Development of A Model for Technical and Commercial Evaluation of Rotating Equipment for Offshore Plant

by

Muhammad Ridhwan b. Abdul Rasid

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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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CERTIFICATION OF APPROVAL

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Approved by,

(AP Ir. Dr. Mohd Amin b. Abdul Majid)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
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.

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MUHAMMAD RIDHWAN BIN ABDUL RASID

ABSTRACT

Heavy duty and safety requirements during the plant operation require the static and rotating equipment specified for any operations fully meet the specification. As such the design engineer has to carefully select the criteria to evaluate any equipment. The current approach of evaluation is time consuming. In this project, research was done to address this issue. At technical and commercial evaluation was developed for selection of rotating equipment for offshore applications. The project focused on two methods which were Pairwise Comparison and Factor Rating method by examining related important criteria between available equipment. The Pairwise Comparison compared all the important criteria of the equipment to get the weight of each criterion for factor rating method. By using factor rating method, criteria were compared the alternative equipment in term of score thus the highest weighted score (weight rating x score) was chosen as the best. Commercial evaluation model also been developed to enhance the selection of the best alternatives in term of economical wise. Present Worth analysis was used to develop the model. Microsoft Excel was used to illustrate a rough model integrating all the mathematical equation, criteria and weight rating method to find solution of the best alternatives.

ACKNOWLEDGEMENT

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INTRODUCTION

1.1 Background of Study

1.1.1 Process Systems of Offshore Plants

The oil and gas process is the process equipment that takes and delivers the crude oil, condensates or gas as stabilized marketable products. Within that, there are many types of equipment involved to treat and filter the crude products; mind that crude products from well contain water, oil, natural gas, microorganisms, carbon dioxide and soil. The facilities are actually related to each other to perform the cleaning, filtering and treating the product. A single process for plant is combinations of several systems or modules such as [1]:

i) Risers
ii) Separation
iii) Gas treatment
iv) Compression
v) Metering, storage and export.

All modules use a lot of static and rotating equipment to operate.

1.1.2 Process Systems Equipment

Risers are connected from platform to the well. Basically, the injection launcher and receiver are using for what people call 'artificial lift' to rise up the crude to the platform to be processed. Launcher and receiver are mainly pressure vessels, water pumps and air compressors [1].

The separation system has the purpose to remove the undesired material such dust or mud from the crude, at the same time separating the gas and water to another process systems. The main equipment in this system are separator, degasser and electrostatic coalescer. They are all basically pressure vessel, named base on their specific main functions [1].

We all know that, air compression cannot be done with existence of water or moisture; otherwise the compressor will break down. This is the main purpose of gas treatment, which is to filter the moisture, water or mud from the production gas using hydrocyclones, scrubbers, glycol contactor etc. until achieve below the standard value (based on American Petroleum Institute, nowadays: 40ppm allowable). Most of the equipment are pressure vessel and pumps.

Compression, metering, and export are doing the same purpose, giving external force either by compressing the gas using compressor or pumping the water in order to deliver from place to another place. The main equipment are compressors, pumps, and pressure vessels.

1.1.3 Offshore Plant Development and Process Equipment Design

Normally, to develop an offshore, there will be a lengthy engineering design phase and done at least a year by consultant before the construction and commissioning. The phases are:

i) Feasibility studies
ii) Conceptual design
iii) Front End Engineering Design (FEED) Study
iv) Detailed Design Study

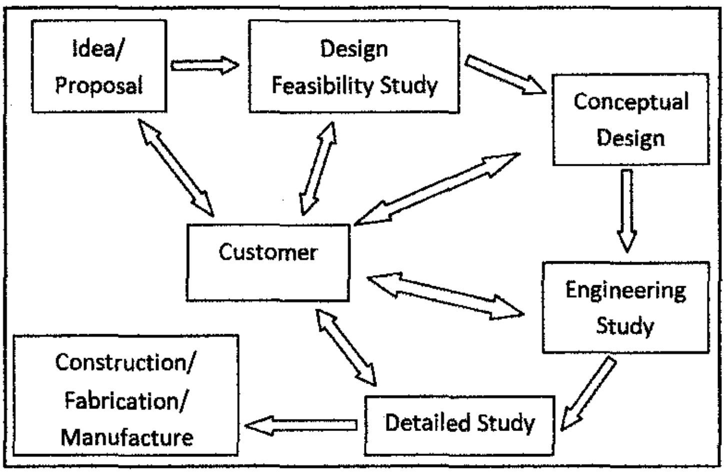

Figure 1.1: Relationship between client, consultant and manufacturer [2]

A design requirement for new equipment is explicitly defined at the Initial Proposal Stage. It's here where engineers define the possible solutions that could be taken, as well as the risks involved. Budget and development time scales are also discussed.

