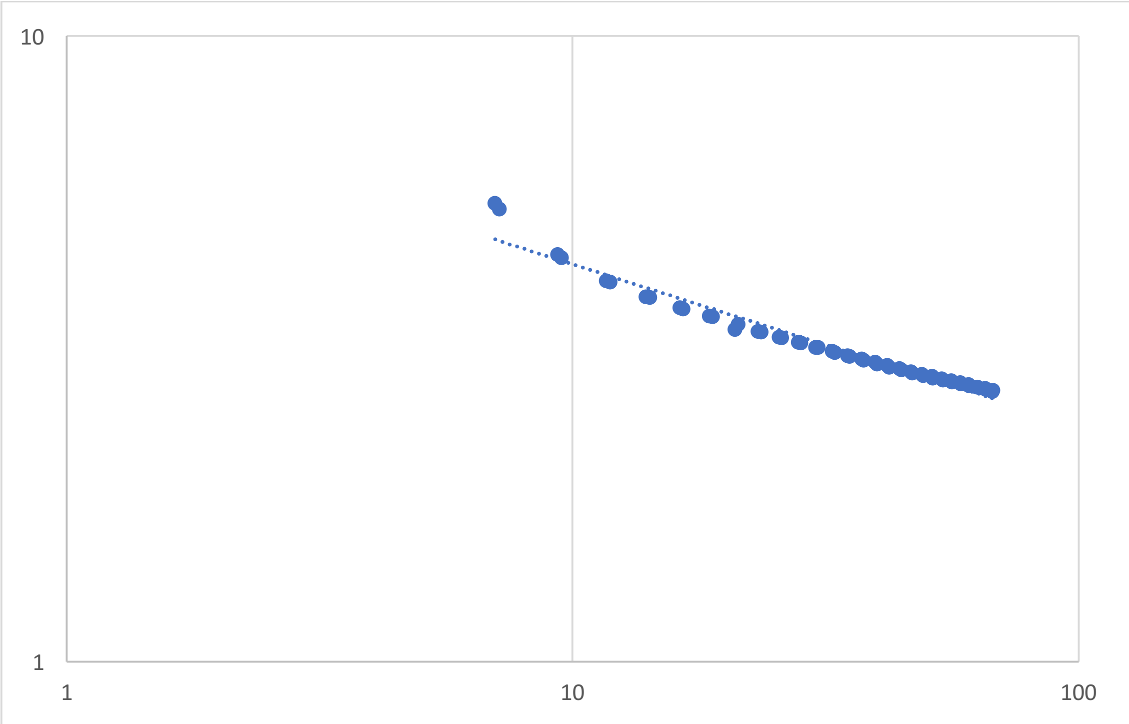


Figure 43. Variation of power number with Reynolds number for Impeller 4RT in Glycerin (Dv=100, C=0.5Dimp)

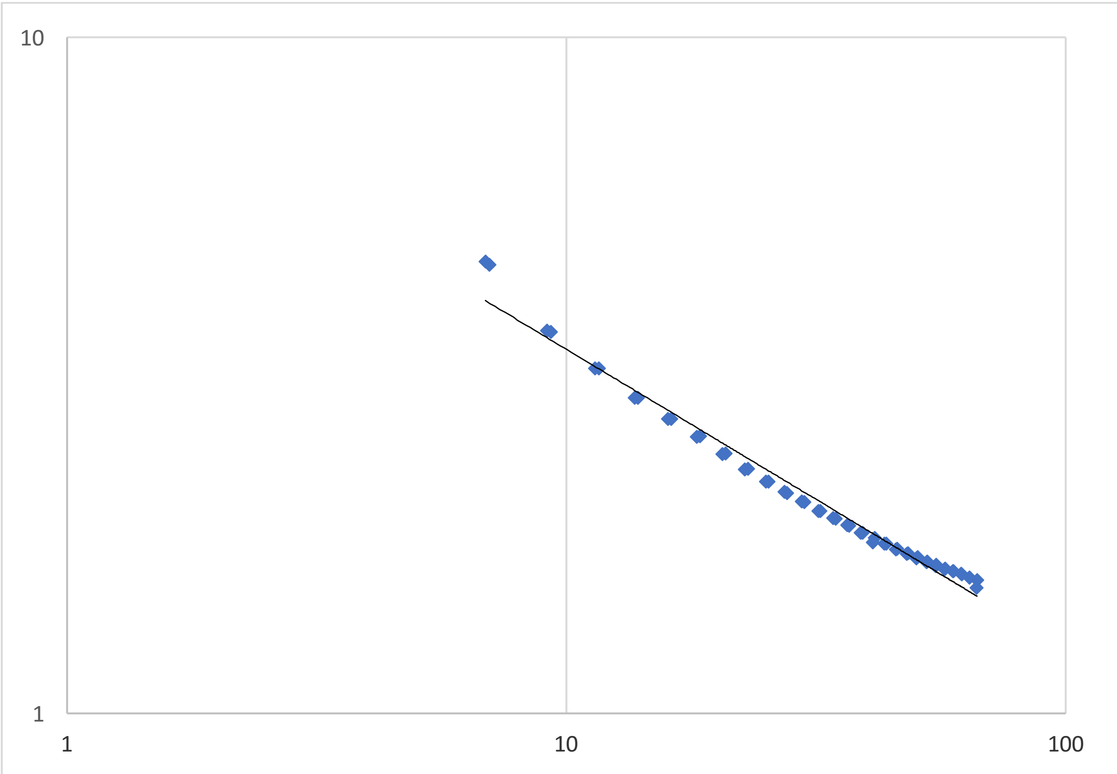


Figure 44. Variation of power number with Reynolds number for Impeller 4PBT in Glycerin (Dv=100, C=0.5Dimp)

