Study on Removal of Particles from Used Turbine Oil

By

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
Mechanical Engineering

MAY 2011

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

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May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ATIKA ILLYANI BINTI ANAS

ABSTRACT

Turbine oil is usually use in gas turbines, and other applications requiring supreme quality turbine oil. Turbine oil cleanliness continues to cause concern because to have optimum performance the oil has to be significantly clean.

The current inventions of turbine oil filtration are widely categorized under different types of filtration methods depending on its objectives or applications. The existence of iron components in industrial turbine oil makes magnetic filter is the effective tools for capturing as well as recycling of small sized magnetic particles.

Turbine oil correction can be quite exhaustive and detailed in nature. Most commercial oil analysis laboratories do not have this capability or technical expertise. Some of the machines also very bulky and not portable. This problem had inspired the author to develop a new design of magnetic filter which is smaller in size and simpler process to remove particles from used turbine oils.

The method used in designing the magnetic filter are modeling and simulation software.After performing calculations and software simulation, the best method in filtering particles in used turbine oil is by using off-line magnetic filter. Agitation is introduced in getting optimum result.

ACKNOWLEDGEMENT

First and foremost, thank god for His grace and mercy that He gave to me, without it, maybe I cannot make it through until the end. I would like to extend my most sincere gratitude to my Supervisor, Ir Idris bin Ibrahim, for his full support and continuous encouragement and guidance for me towards completing this project and also thank you for monitoring my progress and for helping me to face any problem related to my project. Almost certainly without his cooperation, I might not be able to finish my project, as it needs a lot of commitment towards finishing it.

I would like to express my appreciation to all those who had assisted in making my Final Year Project a success.

Last but not least, many thanks go to thank all parties who had also contributed directly and indirectly to the success of my project. Thank you very much, may Allah repays for your kindness.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The current inventions of turbine oil filtration are widely categorized under different types of filtration methods depending on its objectives or applications. The filtration methods can be further divided into on-line or off-line filtration. The existence of iron components in industrial turbine oil makes magnetic filter is the effective tools for capturing as well as recycling of small sized magnetic particles. The unique performance characteristics of magnetic filters differ greatly not only from those of other filtration processes but also from those of magnetic separation. These differences lie in operating conditions, magnetizing characteristics of the matrix elements, the flow regimes of the liquid to be cleaned and others. In general, it has been proven that magnetic filtration is stochastic (a process that shows non-deterministic behaviour and determined by both the predictable actions of process and by random element) in nature when all the parameters affecting the process are considered (Abbasov, K¨oksal & Herdem, 1999). This allow new inventions and alterations to take place in order to improve the filtration performance.

1.2 Problem Statement

Nowadays, turbine system has been developed to replace the manual force in doing heavy work. A lot of improvements were made from day to day in order to maintain the turbine system. Almost all machinery today uses lubrication to smooth the operation of the machine, and one of the most important medium in turbine oil. Lubrication is made of oil generally due to its effectiveness to lubricate machine part contact surfaces and protect it from rust (Mittal, 1995).

According to Jakob (1937) , the magnetic devices have been proposed from time to time in separating iron material suspended in fluids but those devices in general are large in size and complicated in comparison with the conventional filter units, and have been found inefficient when the flow of fluid is rapid. Meanwhile, turbine oil correction can be quite exhaustive and detailed in nature. Most commercial oil analysis laboratories do not have this capability or technical expertise. Some of the machines also very bulky and not portable.

This problem had inspired the author to develop a new design of magnetic filter which is smaller in size and simpler process to remove particles from used turbine oils. The author had simplified the process by only focusing on removing particles in the used turbine oil by using magnet in off-line filtration system. Magnetic filter is a filtration device in which the filter screen is magnetized to trap and remove fine iron from liquids or liquid suspensions being filtered.

1.3 Objectives and scope of Study

The main objectives of this research are:

- Design a magnetic filter
- Simulation to study the effects of several variables to the filter performance

The scope of study for this project cover investigation of the most suitable method to remove particles from the used turbine oil so it can be reuse for other oil application that needs lower cleanliness requirements such as hydraulic oil or lubricants for pump and other equipments. The design of magnetic filter is done by making selection of the design parts and performs calculations for its dimensions. Then, software simulation is being run in modeling and simulating the design parameters in obtaining the required results.

CHAPTER 2
LITERATURE REVIEW

2.1 Method of removal particles from used turbine lubrication oil

The selection can be divided into the type of system, filtration method, type of magnet used and impeller. First, this project will only focus specifically on turbine oil because the cleanliness requirement of turbine oil is quite high and it has to be changed regularly. This will result on the abundance of used turbine oil. Instead of throwing it away, the used turbine oil can be filtered and reuse in other applications that require lower cleanliness standard.

Most of lubricants company in Malaysia used ISO standard to check the quality of the lubrication oil. The Contamination Class according to this standard is described by 3 numbers indicating the number of particles per 100 ml of fluid having bigger size than 4, 6 and 14 μm respectively (George, David & Dierk, 2001). Table 2.1 shows the correlation of ISO code with number of particles per 100 ml. For example, ISO code 21/18/15 indicates:

i) 21 = bigger than 4 μm

ii) 18 = bigger than 6 μm

iii) 15 = bigger than 14 μm

Table 2.1 : ISO code in relation of number of particles per 100 ml (George et al.)

ISO Code	Number of particles per 100 ml	
	more than	up to
22	2, 000 000	4, 000 000
21	1, 000 000	2, 000 000
20	500 000	1, 000 000
19	250 000	500 000
18	130 000	250 000
17	64 000	130 000
16	32 000	64 000
15	16 000	32 000
14	8000	16 000
13	4000	8000
12	2000	4000
11	1000	2000
10	500	1000

9	250	500
8	130	250

The higher the range code, the greater the fluid contamination. In used turbine oil, the size of particles are usually 20 μm which gives ISO standard in between 20/18/15 and 21/19/16. From Table 2.2, for range 18/15 to 20/17 is already considered dirty in turbine oil applications and can no longer being used. The dirty turbine oil is not necessarily dirty in other oil applications. With filtration, the ISO cleanliness level can be reduced, hence can be reused in other application such as gear oils, engine lube or hydraulis fluids that required lower cleanliness level to function.

Table 2.2: Range of oil cleanliness (George et al.)

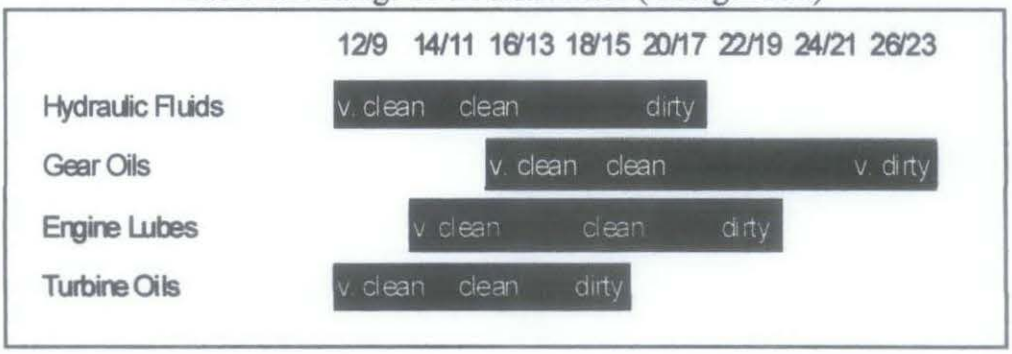

Table 2.3 shows that the oil description according to its ISO code. Oil have different ISO code according to its applications.

Table 2.3: Description of oil according to its ISO code (George et al.)

ISO Code	Description	Suitable for
ISO 14/12/10	**Very Clean Oil**	**All Oil System**
ISO 16/14/11	**Clean Oil**	**Servo and High Pressure Hydraulics**
ISO 17/15/12	**Light Contaminated Oil**	**Standards Hydraulic and Lube Oil Systems**
ISO 19/17/14	**New Oil**	**Medium to Low Pressure System**
ISO 22/20/17	**Very Contaminated Oil**	**Not suitable for Oil System**

2.1.1 Type of system

The system can be divided into on-line or off-line filtration system. On-line filtration will filter particles in the system flow.There is invention of magnetic filter of on-line filtration system that allows the fluids to flow freely in and out of the filter. For example, Gregory and Anthony (2009) had invented a system and process for separating residual magnetic resin from a liquid stream by passing the stream through permanent magnets located within the stream. The process however is much more complicated and tedious compared to off-line filtration system because there are a lot of auxiliary gauge needed to maintain the flow, temperature, pressure and other variables which will make it bulky and harder to analyze.

Off-line filtration systems are widely used in current systems available in market. This is because it gives several benefits beyond other type of filtration such as traditional pressure and return-line filters (Busta, 2011). For this project, the oil will be draws from turbine, agitated into the magnetic filter and returns the clean fluid into intermediate bulk container (IBC) or other type of container for use of other applications that comply the same cleanliness level. Some of the benefits that being listed down are as per below (Busta, 2011) :

- Easy to retrofit into an existing system
- Off-line filters can be serviced without shutting down the main system
- The off-line return line is used to pre-charge the main system pump with clean fluid
- Specific cleanliness levels can be more accurately achieved and maintained,
- Filters are not subjected to flow surges, allowing for optimum element life and performance. Filters are most efficient with a steady flow of fluid, so matching the filter to the flow of the off-line loop ensures optimum operation.

2.1.2 Filtration method

One of the typical circulating turbine oil problems is the change of color from yellow to dark green after about three months of service. Young and Roberton (1989) had performed a laboratory inspection of the oil and showed that the dark green oil contained a considerable amount of sediment consisting iron, aluminum, phosphorus and silicon (quartz).The color change might be explained by the combination of the primary colors, yellow from the turbine oil and the bluish tinge of contaminants, producing a dark green color. Due to massive concentration of metallic residue, it is recommended to change the oil and examine the cause of rapid wear. It shows that continuous effective monitoring of turbine oils in service is required to maintain effective turbine lubrication and to assure a long service life of the turbine oil. Table 2.4 shows the result of analysis of used turbine oil done by Young and Roberton (1989).