Next is Feasibility Study which contains a succinct description of the design as well as any constraints, performance requirements or special customers' specifications. Many questions are asked. Even details of where the equipment is to be placed and what it is to be placed next to in plant. It'd be surprised how even seemingly small factors like that can influence how equipment is designed. Once complete, the customer is encouraged to critique the document so that both parties are absolute agreement [2].

In the Conceptual, the options in the Feasibility Study are developed further and one chosen for development. Assembly drawings or Process Flow Diagram (PFD) are produced and reviewed with the customer. Once the final proposal has been signed off, a 3D dimensional model of the equipment is built. From then on, detailed drawings are made [3].

All phases involve selections and making decision based on operation conditions. Note that, most phases must include customer. The customer will not just leave the work totally to contractor. The customer will monitor the design deliverable to make sure satisfied end design. Especially in Engineering Study phase, the engineer and customer will start evaluating the best equipment for particular conditions.

Greg Livingstone& Kevin Sapp mentioned (2007) that, "The contractor company should provide trained, experienced and certified personnel to execute the project. Both the company and its employee should have an intimate understanding of what is expected and what results are desired during the service. There should be an open line of communication between the equipment owner and the contractor's personnel [4]."

FEED (Front End Engineering Design) is the stage of a project's lifecycle at a time when the ability to influence changes in design is relatively high and the cost to make those changes is relatively low. It typically applies to industries with highly capital intensive, long lifecycle projects including oil and gas industry. During this period, the process flow diagrams are produced by the engineers and consideration is given to material and equipment procurement, fabrication, legislation, and tax issues. Full life-cycle cost analysis is normally carried out. Integrity related issues include material section, chemical treatment facilities, monitoring & inspection requirements etc.

Mark Biasotti mentioned that, "Industrial designers focus on making sure that a product exceeds customer's expectations in function and form while striving to create a truly innovative and unique design. They concentrate on how a consumer will interact with the product, how to build brand loyalty, and elicit an emotional response by imbuing style, novelty and ingenuity into a product. Mechanical engineers pay heed to equally important concerns: Will a product break? Will it functions as intended? Can it be manufactured efficiently and cost effectively [5]?"

1.2 Problem Statement

The plant operations require the rotating equipment specific for any operations on the plant to fully meet the specifications and standards for oil and gas industry. Based on the design standards criteria, engineers should ensure that the equipment are properly evaluated technically and commercially. The current evaluation does not completely cover these scopes. Hence an evaluation tool which could cover both scopes is required.

1.3 Objective

The objective of this project is to develop a model for technical and commercial evaluation of rotating equipment for offshore plants.

1.4 Scope of Studies

The model was focused on technical evaluation of rotating equipment in offshore plant. There are several rotating equipment were covered in this project. Specifically centrifugal pump are covered in details. The equipment are as follows:

i) Centrifugal pumps
ii) Centrifugal compressors
iii) Reciprocating compressors
iv) Positive displacement pumps

The project analyzed the equipment and extract as many as possible the important criteria which those criteria are responsible during real life operations.

In evaluating the criteria, the project used some methods in completing the technical evaluation. For that purpose, study was conducted for two method which applicable; Factor rating and Pairwise Comparison evaluation method, are used as evaluation model for equipment.

CHAPTER 2

LITERATURE REVIEW

2.1 Equipment Evaluation Methods

2.1.1 Economical Evaluation

In part of making decision, economical aspect still observed and there are many tools and techniques available for use by the engineer to analyze and evaluate the equipment and all its alternatives.

Engineering economics is the application of economic techniques to the evaluation of design and engineering alternatives. The role of engineering economics is to assess the appropriateness of a given project, estimate its value, and justify it from an engineering standpoint and Cash-Flow Analysis Method is a very simple tool that can be used with great benefits [29].