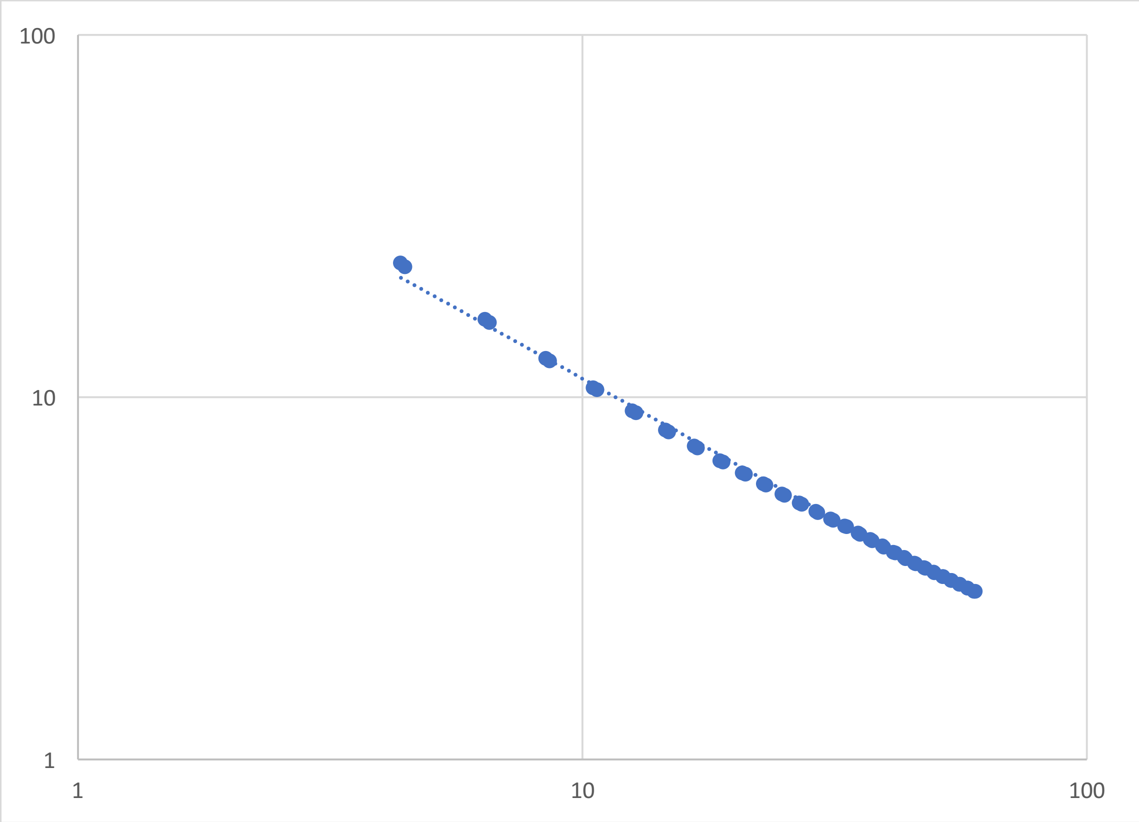


Figure 45. Variation of power number with Reynolds number for Impeller Anchor in Glycerin (Dv=100, C=0.055Dimp)

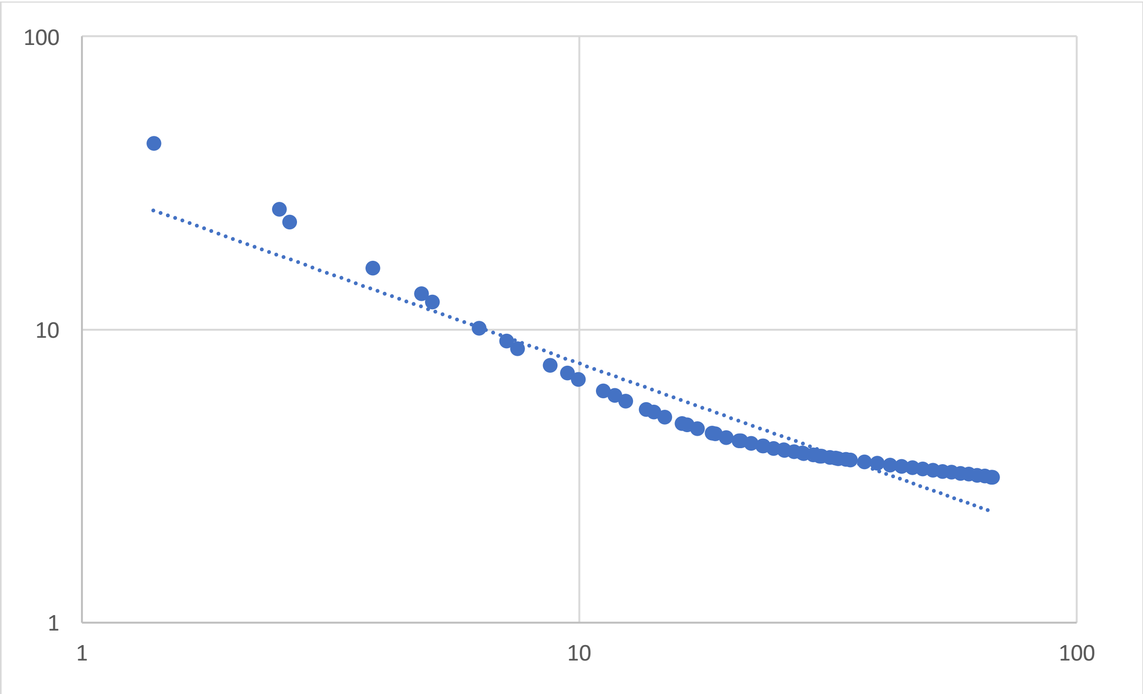


Figure 46. Variation of power number with Reynolds number for Impeller 4RT in Glycerin (Dv=140, C=0.5Dimp)