Table 2.4: Analysis of used turbine oil (Young & Roberton, 1989)

Sample Source	**Used Turbine Oil**
Viscosity at 40°C, cSt	30.5
Viscosity at 100°C, cSt	5.2
TAN, D 974, mg KOH/g	0.11
Appearance	Dark green
Filter residue, mg/ 100 g	12.6
Spectroscopy analysis, ppm Aluminum Iron Phosphorus Silicon	 48 36 26 5

There are several types of methods available in achiving the targeting cleanliness code. The methods are mechanical, magnetic, sedimentation, centrifugal and high efficiency (HE) filter. Each type is being described briefly in Table 2.5 (Jakob, 1937).

Table 2.5: Types of oil filtration method (Jakob, 1937)

Type	Method
Mechanical filter • Catridge and spin-on	Made of bulk material such as cotton waste or pleated filter paper to entrap and sequester suspendended contaminants.

Magnetic filter	Use permanent or electromagnet to capture ferromegnetic particles.
Sedimentation filter	A sedimentation or gravity bed filter allows contaminants heavier than oil to settle to the bottom of a container under the influence of gravity.
Centrifugal filter	A centrifugal oil cleaner is a rotary sedimentation device using centrifugal force rather than gravity to separate contaminants from the oil.
High efficiency (HE) filter	A bypass filter that allow extended oil drain intervals.

Compared to other filters such as mechanical filters and membranes, magnetic filter have other significant construction and regime advantages, though they cannot be effectively used in all industrial areas. Unfortunately, there is not yet a general theoretical approach and enough practice recommendation that fully describes and explain the characteristics of magnetic filters to warrant their efficient application (Abbasov et al.).

Carmon (1969) had patented the catridgeless magnetic filter of metal cuttings from fluid within a transmission. The device will remove metal cuttings from transmission fluid using an auxiliary housing attached to the transmission casing solely by magnetic attraction and the fluid is moving in and out of the auxiliary housing by normal transmission operation.

Roger (2010) had invented a magnetic device that can be removably installed in a vessel to provide a fluid filtering assembly.

2.1.3 Type of magnet

Magnet used in filtration application can be divided into permanent and electromagnet. The differences between the two types of magnet are as per Table 2.6.

Table 2.6: Differences between permanent magnet and electromagnet

	PERMANENT MAGNET	ELECTROMAGNET
Definition	Made of ferromagnetic material (consists of atoms and molecules that each have a magnetic field and are positioned to reinforce each other)	Magnetic field is produced by the flow of electric current
Shape	Can be in any form of shape	Solenoid shape
Strength	Magnetic strength varies according to types of material	Extremely strong magnet
Power	Not require power	Require power
Magnetic field	Always "on"	Can be turn on and off by control the current

Permanent magnets consist of several types such as composites, rare-earth, single-molecules and nano-structured magnets. The most suitable type of permanent magnet in oil filtration application is ceramics/ferrite type which falls under composites. This type of magnets is easily available due to its low cost and easily fabricated in any size or shape required. Hence, the resulting magnets will not corrode and generally stable in moisture.

The magnets will give different magnetization value according on how the materials respond to the magnetic field. The magnetization value of several type of permanent magnet is listed in Table 2.7. It can be used to calculate the magnetic force.

Table 2.7: Magnetization value of permanent magnet (Ashcroft & Mermin, 1976)

Material	**Magnetization (T)**
$BaFe_{12}O_{19}$	0.36
Alnico IV	0.60
Alnico V	1.35
Alcomax I	1.20
MnBi	0.48
$Ce(CuCo)_5$	0.70

$SmCo_5$	0.83
Sm_2Co_{17}	1.15
$Nd_2Fe_{14}B$	1.20

Polyon, Photharin and Wlangnon (2010) had publish an experimental study of a longitudinal magnetic filter. This study using electromagnet instead of permanent magnet and is attach at the outside pipe parallel to the direction of flowing fluid. Figure 2.1 shows the diagram of the experimental longitudinal magnetic filter (Polyon et al.).

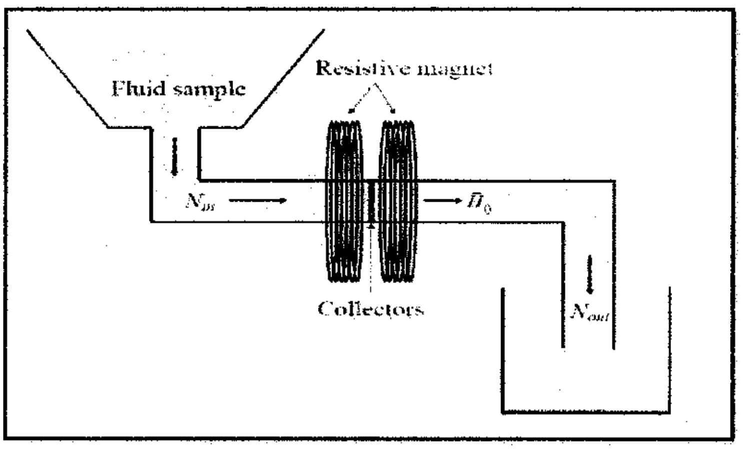

Figure 2.1: Diagram of an experimental longitudinal magnetic filter (Polyon et al.).

2.1.4 Impeller

When oil is stationary, only the particles immediately surrounding the magnet are attracted. To enhance the filtration performance, agitation concept has to be introduced. In order to select the best impeller to be used in this project, the flow patterns have to be studied.

It can be study from the Reynolds number:

$$\mathrm{Re} = \frac{\rho V L}{\mu} \qquad (1)$$

For stirred cylindrical tank, the Reynolds number is

$$\mathrm{Re} = \frac{\rho N D^2}{\mu}. \qquad (2)$$

The system is fully turbulent for values of Re above 10 000 (Sinnot, 2005). Agitator flow can be divided into axial, radial and mixed flow. The characteristic of mixed flow is in between axial and radial flow. The impeller discharge is about 45 degrees to the impeller shaft. However, the impeller size and its position have to be taken into consideration as flow reversal that lead to pile of solids forming in bottom center of tank will possibly occur if impeller is too big or too high off bottom (Abbasov et al.). The mixed flow impeller will work equally well when positioned vertically or at any angle (Mittal, 1995).

Pitch is refers as turning the angle of attack of the blades of a propeller. According to Mittal (1995), for low to medium viscosity liquids, regular pitch must be use meanwhile high lift is use for medium to high viscosity liquids. Figure 2.2 shows the liquid flow and the configuration of mixed flow impeller.

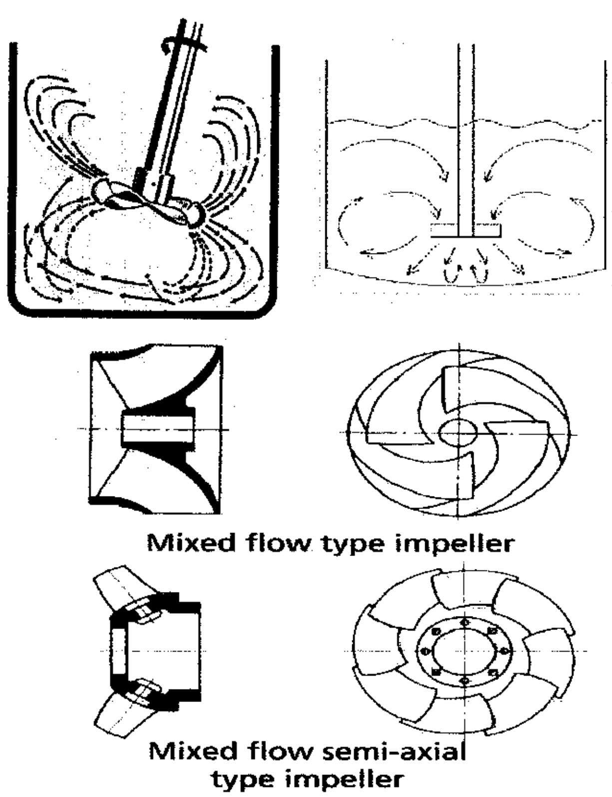

Figure 2.2: Mixed flow impeller (Mittal, 1995)

2.2 Design of magnetic filter

2.2.1 Magnetic force

According to Dan Norrgran (2008), the magnetic field for effective particle collection is determined by size of particles to be filtered. The general guidelines for magnetic field requirements are shown in Table 2.8.

Table 2.8: Magnetic filter in relative to size of particles to be filtered (Norrgran, 2008)

Magnetic Field (B)	Size of particles
1500 Gauss	Relatively coarse (+50 micron) ferromagnetic iron of abrasion.
2500 Gauss	Fine (-50 micron) ferromagnetic iron of abrasion or scale.
5,000 Gauss	Very fine (submicron) ferromagnetic iron of abrasion or scale, or paramagnetic contaminants such as iron-bearing minerals or nickel and cobalt compounds.
10,000 Gauss	Fine paramagnetic contaminants.

The magnetization of magnet can be related to magnetic field by using the equation below (David, 1998):

$$B = \mu_O M \qquad (3)$$

According to David (1998), the force exists between two magnetic poles is explain by Coulomb's Law.

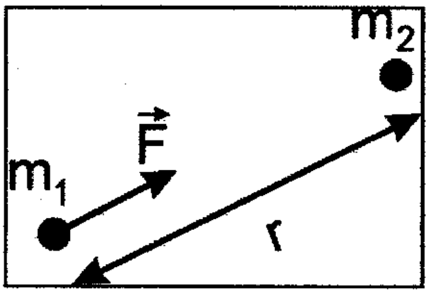

Figure 2.3: Force exists between 2 magnetic poles (David, 1998)

It can be further explained by the equation below (Norrgran, 2008):

$$F = \frac{\mu_0 m_1 m_2}{4\pi r^2} r \quad (4)$$

The force between two cylindrical magnets can be calculated as per equation below (David, 1998):

$$\mathrm{F} = \frac{\pi \mu_0}{4} M^2 R^4 \left[\frac{1}{x^2} + \frac{1}{(x+2L)^2} - \frac{2}{(x+L)^2}\right] \quad (5)$$

2.2.2 Power

According to Albert (1988), magnetic force is equal to centripetal force. Oil or the particles in detail is moving in a circle when magnetic field is applied to it and the radius of the circle is x/4. Magnetic force equal to centrifugal force is true when the shaft speed is constant. The particles are assumed to be circulating in constant speed because there are assumptions that there are no other forces on particles and the magnetic field is uniform. The magnetic force is always perpendicular to the direction of motion. Perpendicular forces consume zero work which means the kinetic energy cannot be add or remove (Jakob, 1937).