In a Present Worth comparison of alternatives, as one of the Cash-Flow analysis method, the costs associated with each alternative investment are all converted to a present sum of money, and the least of these values represents the best alternative. Annual costs, future payments, and gradients must be brought to the present. Converting all cash flows to present worth is often referred to as discounting. Discounting is determining a present amount which will yield a specified future sum. If one of the alternative values is lower than other alternatives, the purchasing of this alternative is worth taking on. [29].

The equipment often have several alternatives available to them. Some of these alternatives are mutually better than others. Cash-flow analysis can be used to determine which alternatives to select or purchase in given a CAPEX (capital expenditures) budget [6].

2.1.2 Technical Evaluation

Technical evaluation in offshore equipment design basically based on checklist provided in the API (American Petroleum Standard) or is called datasheet [7]. Refer Appendices 3 for a full example of datasheet for centrifugal pump. For some reasons, datasheet acquires collaboration between purchasers (consultant), manufacturer and user (client) before the equipment can be fabricated. There are some limitations in manufacturing that manufacturers cannot fulfill the user operation requirements. At the same time, operations have its own standard to be fulfilled in order to place the equipment in the plant.

Minimum data sheet requirements

- (P) (U) ■ Pump application and operating mode (single or parallel)
- (P) (U) ■ Detailed operating conditions
- (P) (U) ■ Accurate site and utility requirements
- (M) ■ Pump performance
- (P) (M) ■ Pump construction and experience
- (P) ■ Spare parts required
- (P) (M) ■ Driver details
- (P) ■ QA inspection and test requirements

Note: to be completed by:
P = Purchaser
M = Manufacturer (vendor)
U = User

Figure 2.1: Minimum data sheet requirements for centrifugal pumps

After the equipment specifications of packages have been prepared and approved, the specifications is sent to the vendors. Then, the vendors or manufacturers will provide technical and commercial proposal in order to be rewarded those packages. The engineering team will collect all the technical data and examining them to comply technically with the specifications. This process called technical bid evaluation. Afterward, commercial bid evaluation will compare the price of the packages proposed by the vendors.

Technical evaluation is done based on some reasons; some of the main reasons are [8]:

i. To list down the main scope of supply, extent of specification compliance, major deviations in order to get a general idea of the completeness of the pump technical proposals.
ii. To provide sufficient information to determine which of the alternatives will be fully evaluated.
iii. "Apple to apple" comparison between alternatives
iv. To ensure that the equipment are provided in compliance with the requisition.
v. Alternatives that do not meet requisition requirements or that are not clearly defined in the vendor's datasheet should be highlighted in technical clarification questionnaire/meeting between manufacturers and purchasers.
vi. To accept / reject all exceptions and deviations.

Ironically, to choose the perfect equipment must take quite long time to analyze all the criteria and to satisfy with the operation acquisition. However, time is very crucial. The engineer cannot put so much time on designing a perfect systems or equipment. Thus having project experience and document archive is very important for design contractor.

Forsthoffer, W. (2007) stated that, "If the former option is selected, the end-user is exposed to unreliability over the lifecycle of the project, which can cost several millions of dollars. But if the latter option is selected, the time required for bid assessment can extend the project schedule by one month or more. Today, daily plant revenues often exceed 1 million dollar. A one-month delay could lead to a 30 million dollar loss. Either option can generate significant losses [9]."

2.2 Rotating Equipment in Offshore Plants

2.2.1 Dynamic and Positive Displacement Pumps

A pump is defined as a device that moves a liquid by increasing the energy level of the liquid. Pumps are divided into two distinct groups. One group pumps the liquid by means of positive displacement - the other group pumps the liquid by means of dynamic action [10].

Types of pumps

Positive displacement		Dynamic	
Reciprocating	**Rotary**	**Single stage**	**Multistage**
■ Power	■ Screw	■ Overhung	■ Horizontal split
■ Diaphragm	■ Gear	■ Inline	■ Barrel
■ Metering		■ Integral gear	■ Canned
■ Direct acting		■ Centrifugal	■ Sump
		■ Double flow	■ Submersible
		■ Sump	
		■ Submersible	
		■ Magnetic drive	

Figure 2.2: Types of pumps [29]

Pumps are an integral part of almost every process system. They need to operate continuously at a high level of reliability and availability in order to achieve established plant production quotas with minimum power usage and without loss of revenue. The effect of the process system on pump availability is significantly different for systems using kinetic pumps or positive displacement pumps. Kinetic pump capacity varies as the head (energy) required by the process system changes [11].