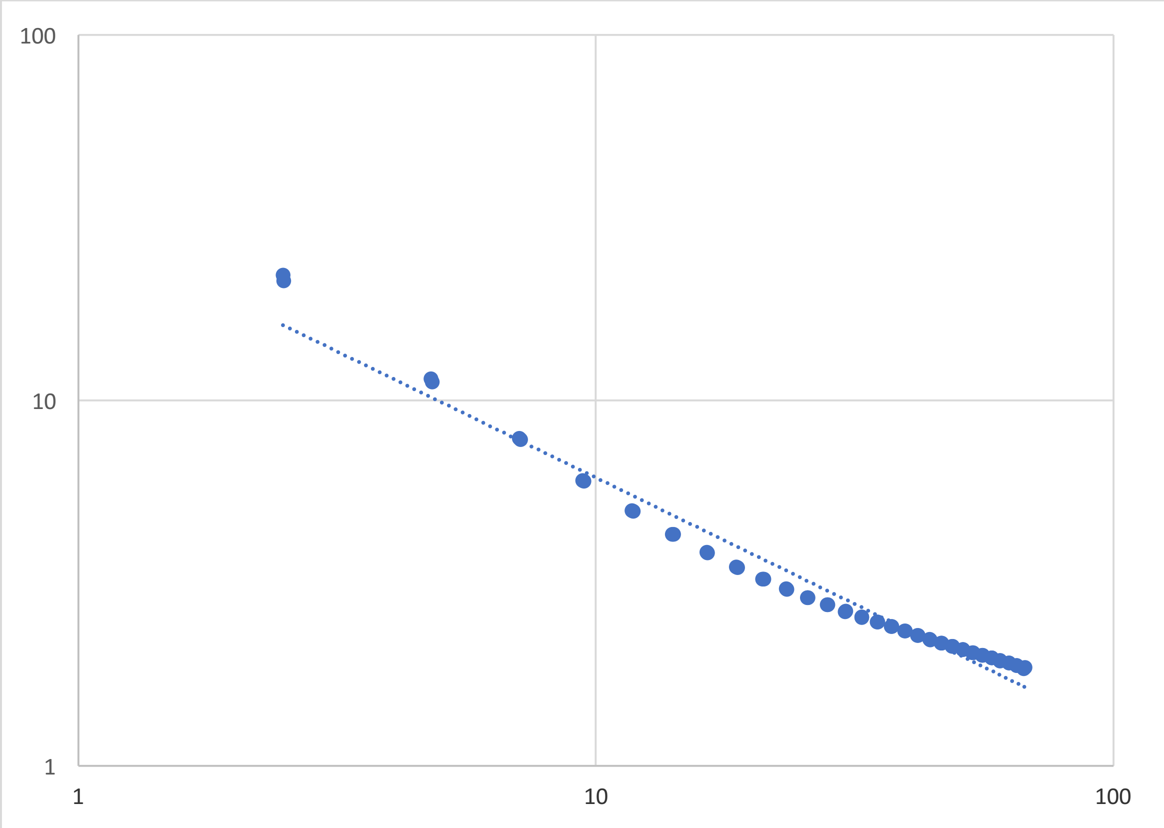


Figure 47. Variation of power number with Reynolds number for Impeller 4PBT in Glycerin (Dv=140, C=0.5Dimp)