F (magnetic) = F (centrifugal)

$$\frac{\pi \mu_0}{4} M^2 R^4 \left[\frac{1}{x^2} + \frac{1}{(x+2L)^2} - \frac{2}{(x+L)^2}\right] = \mathrm{m}\omega^2 r \quad (6)$$

$$\mathrm{T} = \mathrm{F.d} \quad (7)$$

$$\mathrm{P} = \mathrm{T}.\,\omega \quad (8)$$

In defining the problem magnitudes there are many methods available with wide range of accuracy and complicated steps. Madhavi, Juvekar and Vivek (2011) had successfully analyzed the behavior of solid suspension in stirred tank by using ultrasound velocity profile (UVP) approach. This method needs a very high technology machine that will give accurate result but expensive and time consuming. The fluid flow can be defined manually by long complicated mathematic formulas such as discretization method but with the ongoing research, simpler method had been invented with the help of computer software.

Piero and Ernesto (1997) had solved the effect of low off-bottom impeller clearance with changing agitation speed by using exponential function.

2.3 Simulation

Derksen (2003) had published a study about solving problem of solid suspension in stirred tank using numerical simulation method. By taking water as the working fluid and glass beads as solid particles, the behavior of particles and the way the liquid flow is altered by the presence of particles are being observed. In this study, the flow is driven by a Rushton turbine that coupled to a Lagrangian description of spherical, solid particles immersed in the flow.
Figure 2.4 shows the flow geometry and (*r*, *z*) coordinate system from Derksen (2003).

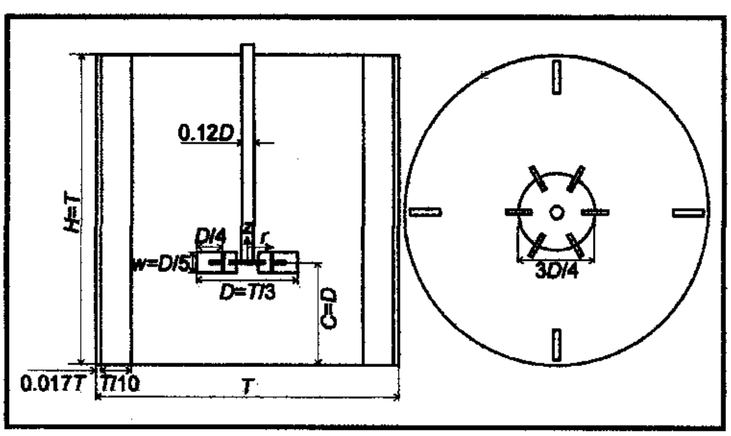

Figure 2.4: Flow geometry and (*r*, *z*) coordinate system (Derksen, 2003)

Syrjanen, Haavisto, Koponen and Manninen (2009) also published the measurements and modeling of particle velocity and concentration profiles of sand- water slurry in stirred tank using CFD .The particles velocities and volume frictions is being studied at 5% and 10% solid phase. The mixing of sand-water slurry at varying consistencies was studied in a laboratory scale cylindrical tank equipped with a 45° pitched blade turbine.

According to the studies, standard k-ε model need to be applied in turbulence modeling. The time dependent 3D studies of the slurry flow in the tank were conducted with algebraic slip mixture model and full Eulerian multiphase model. The agreement of particle velocity components was generally good in the centre of tank, while some deviation took place near the wall.

The relationship between number of iterations and time step is mentioned in Computational Fluid Dynamics Review book by Hafez, Oshima & Kwak (2010). As stated in the book, larger time steps can be efficiently used provided that enough iterations are performed to converge the solution and eliminate any spurious behavior. As the time step decreases, the number of iterations needed to generate physically relevant results will also be decreased.

2.4 Summary of literature review

Table 2.9: Summary of literature review

Title	Author	Description	Limitation
Magnetic Particle Removal Process	Gregory and Anthony (2009)	Invented a system and process for separating residual magnetic resin from a liquid stream by passing the stream through permanent magnets located within the stream	Complicated and tedious
Turbine Oil Monitoring	Young and Roberton (1989)	Explain the details of turbine oil monitoring	
Magnetic Filtration of Transmission Fluid	Carmon (1969)	Catridgeless magnetic filter of metal cuttings from fluid within a transmission	Not suitable for turbine oil filtration
Magnetic filter and Magnetic Filtering Assembly	Roger (2010)	Invented a magnetic device that can be removably installed in a vessel to provide a fluid filtering assembly	Low efficiency
Experimental study of a Longtudinal magnetic Filter	Polyon, Photharin and Wlangnon (2010)	Experimental study of a longitudinal magnetic filter	On-line filtration system and electromagnet
Magnetic filtration: Producing fine high-purity feedstocks	Dan Norrgran (2008)	Magnetic field for effective particle collection is determined by size of particles to be filtered	Limited of particles sizes and magnetic field values
Introduction to Electrodynamics	David (1998)	Get the equation of magnetic force between two cylindrical magnets from Coulomb's Law	
The Electromagnetic Field	Albert (1988)	Magnetic force is equal to centripetal force	

Solid suspension in stirred tanks: UVP measurements and CFD simulations	Madhavi, Juvekar and Vivek (2011)	Analyzed the behavior of solid suspension in stirred tank by using ultrasound velocity profile (UVP) approach	Need an expansive high technology machine and time consuming
Effect of low off-bottom impeller clearance on the minimum agitation speed for complete suspension of solids in stirred tanks	Piero and Ernesto (1997)	Solve the effect of low off-bottom impeller clearance with changing agitation speed by using exponential function	Tedious and complicated
Numerical simulation of solids suspension in a stirred tank	Derksen (2003)	Study about solving problem of solid suspension in stirred tank using numerical simulation method	No magnetic components and different fluid type
Particle velocity and concentration profiles of sand-water slurry in stirred tank-Measurements and modeling	Syrjanen, Haavisto, Koponen and Manninen (2009)	Study of particles velocity and volume frictions using CFD simulation.	No magnetic components and different fluid type

CHAPTER 3

METHODOLOGY / PROJECT WORK

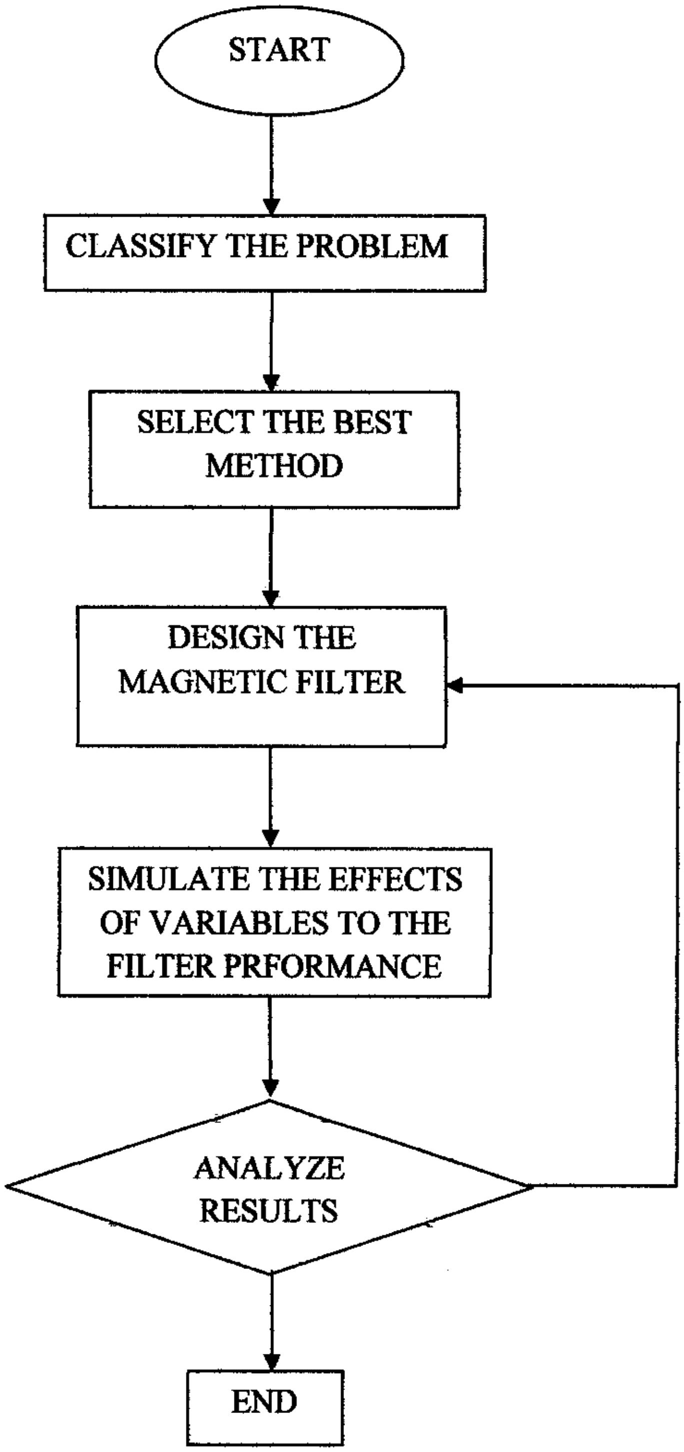

Figure 3.1: Flow chart

3.1 Research activities

Figure 3.1 shows the flow chart of this project. The following procedure illustrates the steps needed to solve the main categories of fluid agitation problems.