The most common type of pump used in offshore plant is dynamic or centrifugal pump. It is a machine that imparts energy to a fluid. In operation, an impeller inside the centrifugal pump 'slings' liquid out of the impeller via centrifugal force This energy infusion can cause a liquid to flow, rise to a higher level, or both [10].

William E Forsthoffer (2005) wrote that, "Centrifugal pumps are calculated using characteristic curve. The characteristic curve defines the signature of a pump over its entire life. It identifies the range of flows and energy produced for a fixed speed, size, design and suction conditions of the pump. In order for a pump to move a liquid from a level of low pressure to a level of higher pressure, the head (energy) produced by the pump must equal or exceed the net head (energy) required by the system. Also, the net head (energy) available on the suction side of the pump system must be greater than the liquid vapor pressure to assure that liquid enters the pump without potential deterioration of performance or mechanical damage. The total head (energy) the pump is capable of producing is increased as the flow is reduced. A complete characteristic curve also includes efficiency, brake horsepower and NPSHr (net positive suction head required) curves [11]". Refer Appendices 2 for an example of characteristic curve.

Another type of pump used in offshore plant is positive displacement pump. A positive displacement pump is one in which a definite volume of liquid is delivered for each cycle of pump operation. This volume is constant regardless of the resistance to flow offered by the system [11].

It delivers liquid in separate volumes with no delivery in between, although a pump having several chambers may have an overlapping delivery among individual chambers, which minimizes this effect. The positive displacement pump differs from centrifugal pumps, which deliver a continuous flow for any given pump speed and discharge resistance.

2.2.2 Dynamic and Positive Displacement Compressors

A compressor is a device that pressurizes a working fluid. One of the basic aims of using a compressor is to compress the fluid and deliver it at a pressure higher than its original pressure. Compression is required for a variety of purposes, which some of offshore plant applications are listed below [12]:

- To provide air for combustion
- To transport process fluid through pipelines
- To provide compressed air for driving pneumatic tools
- To circulate process fluid through a certain process

Of many types of compressors mostly used in the oil and gas process industry, some of the more significant are shown below:

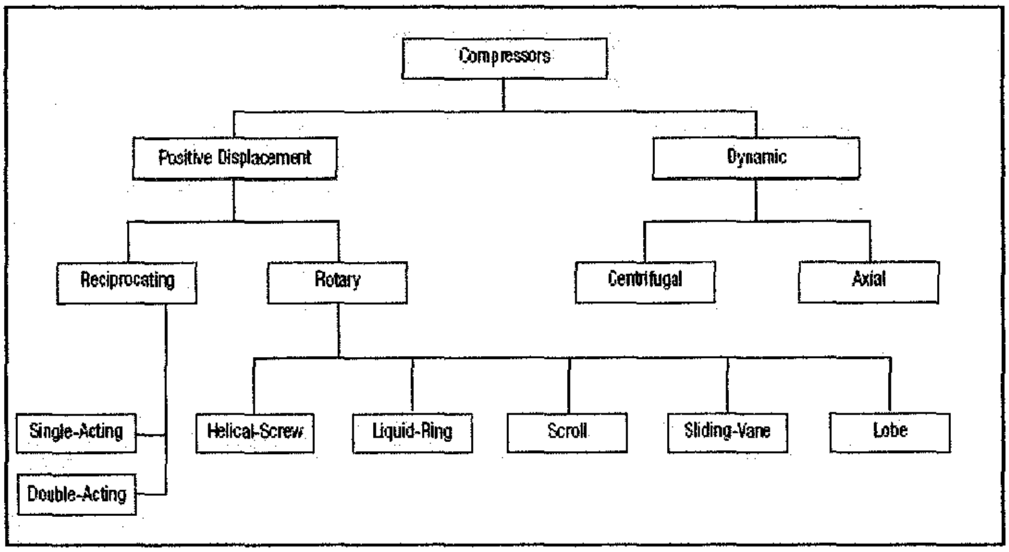

Figure 2.3: Types of compressors [13]

The positive displacement compressors are used for intermittent flow in which successive volumes of fluid are confined in a closed space to increase their pressures. Dynamic compressor or continuous-flow compressors are machines that the flow is continuous. These include centrifugal compressors and axial flow compressors. These types of compressor are widely used in chemical and petroleum refinery industry for specific services especially centrifugal compressor [13].