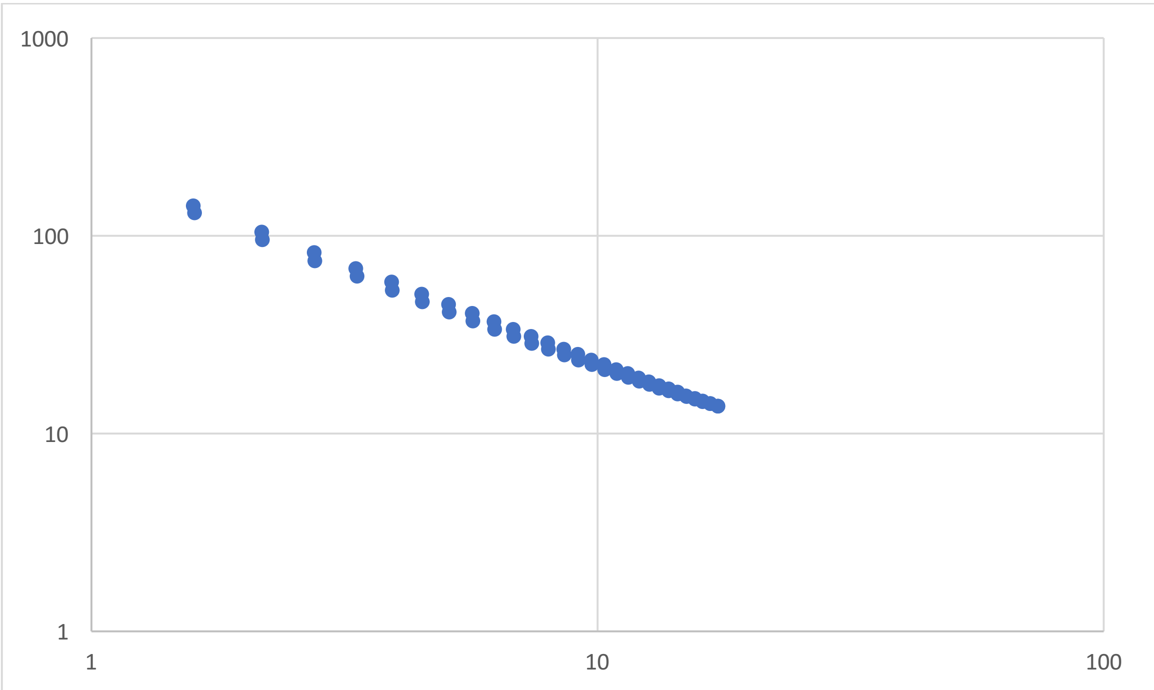


Figure 48. Variation of power number with Reynolds number for Impeller Anchor in Glycerin (Dv=140, C=0.055Dimp)

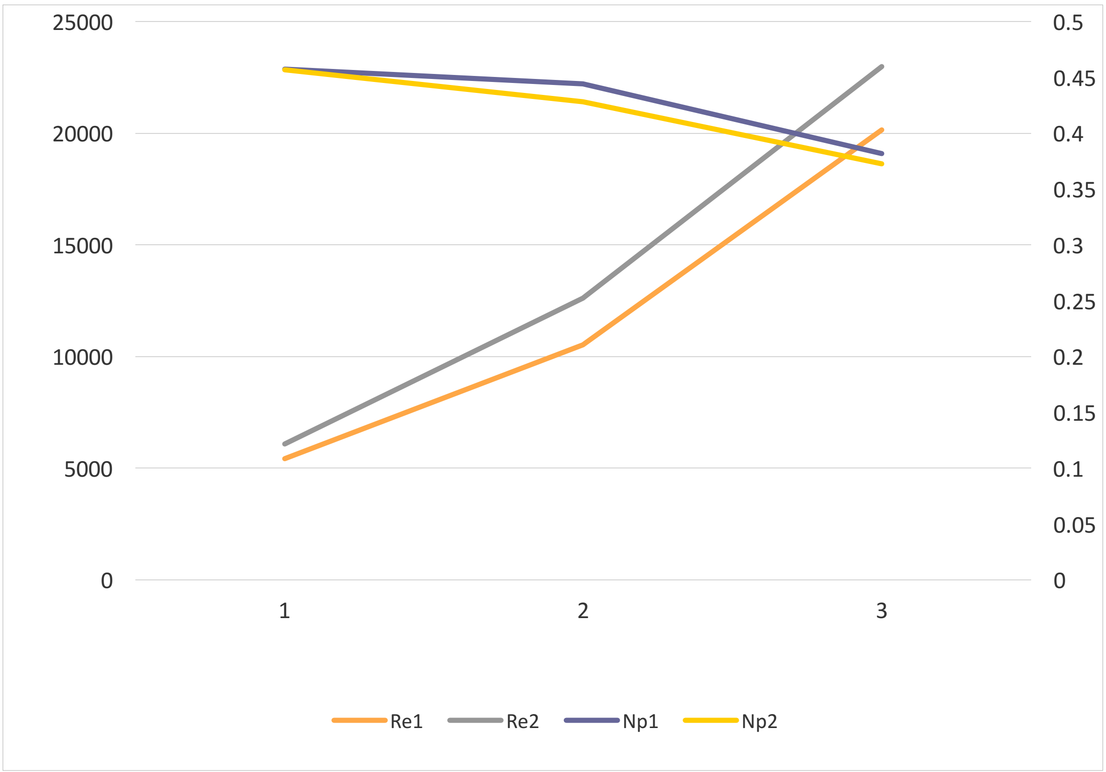


Figure 49. Values of Re and Np in water for Anchor impeller placed at a height C=0.055Dimp, in vessels with Dv=70 (point 1), 10 (point 2), 140 (point3) at Ni1=1.35 rps and Ni2=1.8 rps.