Classify the problem

Researches from articles, books, patent and other resources had been made to compare the best method in filtering the turbine oil. As stated in the problem statement, a magnetic filter that smaller in size with simpler process needs to be designed to be reused in other application that require lower cleanliness level. The type of system, fluid flow, impeller and magnet are the crucial parameters to be taken into consideration before proceed to the next step. The magnitude variables and equations are being adjusted based on the problems requirements.

Define problem magnitudes

The principal problem magnitudes are size, difficulty and required process result. These magnitudes will vary with each problem classification. The size of particles to be filtered, separation distance between two magnets, size of magnets and size of impeller were first defined by the author based on the standard value. Then, other magnitudes are defined by calculations and comparison.

Calculate the magnetic filter dimensions

For any given set of problem magnitudes, there are in principle an infinite number of designs that will satisfy them. Dimensions to be calculated are magnetization of magnet, magnetic force between two cylindrical magnets, speed shaft of impeller and power.

Simulate the effects of variables to the filter performance

This step is fully dependence on software. First, the magnetic filter is being drawn in 3D using CATIA software. Next, import the drawing into Gambit software for meshing and specifying boundary conditions. Then, import the file into Fluent to study the fluid flow and vary certain variables to test its performance.

Analyze result

From the results in Fluent, the graph will be analyzed. All the effects and values will help to choose the best magnetic filter.

3.2 Method of removal particles from used turbine oil

They are four major things that need to be select for this project. They are type of system, filtration method, type of magnet and impeller. All the selection is being made through research and comparison. The best selection is base on the output it gives that satisfies the objectives of this project. First, researches of options will be made and been listed down. Then, the best option will be select by comparison.

3.3 Design of magnetic filter

Design of magnetic filter is achieved by calculations. The steps of calculations are being listed as per below:

3.3.1 Magnetic force

1. Determine the size of particles to be filtered.
2. Choose the suitable value of magnetic field from Table.
3. Solve the equation (3) , and get the magnetization value.
4. Choose the suitable magnet base on the magnetization value.
5. Define the distance between two magnets. ($x = 0.2$)
6. Put values into equation (5) and get the magnetic force.

3.3.2 Power

1. Put values into equation (6) and get the shaft speed.
2. Put values into equation (7) and get the torque.
3. Put values into equation (8) and get the power.

3.4 Simulation

In simulation part, the software used are Gambit 2.0 and Fluent 6.0. The details are as below:

3.4.1 Gambit 2.0

GAMBIT 2.0 is a general-purpose preprocessor for CFD Analysis, which continues to allow engineers the easier access into the CFD world. Gambit is used for modeling and boundary conditions setup.

Steps

1. Model the volume of the design with exact measurement.

The three dimensional grid is being created using the commercial grid generator package Gambit by meshing the domain of integration. Figure 3.2 shows the volume that had been modeled in Gambit software which divided into magnets, impeller and tank.

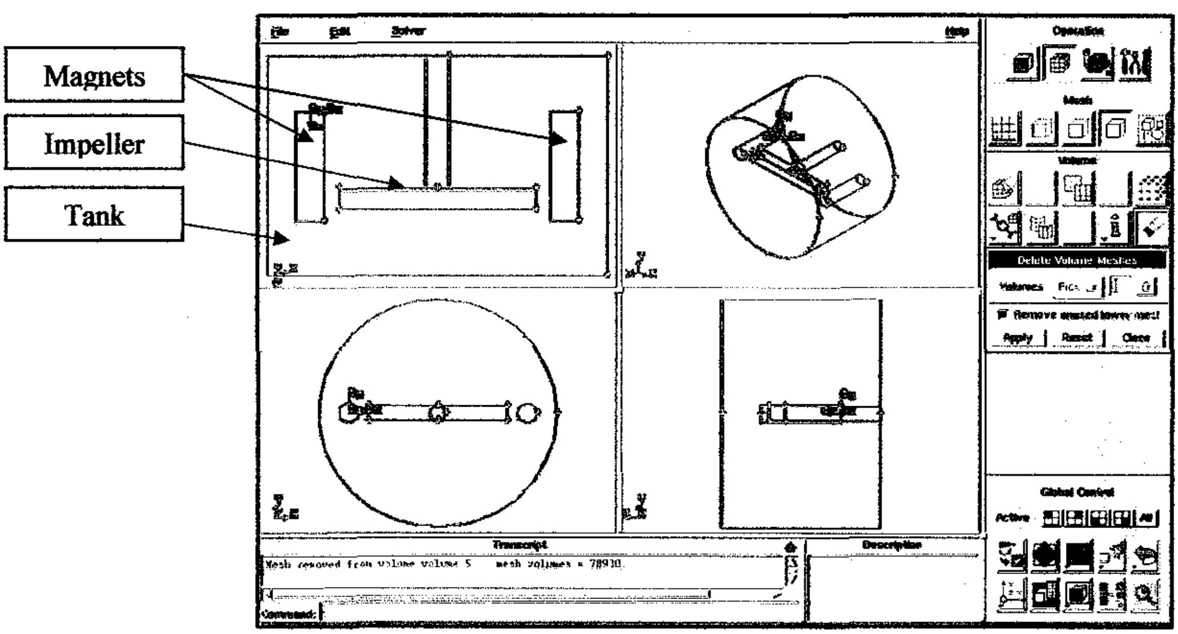

Figure 3.2: Design volumes in Gambit

The volumes of the model consist of two stationary magnets, one rotating impeller, a tank and an imaginary volume of rotational zone (between the two magnets, x = 0.2m).

Figure 3.3 shows the volume of the design with the dimensions.

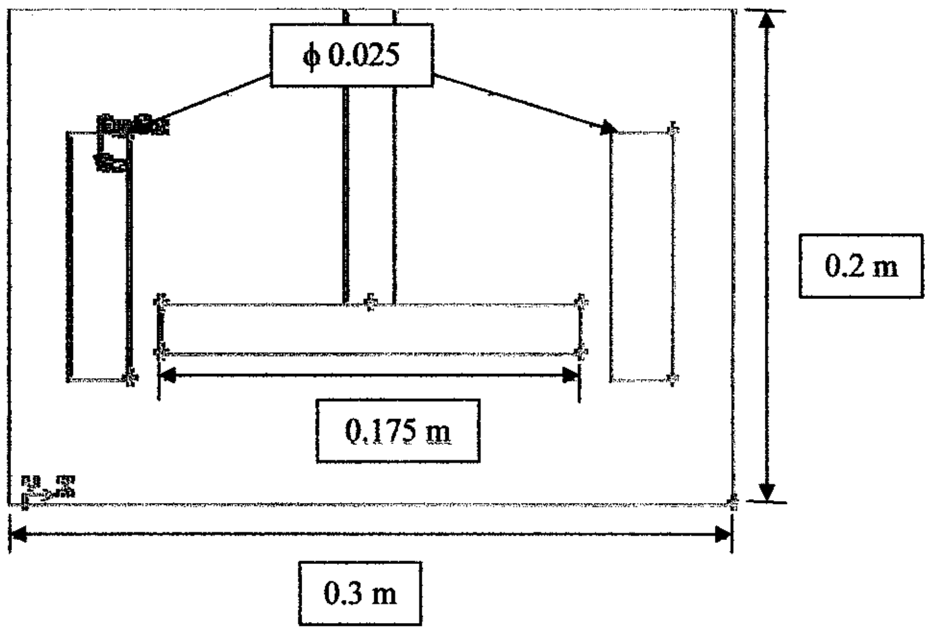

Figure 3.3: The design dimensions

2. Setting the boundary conditions

The boundary type command can specify different types of boundary conditions such as wall, axis, outflow, symmetry, periodic or others. Next, set the zone of the volume as fluid or solid.

3. Meshing the model

The grid is made of unstructured gird that contains different type of elements. The choice of having an unstructured grid versus a structured one was made due to the fact that in a complex flow like the present, details of the flow field everywhere in the tank and especially in the rotational area of the impeller and around the magnets must be captured. For this project, all volume is meshed by tetrahedral/ hybrid elements. The interval size is depends on the detailed of the volume to be analyzed. All of the volume is set with interval size of 0.01.

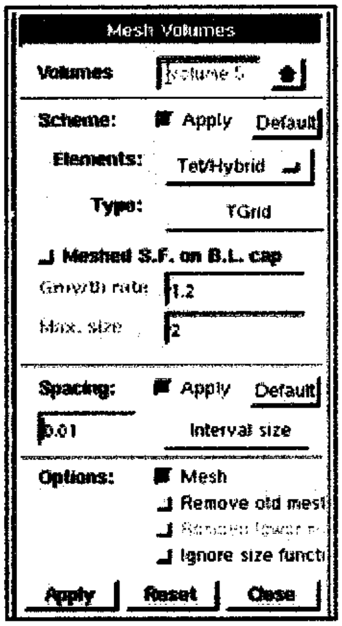

Figure 3.4: Mesh volumes in Gambit

4. Export the design model into msh file to be launched in Fluent 6.0.

3.3.2 Fluent 6.0

Fluent 6.0 is an engineering simulation software contains the broad physical modeling capabilities needed to model flow, turbulence, heat transfer, and reactions for industrial applications.

Steps

1. Read case from Gambit.

2. Check the grid.

After launched the Gambit file to Fluent software, the grid is checked to ascertain the modeling part from Gambit. By checking the grid, the volume of the design that had been modeled before must be the same as the grid appear in Fluent. Figure 3.5 shows the grid of the design which consists of volume of magnet, volume of impeller and volume of rotational zone.