In centrifugal compressor, the gases flow enters the impeller in an axial direction and exits in a radial direction. The gas is forced through the impeller by rapidly rotating impeller blades. The kinetic velocity energy from rotating impeller is converted to pressure energy.

There are three basic principles that need to know about centrifugal compressor [14].

i) Centrifugal action of high speed rotating impeller

ii) A centrifugal stage which mean the gas will repeat the compression process (from impeller to other impeller) inside a single machine

iii) Energy conversion of high velocity head (energy) into pressure energy

2.2.4 Gas Turbine

A gas turbine is an internal combustion engine. It generates power and electricity for plant and sufficient power to run other equipment. From all points of view, it can be considered a self-sufficient system: in fact, it takes and compresses atmosphere air in its own compressor, increase the energetic power of the air in its combustion chamber and converts this into useful mechanical energy during the expansion process that takes place in the turbine section. The resulting mechanical energy is transmitted via a coupling to a driven machine, which produces power useful for the industrial process in which the gas turbine is applied [15].

A gas turbine is composed of three main sections, described in the following paragraphs [16].

i) Compressor - The compressor serves to supply a source of air needed for combustion and also to cool the walls of nozzles, buckets and turbine disks itself.
ii) Combustion section – just to provide enough room for fuel gas combustion and flow out high pressure fluid to the turbine.
iii) Turbine section – The turbine completes the energy conversion, as kinetic energy is transformed into energy that drives the shaft, thus generating the power required to drive the compressor or alternator (generator).

In offshore plant application, gas turbine is intended as [16]:

i) Mechanical drive – The power from the gas turbine will run the shaft which is connected to compressor. The shaft will directly rotate the shaft of the compressor. Sometimes it used to run the pump too.
ii) Generator drive. – Same as compressor drive, but the power shaft will be connected to generator. The shaft will rotate the altenator to produce electricity for another users.

2.3 Design Standard for Rotating Equipment

Abdullah s. al-Humaid (2007) had given an example of the importance of to design according to standard and process acquistions, "A high-pressure, associated gas compressor (18, 170hp) was commissioned in a gas-oil separation facility in Saudi Arabia in September 2004. Less than a week later, the compressor tripped on high vibration. Analysis of vibration data showed that the compressor was badly unbalanced. Further investigation and process data review revealed that the compressor was about to fail catastrophically." It was then suspected that dirt in gas from one of the other wells had gone into the unit. As part of the commissioning procedures, suction strainers with fine mesh were installed upstream of the compressor to protect them [17].

Basically, in oil and gas industry, there is much type of equipment available for each systems or modules. Thus, it takes time just to choose the suitable equipment. Meantime, time cost a lot of money to the client.

The idea to create an evaluation model is to reduce the time used for choosing the mostly right equipment at certain operations. It should cover all main specifications or criteria which have been stated earlier in this literature review. American Petroleum Institute (API) has delivered many written standards majorly for rotating equipment. The standards codes available for offshore rotating equipment are as follows [18]:

i) API Std 610 Centrifugal Pumps
ii) API Std 611 General Purpose Steam Turbines
iii) API Std 616 Gas Turbines
iv) API Std 617 Axial and Centrifugal Compressors and Expander-compressors
v) API Std 618 Reciprocating Compressors
vi) API Std 619 Rotary-Type Positive Displacement Compressors
vii) API Std 674 Positive Displacement Pumps — Reciprocating
viii) API Std 675 Positive Displacement Pumps — Controlled Volume
ix) API Std 676 Positive Displacement Pumps — Rotary
x) API Std 681 Liquid Ring Vacuum Pumps and Compressors
xi) API Std 682 Pumps—Shaft Sealing Systems

American Petroleum Institute (API) is defined as the only national trade association that represents all aspects of America's oil and natural gas industry. Nearly 400 corporate members of producers, refiners, suppliers, pipeline operators and marine transporters, as well as service and supply companies, from the largest major oil company to the smallest of independents, come from all segments of the industry [19]

The International Organization for Standardization (ISO) is a non-governmental organization, established to promote the development of standardization and related activities in the world with a view to facilitating the international exchange of goods and services, and to developing cooperation in the spheres of intellectual, scientific, technological, and economic activity. ISO's work results in international agreements which are published as international standards [20].