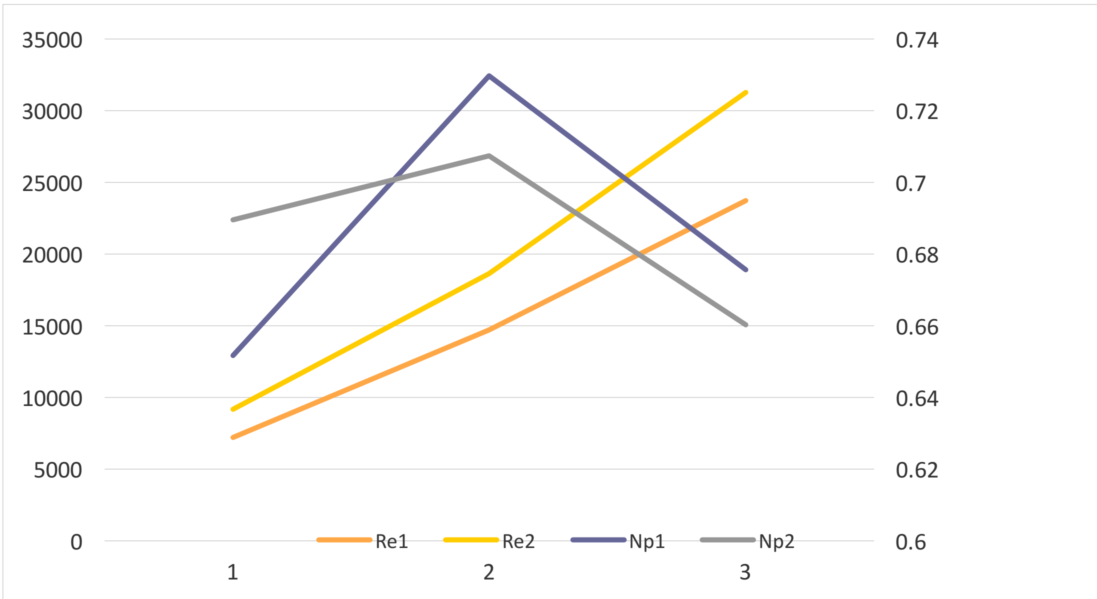


Figure 50. Values of Re and Np in water for 4RT impeller placed at a height C=Dimp , in vessels with Dv=70 (point 1), 10 (point 2), 140 (point3) at Ni1=5.12 rps and Ni2=6.49 rps

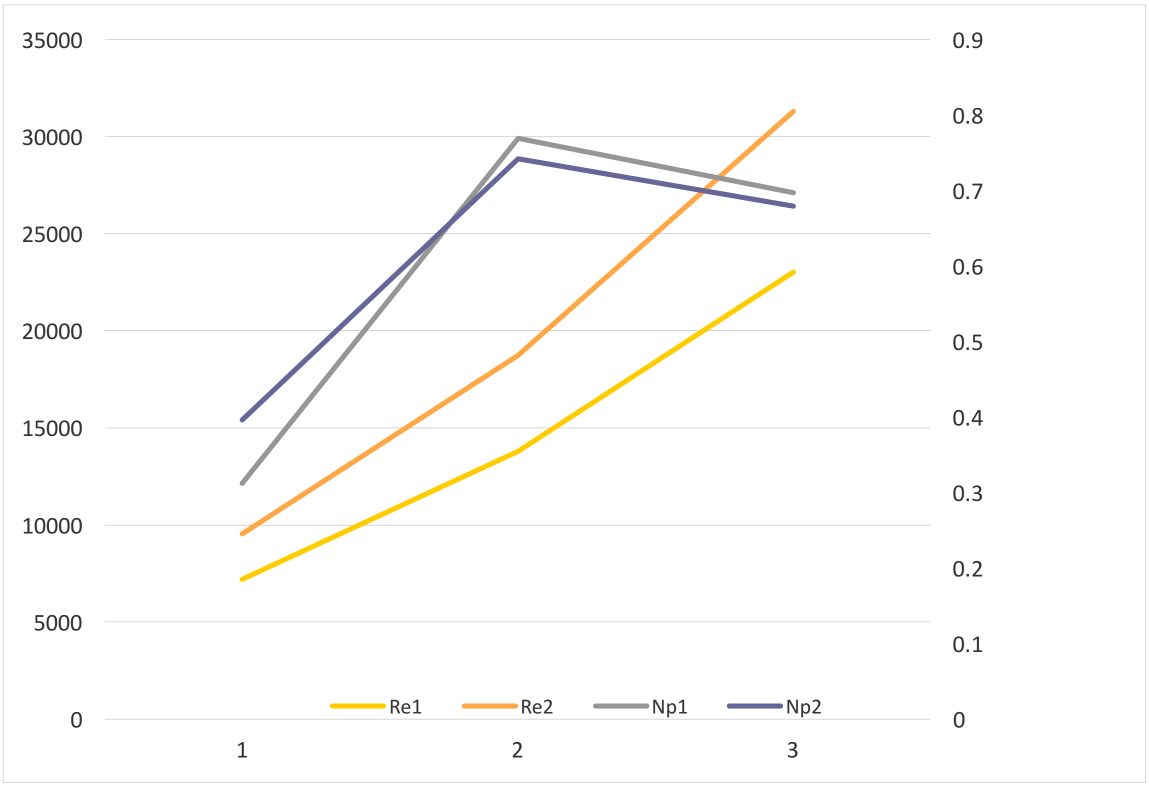


Figure 51. Values of Re and Np in water for 4RT impeller placed at a height C=0.5Dimp , in vessels with Dv=70 (point 1), 10 (point 2), 140 (point3) at Ni1=4.88 rps and Ni2=6.49 rps