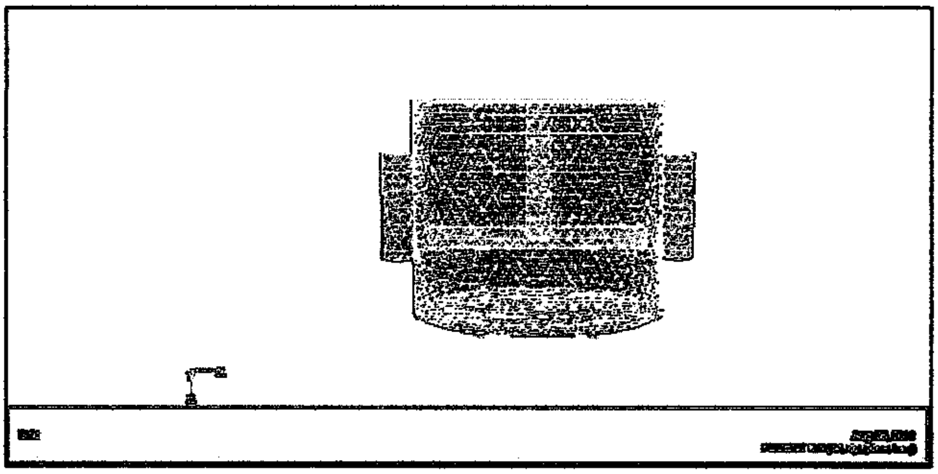

Figure 3.5: Grid of the design

3. Define models.

The model is defined as density based, implicit, steady flow and absolute. Figure 3.6 is showing the solver of the model that has been chosen. In Fluent simulation, turbulent flow is modeled using *k*-ε model with wall functions as shown in Figure 3.7. The grid will be divided into two reference frames to account stationary and rotating part. The impeller blade and the rotational zone will be included in computational domain. They will be describing as thin surfaces in computational grid. The time-dependent sliding mesh approach will be use to model the impeller (Derksen, 2003). The rotating part of the grid contained the impeller blade, and the stationary part contained the magnets and the tank.

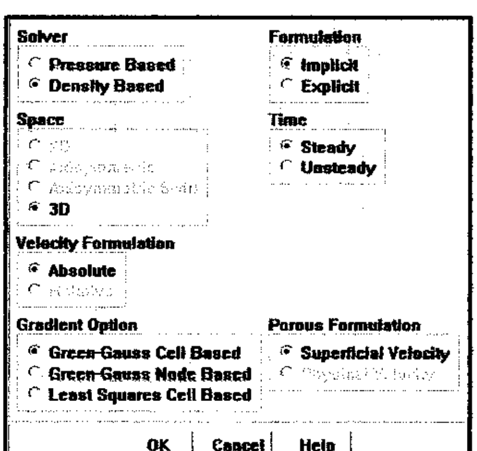

Figure 3.6: The solver of model

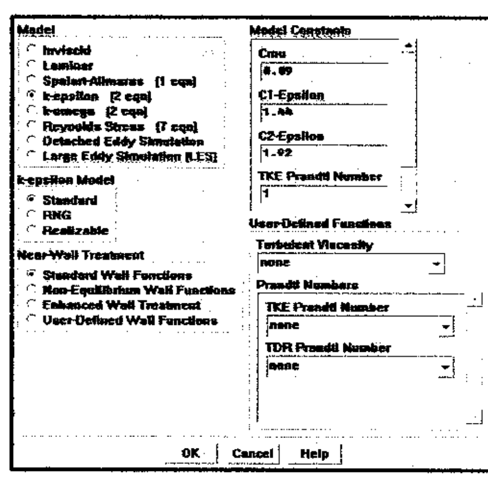

Figure 3.7: The viscous of model

4. Define materials.

The available material in fluent database is limited. For the oil, the author set it as water-liquid and alters the density and viscosity values according to the turbine oil values. The turbine oil specification is attached in the appendices. For the tank, it is set as solid steel. The materials setting are as in the Figure 3.8.

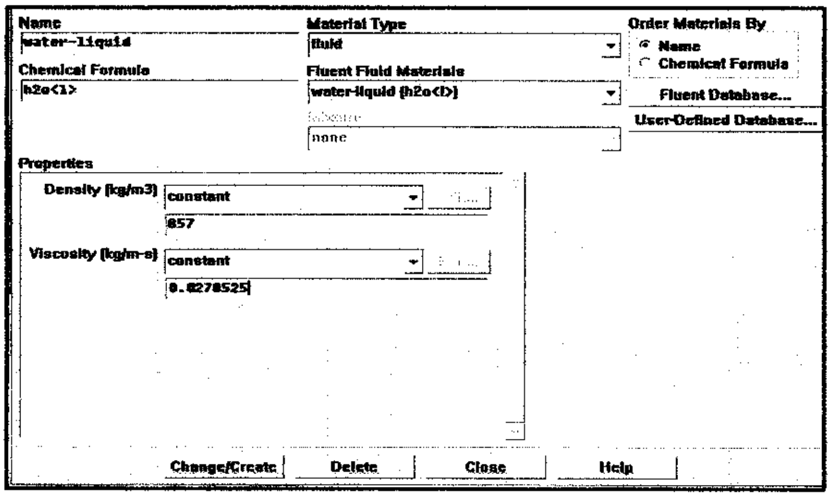

Figure 3.8: The materials of model

5. Define the operating conditions.

The operating pressure is set at 101325 Pascal which equal to 1 atm. The gravity acceleration is set at -9.81 m/s^2 in the z-axis because the fluid is pointing downward. The operating conditions are as per Figure 3.9 below.

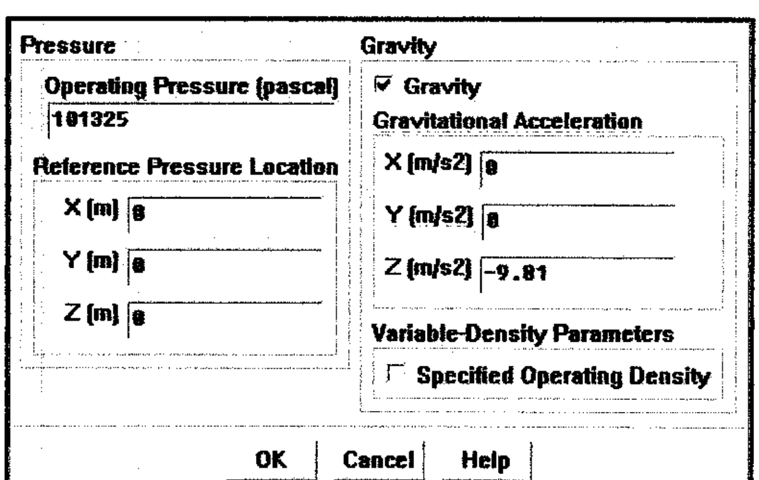

Figure 3.9: the operating conditions of model

6. Define the boundary conditions.

There are two boundary conditions to be set. First is the stationary wall with no slip shear condition. Second is the oil that set as fluid that moves in reference frame. The standard pressure discretization of Fluent 6.0 will be used in momentum equation. The rotational speed is set at 0.603 rad/s based on calculations. In this project, the model consists of the following boundary conditions as listed in the Figure 3.10. The vol_tank is the fluid inside the tank which is oil so the type is fluid.

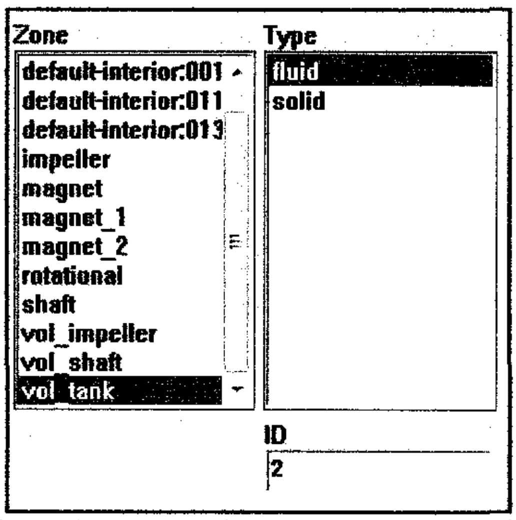

Figure 3.10: Boundary conditions of model

7. Solve.

First, set the solution initialization. Under the reference frame, there are two of choices that can be made which are either absolute or relative to Cell Zone values. In this case, the selected reference frame is absolute as shown in Figure 3.11.

Then, set the solution controls. Set the residual monitors and plot the iterations. Set larger number of iterations to make sure no data will be left out. In addition, fill up the continuity of 10^{-3} in convergence box. That means when all the residues of every variable reach the number, the simulation will converge. The model is converged when the residuals will no longer change as the iterations increase and the lines are almost flatten out. Figure 3.12 shows the residual monitors and iterations setting.

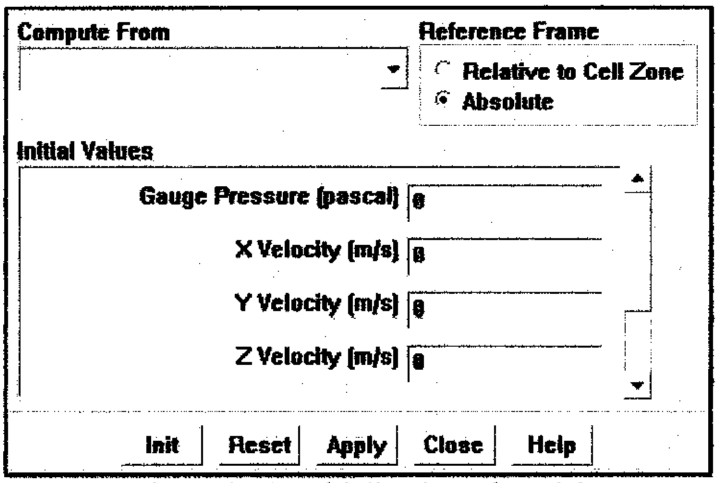

Figure 3.11: Initialization of model

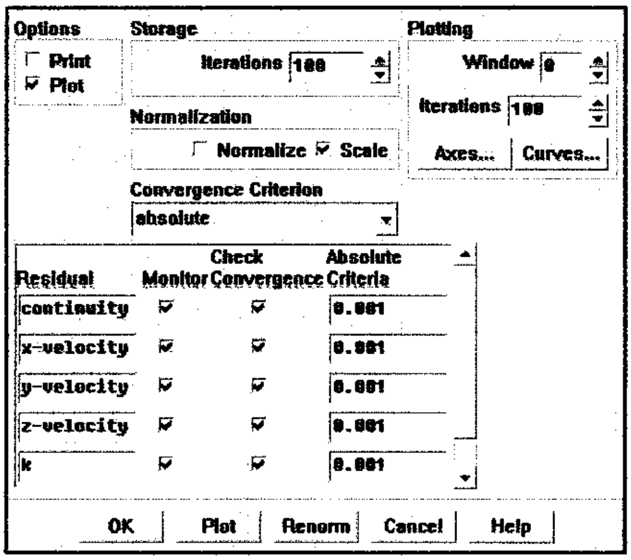

Figure 3.12: Residual monitors

8. Display and save the results.

9. Analyze the results.

10. Suggest improvements.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 The best method to remove particles from used turbine oil

Table 4.1: Final selection

	Selection
Type of system	Off-line filtration
Filtration method	Magnetic filter
Type of magnet	Permanent magnet (Barium Iron Oxide)
Impeller	Mixed type impeller

For this project, magnetic filtration method is being used in filtering used turbine oil because it contains iron particles that can be filtered best by using magnets.