The American Society of Mechanical Engineers (ASME) is a professional body, specifically an engineering society, focused on mechanical engineering which its mission is to promote and enhance the technical competency and professional well-being of its members, and through quality programs and activities in mechanical engineering, better enable its practitioners to contribute to the well-being of humankind. The organization is known for setting codes and standards for mechanical devices [21].

2.4 Evaluating Centrifugal Pump

Joe Evan (2005) described centrifugal pump is a machine that imparts energy to a fluid. This energy infusion can cause a liquid to flow, rise to a higher level, or both [22]. Rotation imparts energy to the liquid causing it to exit the impeller's vanes at greater velocity than it possessed when it entered. This outward flow reduces the pressure at the impeller eye, allowing more liquid to enter. The liquid that exits the impeller is collected in the casing (volute) where its velocity is converted to pressure before it leaves the pump's discharge. The unit used in pumps applications called 'feet'. The reason is to satisfy with all type of liquid characteristic.

The Figure 2.4 is a cross section of a centrifugal pump and shows the two basic parts.

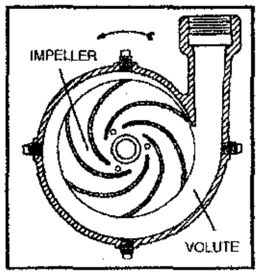

Figure 2.4: Cross-section of centrifugal pumps [22]

2.4.1 Impellers

Impellers shall have solid hubs. Impellers may be made from a cored pattern if the core is completely filled with a suitable metal that has a melting point of not less than 260 °C (500 °F) for pumps with cast iron casings and not less than 540 °C (1 000 °F) for pumps with cast steel casings. The requirement to fill cored impeller hubs is intended to minimize the danger to personnel if and when impellers are removed by heating [7].

2.4.2 Power and Voltage

The power input of a centrifugal pump is the mechanical energy at the pump coupling or pump shaft absorbed from the drive.

Pump operates using electric motor which power supply usually from generator. The main thing is the pump efficiency. It is observed to estimate the power required to run the pump. Low efficiency will waste valuable power in production plant [12].

2.4.3 Drivers and Shafts

The driver is used to rotate the impeller. It could be either induction motor, motor turbine or gear must be as follows [7]:

i) Be suitable for satisfactory operation under the site conditions specified,
ii) Be suitable for the specified utility conditions,
iii) Be sized to accommodate all specified process variations such as changes in pressure, temperature or
iv) properties of the liquid handled,
v) Be sized to accommodate all plant start-up conditions,

vi) Be sized to meet the maximum specified operating conditions, accounting for all losses (e.g. bearing, mechanical seal, external gear and coupling losses).

The impeller is connected to the driver through shaft. The basic purpose of a centrifugal pump shaft is to transmit the torques encountered when starting and during operation while supporting the impeller and other rotating parts. It must do this job with a deflection less than the minimum clearance between the rotating and stationary parts. Shaft couplings used with centrifugal pumps can be divided into rigid and flexible types. Rigid couplings are mainly used to connect shafts in perfect alignment. The smallest degree of misalignment will cause considerable stress (deflection) on the coupling and on the shafts. [23].

Each shaft shall be supported by two radial bearings and one double-acting axial (thrust) bearing which may or may not be combined with one of the radial bearings. Bearings shall be sized for continuous operation under all specified conditions, including maximum differential pressure. All loads shall be determined at design internal clearances and also at twice design internal clearances. They shall provide full-load capabilities [7].

Couplings and guards between drivers and driven equipment shall be supplied and mounted by the manufacturer of the pump.

Guards shall be fabricated from solid sheet or plate with no openings. Guards fabricated from expanded metal or perforated sheets may be used if the size of the openings does not exceed 10 mm. Guards shall be constructed of steel, brass or non-metallic (polymer) materials. Guards of woven wire shall not be used. If specified, non-sparking guards of agreed material shall be supplied [7].

2.4.4 Peripheral Velocity & Head

The description above demonstrates that the flow and head (pressure) developed by a centrifugal pump depends upon the rotational speed and more precisely, the peripheral velocity of its impeller.