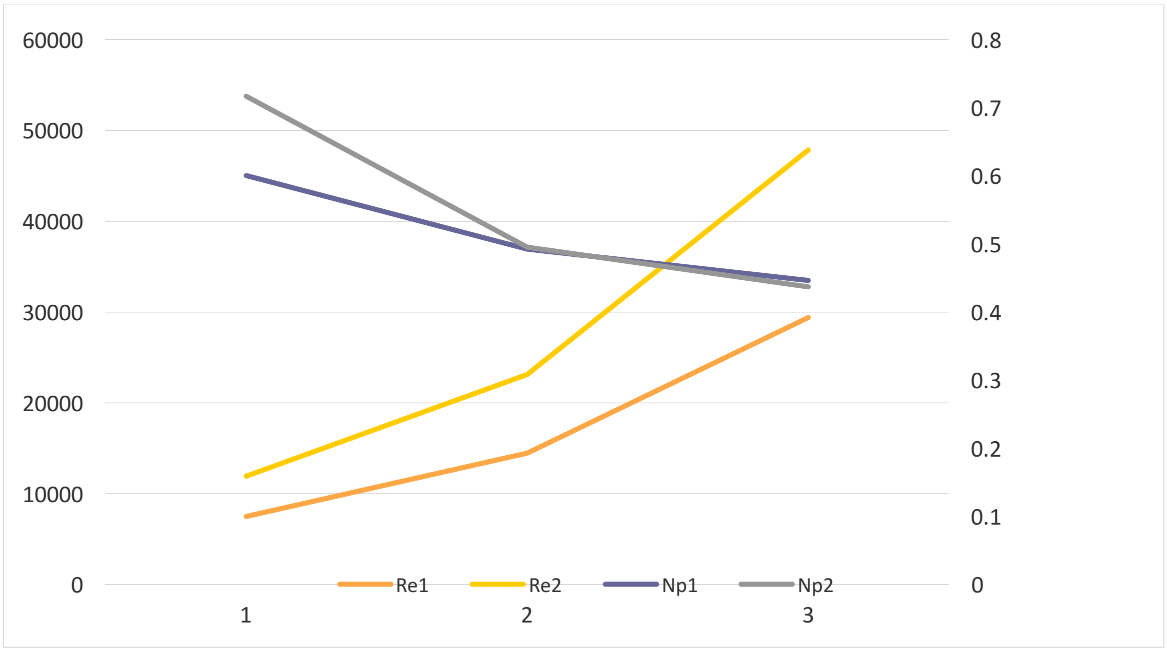


Figure 52. Values of Re and Np in water for 4PBT impeller placed at a height C=0.5Dimp , in vessels with Dv=70 (point 1), 10 (point 2), 140 (point3) at Ni1=5.12 rps and Ni2=8.2 rps

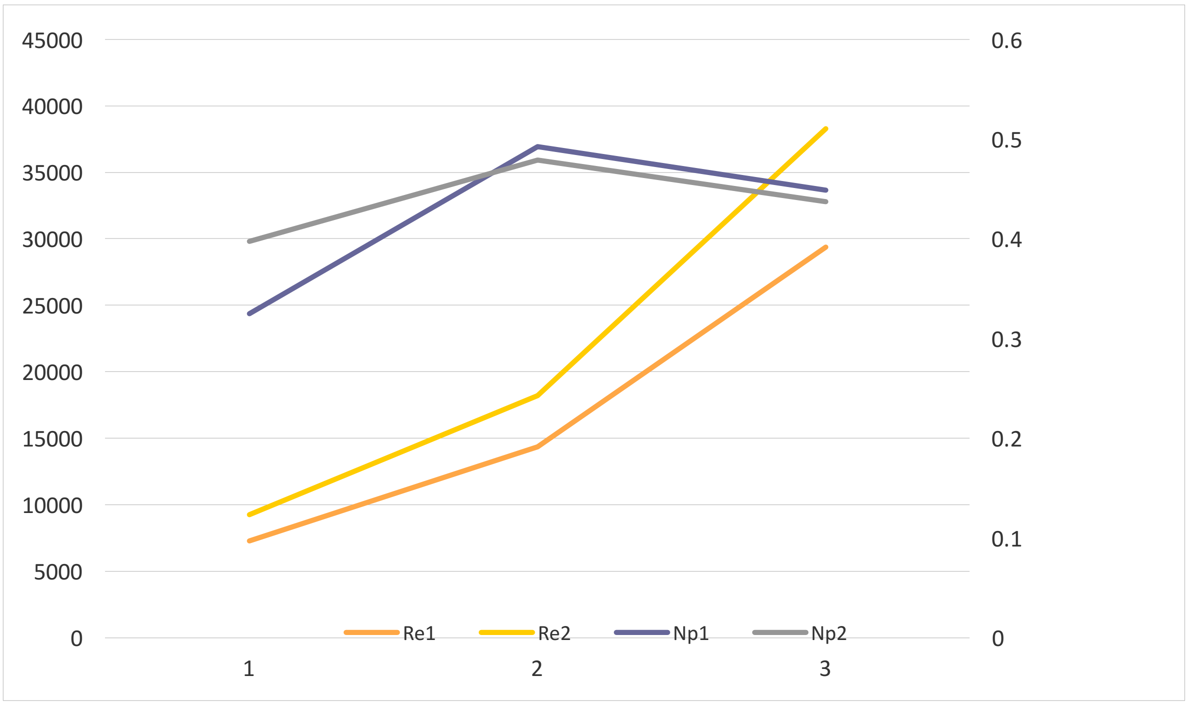


Figure 53. Values of Re and Np in water for 4PBT impeller placed at a height C=Dimp , in vessels with Dv=70 (point 1), 10 (point 2), 140 (point3) at Ni1=5.12 rps and Ni2=6.49 rps