Permanent magnet is the most suitable magnet to be used in this project. Its flexibility to be in any form of shape is vital because this project require magnet that can be mounted into the small size of magnetic filter. The strength of permanent magnet is lower than electromagnet but it is sufficient for the magnetic filter application and it can be manufactured to produce stronger fields than electromagnets of similar size. Hence, permanent magnet does not required power which is an important point in lowering the overall cost. This project does not required variable magnetic field, so permanent magnets are generally superior.

The permanent magnet material with suitable magnetization value is Barium-Iron Oxide magnet, $BaFe_{12}O_{19}$ .Barium Iron Oxide magnet is a part of composites magnet that is inexpensive and can be easily manufactured which makes it the best choice. Also, this magnet is highly insoluble and thermally stable. The casing or canister should be made of nonmagnetic material such as stainless steel.

Mixed type impeller had been widely used in filtration application especially in small diameter shafts because it reduces vibration to minimum and provides a definite safety factor at higher speeds. By using the mixed flow impeller, shock and possibility of damage to impeller or container is reduced to minimum when walls of container are accidentally contacted during mixing operation because of self-centering action that the flowing design and pitch of blades creates (Mittal, 1995).

4.2 Design of magnetic filter

Table 4.2: Final calculations

Size of particles to be filtered	20μm- 35μm
Magnetic field (B)	5000 G / 0.5 T
Separation distance between two magnets (x)	0.2m
Magnetization (M)	0.04 T
Magnetic force (F)	0.034 T.m.A
Shaft speed (ω)	5.76 rpm
Torque (T)	0.33 N.m
Power (P)	1.9 W

From calculation, the power needed to move the impeller shaft is around 2 Watts. The value is rather small but according to Piero and Ernesto (1997), the power of six blade (45°) pitched-blade turbine with tank diameter of approximately 0.3m is in the range of 1.8 to 2.9 Watts. The value is theoretically acceptable but need further analysis using simulation. The detail calculations are attached in the appendices.

4.3 Simulation

The drawing for this project had been successfully modeled using Gambit software. The simulation will involved moving parts (rotating shaft) so it had to be drawn in 3 dimensions. Then, meshing the volume and launch into Fluent for simulation. In this project, about 340 000 quadrilaterals and triangle elements were used to construct the mesh.

The meshed model is as shown in Figure 4.1 below:

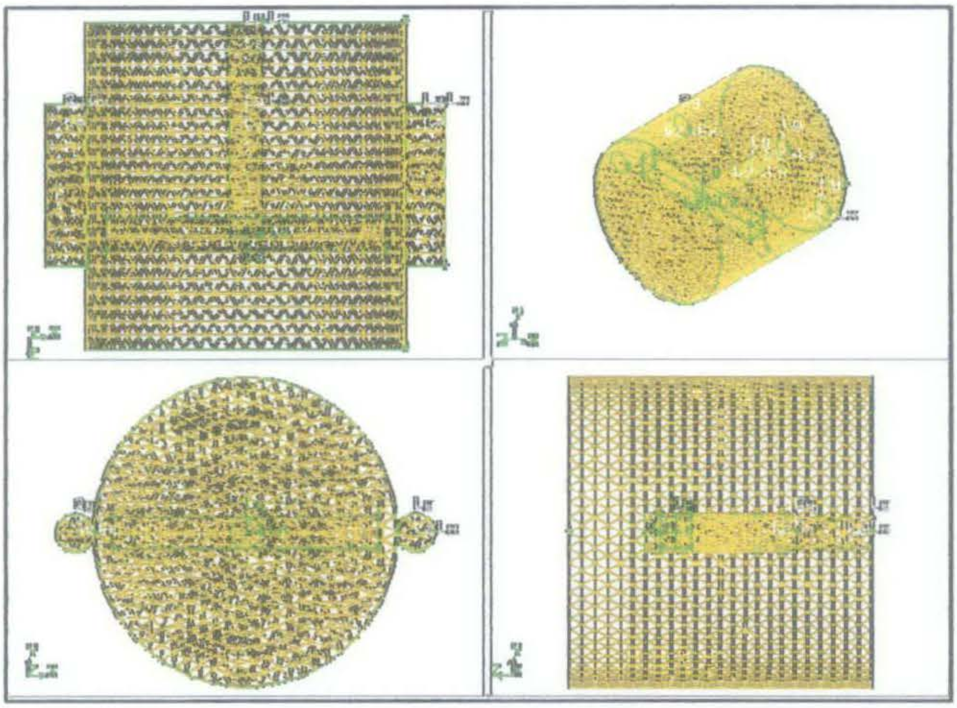

Figure 4.1: The meshed model

The meshed volumes are the two magnets, one impeller and rotational zone between the two magnets. The flow of oil to be observed is in the rotational area.

In monitoring the results, the radial velocity and x-velocity is being observed. Range of shaft speed are being used in observing the flow pattern in the rotational zone.The impeller rotational speed is started at 0.603 rad/s (based on calculations) .Figure 4.2 shows the X-velocity at the initialization of 0.603 rad/s shaft speeds. As shown in the figure, the velocity at both magnets (represent by red and green horizontal line at postion 0 and 0.2) are low which will give optimum condition for the particles to be trapped by the magnets.

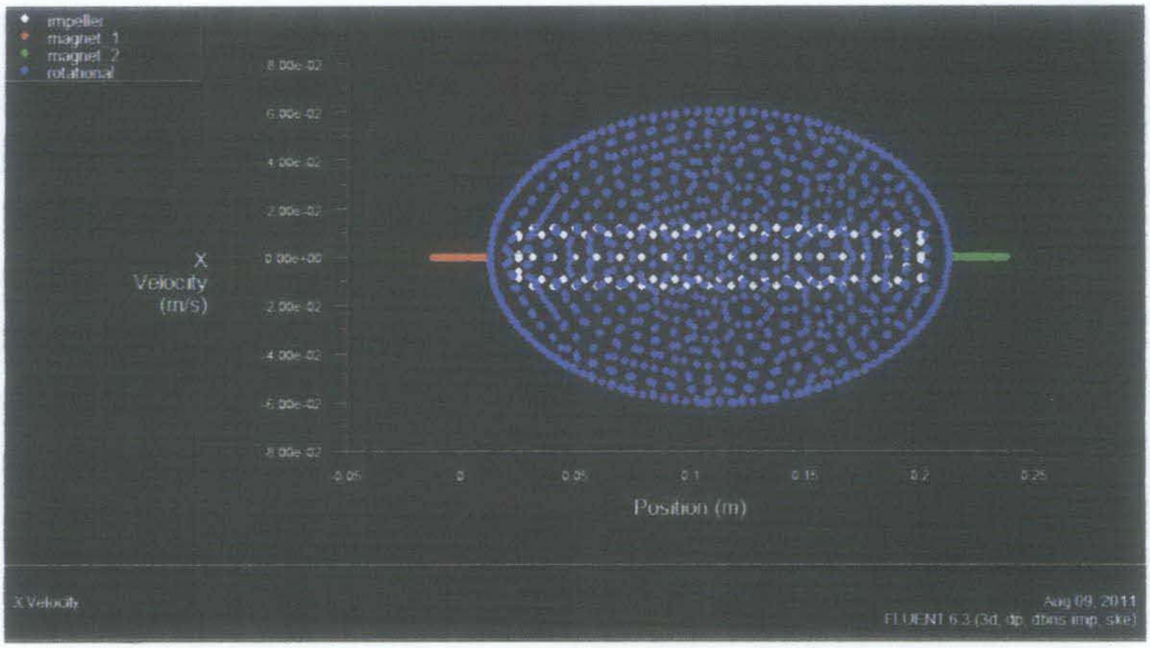

Figure 4.2: X-velocity of oil at 0.603 rad/s

Figure 4.3 shows the radial velocity of oil in rotational zone at initialization of 0.603 rad/s shaft speed. The horizontal white and red lines are representing the magnets at position 0 and 0.2. From Figure 4.3, the maximum radial velocity when the shaft speed is set at 0.603 rad/s is **1.5e-3 m/s.**