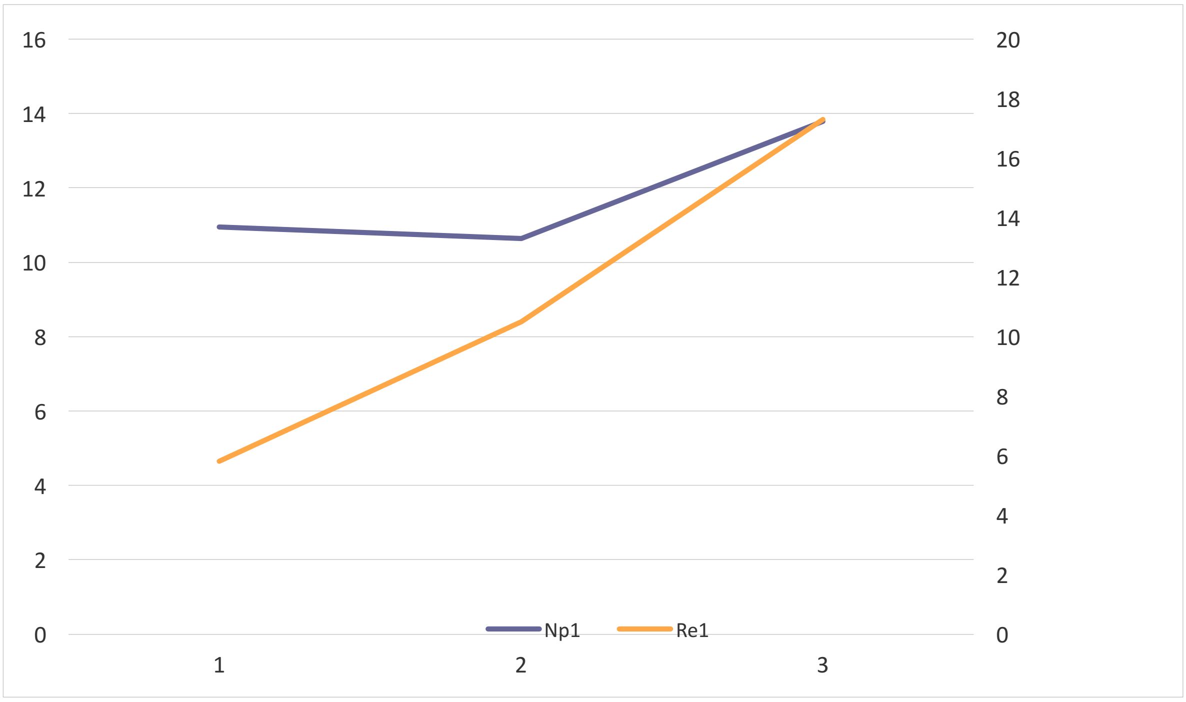


Figure 54. Values of Re and Np In Glycerin for Anchor impeller placed at a height C=0.05Dimp , in vessels with Dv=70 (point 1), 10 (point 2), 140 (point3) at speed Ni1=0.66 rps

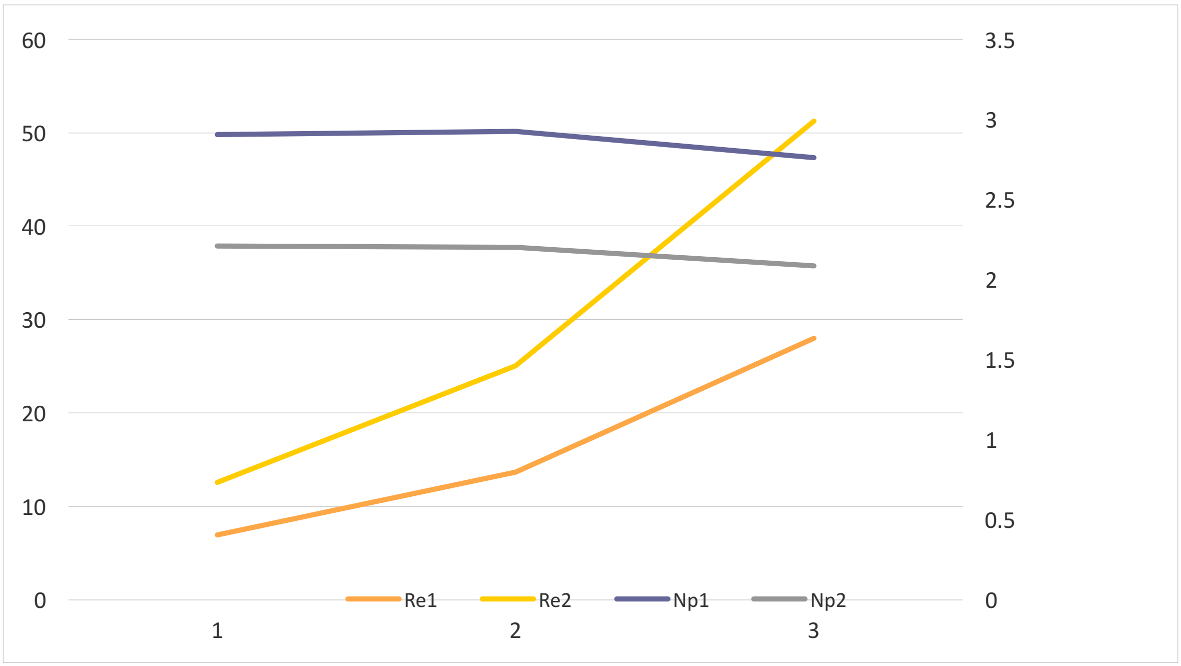


Figure 55. Values of Re and Np In Glycerin for 4PBT impeller placed at a height C=0.5Dimp , in vessels with Dv=70 (point 1), 10 (point 2), 140 (point3) at Ni1=2.7 rps and Ni2=5rps