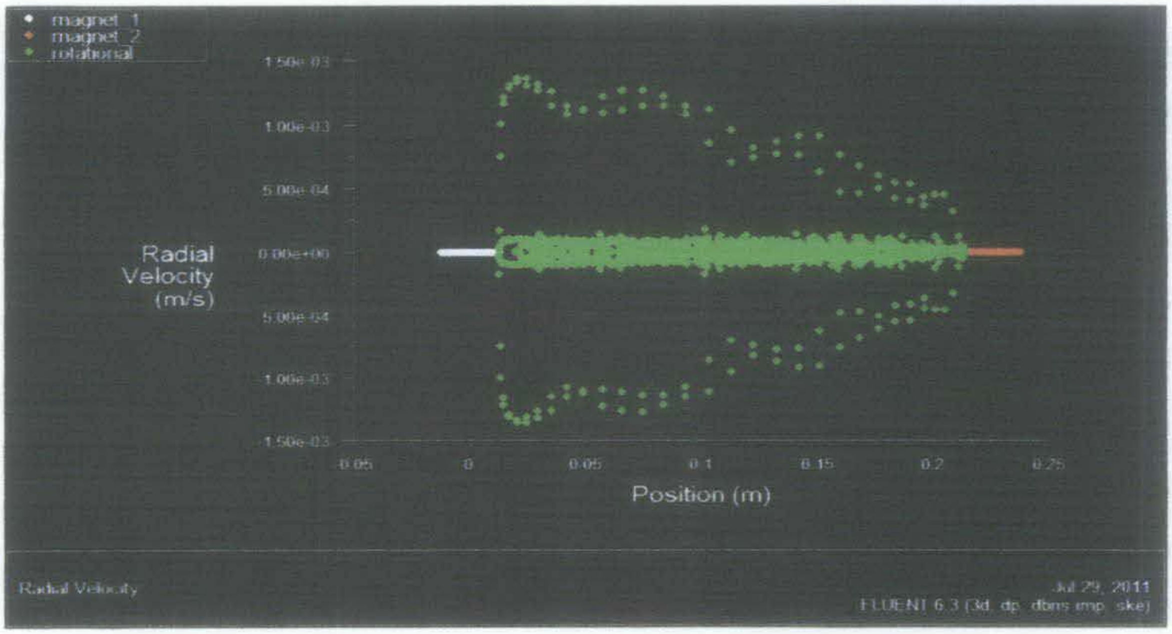

Figure 4.3: Radial velocity of oil at 0.603 rad/s

Figure 4.4 shows the radial velocity of oil in rotational zone at initialization of 1.2 rad/s shaft speed which is double than before. The figure shows that the flow pattern of the oil is quite the same even when the shaft speed is doubled. The maximum radial velocity increases when shaft speed increases. When shaft speed is increased, the oil will flow more rapidly in the tank and increase the radial velocity. Increasing radial velocity is not desirable because the oil will not having enough time to be attracted to the magnets.

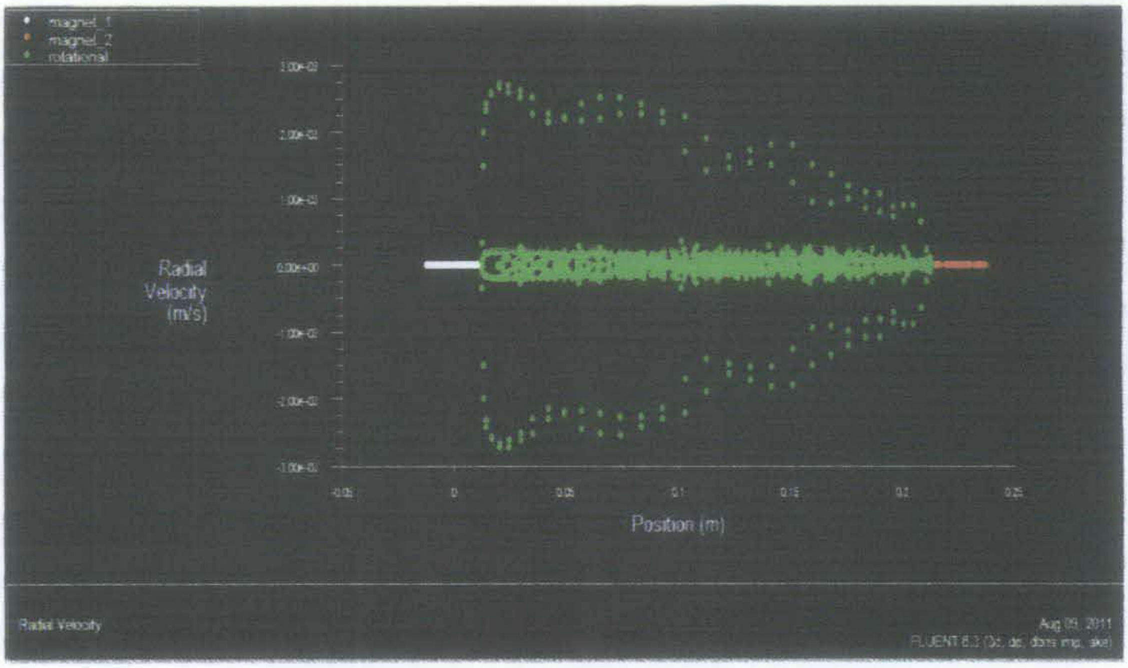

Figure 4.4: Radial velocity of oil at 1.2 rad/s

At shaft speed of 0.603 rad/s, the flow rate of the oil can be calculated depending on the oil volume in the tank. If set the volume of oil as 0.01 m^3 at each filtration cycle, the flow rate of the oil is 1.06 m^3/s and the cleaning time is 106 seconds.

As shown in Figure 4.3 and 4.4, there are particles that flow around the impeller with zero velocity. Modifications can be made to reduce this effect. The area that can be look upon to fix this problem are changing the type of impeller or adjusting the shaft speed.

Figure 4.5 is the results of x-velocity, y-velocity and z-velocity of oil after 100 iterations. The velocities at x, y and z axis are represent by red, green and blue line accordingly. First, the iteration is set at 100 iterations which indicate shorter time for particles to attract by the magnets. The number of iterations is directly proportional to time step and the higher number of iterations will gives more accurate results (Hafez, Oshiwa & Kwak, 2010). Figure 4.5 shows unclear pattern of oil velocity since it does not show any sign of convergence.

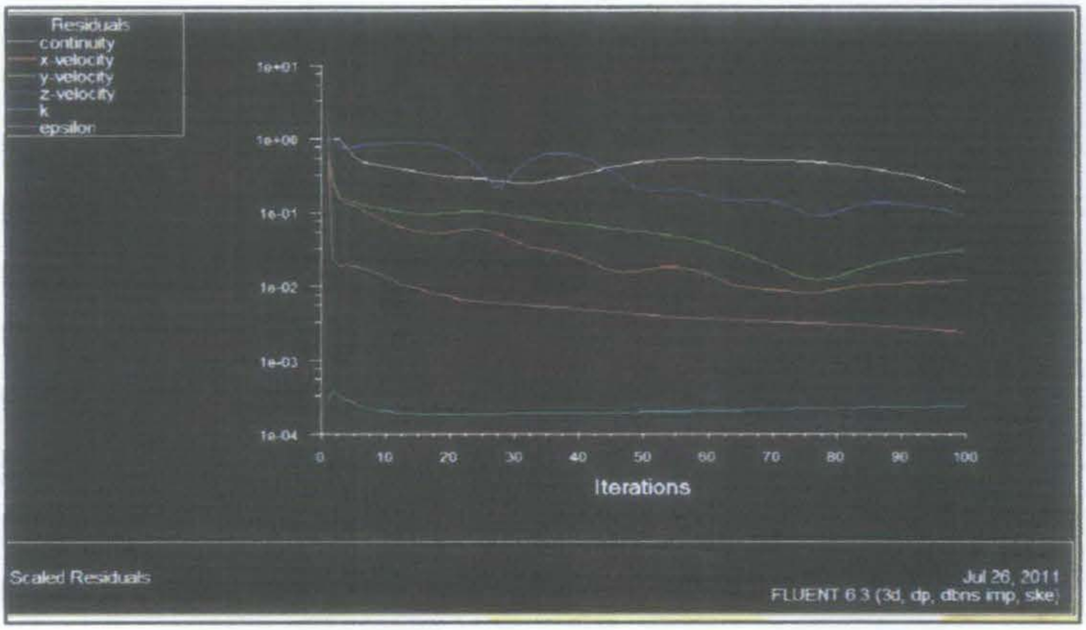

Figure 4.5: Velocities of oil at x,y & z axis after 100 iterations

Figure 4.6 shows the velocities of oil at x, y & z axis after 1000 iterations. After proceed with 1000 iterations, the pattern of convergence is slowly appearing. The overall velocity is also decreasing with time which is the required result because particles are easily attracted to magnet when velocity is low. This shows that the attraction of particles by magnets is increasing with increasing time.

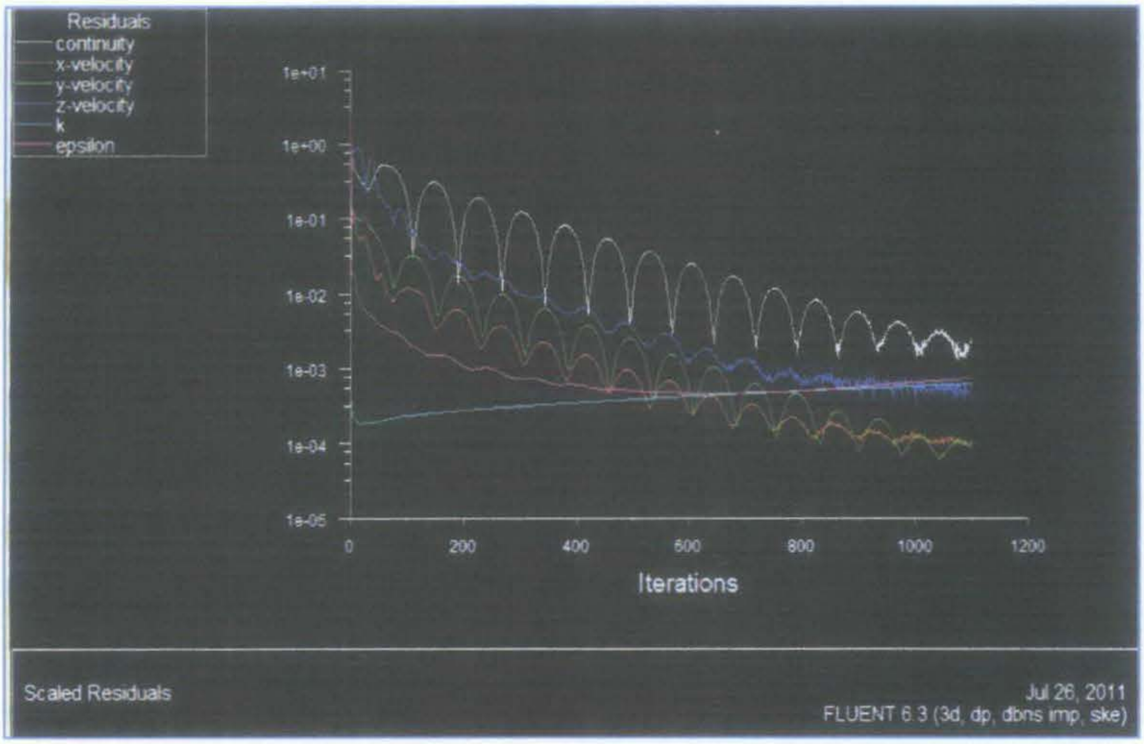

Figure 4.6: Velocities of oil at x,y & z axis after 1000 iterations

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

As the conclusion, the selection of the best method to remove particles from used turbine oil had been successfully chosen and analyzed. Used turbine oil contains iron particles that can be removed using magnetic filter. Mixed flow impeller had been introduced to agitate the flow accordingly and give optimum results.

All the design details had been calculated and compared with the standard values. The volume of oil that can be cleaned at a time is about 0.01 m^3 based on the tank dimensions. From result, the optimum flow rate is 1.06 m^3/s and the cleaning time is 106 seconds for every 0.01 m^3 of oil. The simulation show that at 0.603 rad/s of shaft speed, the particles will agitate in the tank and attracted to the magnets. The simulation gives the desired results but still open for improvements and modifications.

5.2 Recommendations

The recommendation that can be made to improve the results is by modeling the exact design of mixed type impeller. The design will be much more complicated but will give more accurate modeling of the fluid flow. Automatic devices can be used to check the number of particles that attracted to the magnets instead of reading results from simulation. Laboratory test can be performed to observe the number of particles that can be filtered.

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APPENDICES

Turbine Oil specifications

PETRONAS LUBRICANTS

Jenteram HC
Extended Service Life Premium Quality Turbine Oil

Intro
Petronas Jenteram HC is an extended service life turbine oil specially developed to completely satisfy the severe lubrication requirements of steam, hydroelectric and frame type gas turbines couple with gearing system.

They are manufactured with highly-refined unconventional base oils and specially selected high performance additives to provide good viscosity/temperature characteristics, rapid air release, good water separation, excellent oxidation stability and excellent rust and corrosion resistance.

Applications
Recommended for use in all steam, hydroelectric and frame type gas turbines requiring non-antiwear types turbine oils. Also suitable for use in speed reducers, air compressors, vacuum and deep well pump, electric motors, lightly loaded plain bearings and other equipment requiring turbine oil quality.

Customer Benefits

- Superior oxidation control and thermal stability – longer life, deposits free
- Extended oil service life and reduced operating and maintenance cost
- Superior water separation capability – less processing and disposal cost (minimize purification needs)
- Low foaming and rapid air release – full fluid lubrication (enhance performance) in high-speed bearings and meshing gear teeth.

Product Typicals

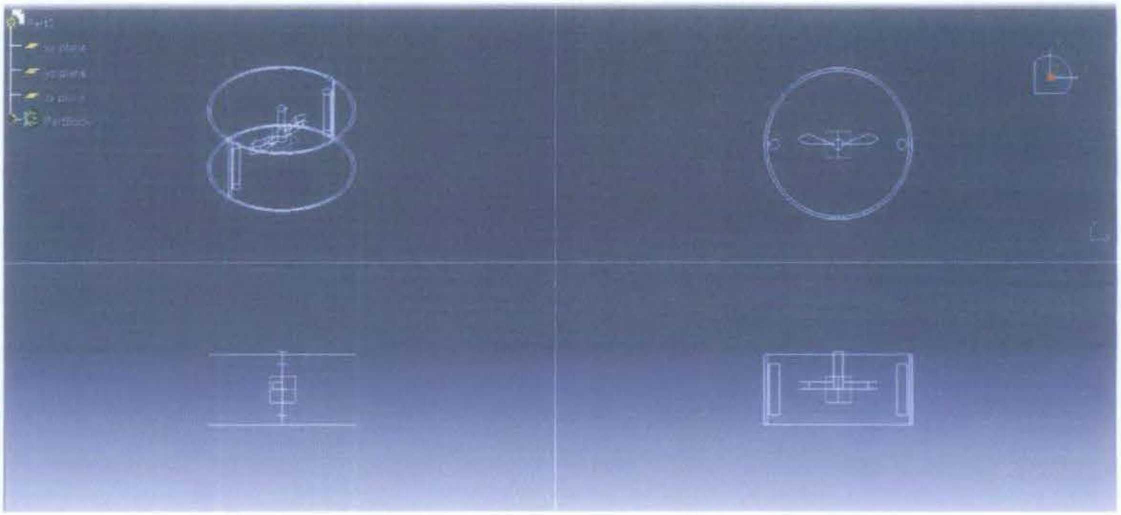
Product Typicals

Characteristics	ISO Viscosity Grade 32	46	68	80 *
Density @ 15 °C, kg/l	0.857	0.877	0.874	0.876
Pour Point, °C	-12	-9	-9	-9
Flash Point, °C	214	218	226	232
Kinematic V Iscosity, cSt				
@ 40 °C	32.5	46.9	68.3	78.8
@ 100 °C	5.8	7.2	9.0	9.6
Viscosity Index	122	111	106	98
TAN, mgKOH/g	0.05	0.05	0.07	0.07
Rust Test	Pass	Pass	Pass	Pass
Foaming characteristics, ml				
Sequence I	0/0	0/0	0/0	0/0
Sequence II	10/0	30/0	30/0	40/0
Sequence III	0/0	0/0	0/0	0/0
Water Separability	40/40/0 (10)	40/40/0 (15)	40/40/0 (20)	40/40/0 (20)
RBOT, minutes	1774	1570	1226	1414
+Oxidation Control (TOST), hrs	> 15,000	> 15,000	> 15,000	> 15,000

Design of magnetic filter (Calculations)

The size of particles to be filtered is specified to **20µm- 35µm**. From Table, the magnetic field required to filter these range of particles size is 5000 Gauss or **0.5 Tesla**.

The design is consist of two cylindrical permanent magnets, a stainless steel casing, and a shaft mounted on top of the casing that uses to rotate the impeller.



Design of magnetic filter using Catia software

Separation distance between two magnets is **0.20m.**

$B = \mu_O M ; M = \frac{B}{\mu_O} = \frac{0.5T}{4\pi x 10^{-7} Tm/A}$

M = 3.98 x 10^5 A/m = 398 Gauss = **0.04 T**

Table 4: Magnetization value of permanent magnet

Material	Magnetization (T)
$BaFe_{12}O_{19}$	0.36
Alnico IV	0.60
Alnico V	1.35
Alcomax I	1.20
MnBi	0.48
$Ce(CuCo)_5$	0.70
$SmCo_5$	0.83
Sm_2Co_{17}	1.15
$Nd_2Fe_{14}B$	1.20

4.3.1 Magnetic force between two cylindrical magnets

$$F = \frac{\pi\,\mu_O}{4} M^2\, R^4 [\frac{1}{x^2} + \frac{1}{(x+2L)^2} - \frac{2}{(x+L)^2}]$$

Where

μ_O= permeability of space, which equals $4\pi\times10^{-7}$ T·m/A

M = magnetization of magnet (A/m)

R = radius of each magnet, m

x = separation between two magnets, m

L = length of each magnet, m

$$= \frac{\pi \times 4\pi x 10^{-7} \mathrm{T.m/A}}{4} (3.98 \times 10^5 \mathrm{A/m})^2 (0.0125\mathrm{m})^4 [\frac{1}{0.2\mathrm{m}^2} + \frac{1}{0.2\mathrm{m}+2(0.1\mathrm{m})^2} - \frac{2}{(0.2\mathrm{m}+0.1\mathrm{m})^2}]$$

$$= \mathbf{0.034\ T.m.A}$$

4.3.2 Impeller

To study the types of impeller to be used in this project, the flow patterns have to be studied.

$$Re = \frac{\rho N D^2}{\mu} = \frac{857\frac{kg}{m^3} \times 5.76 \text{ rpm} \times \frac{60s}{m} \times 0.175^2 \mathrm{m}}{0.02785\frac{\mathrm{m}^2}{s}} = 3.26 \times 10^5$$

Since, Re = $3.26 \times 10^5 > 10000$ so the flow is turbulent.

$$= \frac{\pi\,\mu_O}{4} M^2\, R^4 [\frac{1}{x^2} + \frac{1}{(x+2L)^2} - \frac{2}{(x+L)^2}] = \mathrm{m}\omega^2 r$$

Where

m = ṁ x V = 857 kg/m^3 x π x 0.15^2 x 0.15 = 9.09 kg

ω = shaft speed

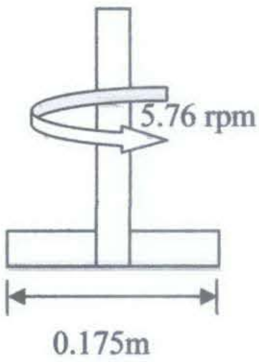
r = radius of particles, r << small so the value is negligible

$= \omega^2 = \frac{0.034}{9.09\ kg} = 3.74 \times 10^{-3}$

$= \omega =$**5.76 rpm**

$T = F.d = 9.09kg \times 0.603^2 \times 0.1m =$ **0.33 N.m**

$P = T.\omega = 0.33 \times 5.76 =$ **1.9 Watts**



Impeller

Gantt chart

Project Steps	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1. Revise and make corrections from FYP I (Report)	■													
2. Revise and make corrections from FYP I (Calculation)	■	■												
3. Finalize the characteristics of the magnetic filter			■											
Size of particles to be filtered			■											
Distance between two magnets			■											
4. Finalize the mathematical dimensions			■	■										
The type and size of magnet to be used			■	■										
The magnetic force				■										
The shaft speed				■										
5. Modeling design in Gambit				■	■	■								
6. Simulation in Fluent				■	■	■								
7. Prepare progress report							■							
8. Submit Progress Report								●						
9. Analyze results from Fluent									■	■				
10. Pre-EDX											●			
11. Draft Report submission												●		
12. Dissertation(soft bound) submission													●	
13. Technical paper submission													●	
14. Viva														■
15. Project dissertation (hard bound) submission														■