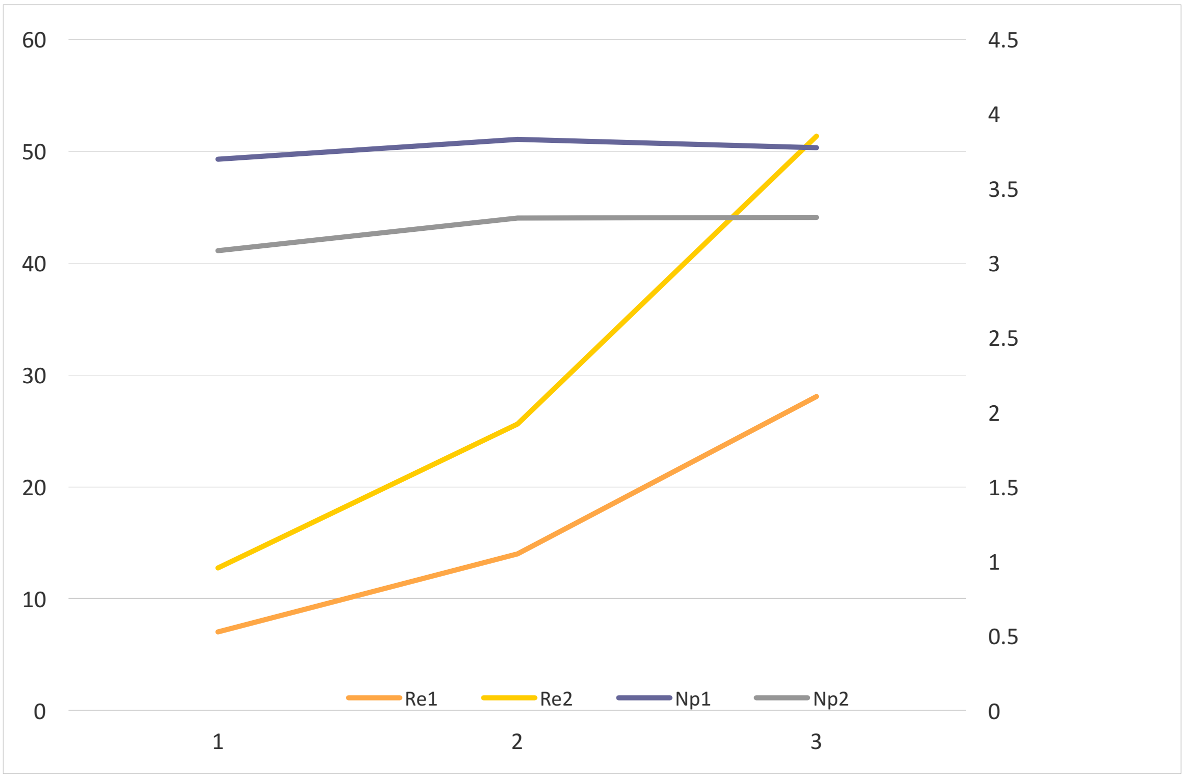


Figure 56. Values of Re and Np In Glycerin for 4RT impeller placed at a height C=0.5Dimp , in vessels with Dv=70 (point 1), 10 (point 2), 140 (point3) at Ni1=2.7 rps and Ni2=5rps

Part 4: Conclusion

As we can see from the results , its obvious that the scale up affects the power characteristics significantly as we increase the impeller diameter , the power number decreases and Reynold's number increases .The results of this analysis supports literature data I collected; But some curves' slopes ,for impellers 4rt and 4PBT in the small vessel (Dv), were increasing instead of decreasing . At low Dimp values the value of the torque is so low, So the precision is bad. In glycerin there was no vortex formation during testing impellers 4RT and 4PBT in the three Vessels as it was in laminar regime with low reynold's number; For Anchor impeller vortex formations happened in vessels Dv=70,100 but in the bigger vessel Dv=140 it started forming. This proves that Glycerin is a high viscous fluid and this is the reason why vortex didn't form. Some of the problems I faced was that the software sometimes would crash in the middle of the experiment and oi would have to repeat it atleast 2 times before it would start functioning properly again. Also sometimes I found difficulty in figuring out which maximum speed I should use so that the water doesn't splash on the whole counter while working , as for each impeller the speed had to be chosen separately.

Lists

1. Table of Symbols

Symbol	Quantity	Unit
R_e	Reynold's number	
N_i	Speed	rps
D_{imp}	Impeller Diameter	mm
ρ	Density	Kg/m^3
μ	Viscosity	Pa.S
M	Torque	N.m
P	Power	Watt
D_v	Vessel Diameter	mm
C	Off-bottom clearance	mm
t_m	Mixing time	s

2. List of figures

3. List of tables

Appendix

Number	Equation	Name
1	$P = 2 * \pi * Ni * M$	Power
2	$Np = \frac{P}{\rho * Ni^3 * Di^5}$	Power Number
3	$Re = \frac{Ni * D^2 * \rho}{\mu}$	Reynold's Number

References

Rushton, J. (1956). Principles of mixing in the fatty oil industries. [online] Wiley online library. Available at: http://onlinelibrary.wiley.com/doi/10.1007/BF02638498/abstract

Van de Vusse, J. (1955). Mixing by agitation of miscible liquids Part I. Chemical Engineering Science, [online] 4(4), pp.178-200. Available at: https://www.sciencedirect.com/science/article/pii/0009250955850208

Holland, F. and Bragg, R. (1995). Fluid Flow for Chemical and Process Engineers. Burlington: Elsevier.

Life.dlut.edu.cn. Research. [online] Available at: http://life.dlut.edu.cn/english.htm

Correlation of Power Consumption for Several Kinds of Mixing Impellers [Report] : International Journal of Chemical Engineering / auth. Furukawa Haruki, Yoshihito Kato and Yoshiro Inoue. - Osaka : Hindawi Publishing Corporation, 2012.

HANDBOOK OF INDUSTRIAL MIXING SCIENCE AND PRACTICE [Book] / auth. Paul Edward L.. - New Jersey : A JOHN WILEY & SONS, INC., 2004. - Vol. 1.