API 610 states that, all centrifugal pumps must be specified of all these data and are rated equally to its operation conditions [7]:

i) Static Suction Head, h_S
ii) Static Discharge Head, h_d
iii) Friction Head, h_f
iv) Vapor pressure Head, h_{vp}
v) Pressure Head, h_p
vi) Velocity Head, h_v
vii) Total Suction Head, H_S
viii) Total Discharge Head, H_d
ix) Total Differential Head, H_T

Design Head of centrifugal pump (specific to offshore plant) is within range of ±70% to 120% of best efficiency performance (refer Appendices 2) [7].

2.4.5 Capacity and Operating Conditions

The suction lift of a centrifugal pump also varies inversely with pump capacity. Illustration below shows how the head – capacity curve falls off quickly at various suction lifts. The maximum suction lift increases as pump capacity decreases. For this reason pumps used in high suction lift applications are selected to operate in a range considerably to the left of their peak efficiency (Refer to Appendices 1). Some of the major things involved in change of capacity are as follows:

i) Process liquid characteristics i.e. density, viscosity
ii) Size of the pump and its inlet and outlet sections
iii) Impeller size
iv) Impeller rotational speed RPM
v) Size and shape of cavities between the vanes
vi) Pump suction and discharge temperature and pressure conditions

Most centrifugal pumps should not be used at a flow rate less than 50% of the B.E.P. (best efficiency point) flow rate without a recirculation line. If your system requires a flow rate of 50% or less then use a recirculation line to increase the flow through the pump keeping the flow low in the system, or install a variable speed drive [24].

2.4.6 Net Positive Suction Head (NPSH)

Net Positive Suction Head Required (NPSHR) – is a function of specific pump design. In simple terms it is the pressure, measured at the centerline of the pump suction, necessary for the pump to function satisfactorily at a given flow. NPSHR varies with flow; however temperature and altitude have no effect [8].

Net Positive Suction Head Available (NPSHA) – is a characteristic of the system in which the pump operates. It depends upon the elevation or pressure of the suction supply, friction in the suction line, altitude of the installation, and the vapor pressure of the liquid being pumped [8].

2.4.7 Material Selection and Life Expectancy

Val S. Lobanoff & Robert R. Ross (1992) wrote in their book 'Centrifugal Pumps Design & Application' that in order to have reasonable life expectancy, pump materials must be compatible with the liquid. Having intimate knowledge of the liquid to be pumped, the user will often specify materials to the pump manufacturer. When the pump manufacturer is required to specify materials, it is essential that the user supply all relevant information. Since liquids range from clear to those that contain gases, vapors, and solid material, essential information includes temperature, specific gravity, pH level, solid content, amount of entrained air and/or dissolved gas, and whether the liquid is corrosive [25].

Engineer shall specify the material class for pump parts that may be appropriate for various services. Alternative materials recommended for the service by the vendor, including material that can improve life and performance in service, may also be included in the proposal and listed on the final data sheets.

The equipment's design life (including auxiliaries) covered by this API shall be designed and constructed for a minimum service life of 20 years (excluding normal-wear parts) and at least 3 years of uninterrupted operation. It is recognized that these requirements are design criteria and that service or duty severity, disoperation or improper maintenance can result in a machine failing to meet these criteria [7].

As stated in API 610 about design life, except wear parts in rotating chamber. Manufacturer is advised to list down spare parts to ease operation engineers to change the wear parts. At the same, the spare part are bought earlier and stored in the plant in case emergency. No need delivery to offshore.

2.4.8 The Effect of Temperature with Viscosity

In definition, viscosity is the internal friction of a fluid. Fluids having a high viscosity are sluggish in flow. However viscosity varies greatly with temperature with viscosity decreasing as temperature rises [15].

High viscosity can gum up the internals of a centrifugal pump. Viscous liquids tend to reduce capacity, head and efficiency while increasing the brake horse power (BHP) [22]. For high viscosity fluid that been pumped, it is required to have pre-heat device before the entering the pump.

Fluid temperature basically is temperature at suction. User must put a range between minimum and maximum temperature because the pump is basically materially design for certain temperature. Higher temperature definitely need better material that can withstand extended temperature.

2.4.9 Protection and Warranty

Manufacturer will responsible if anything happen during pump operation for period of time. This is to ensure that the client didn't lose money for manufacturing broken equipment. The maintenance must be low cost and high availability which mean the suppliers or servicers are near and easy to come.

Pumps in offshore plant are high in temperature and protections are needed to prevent someone from touching the pump. At the same time, rust prevention can increase the design life and avoid too frequent preventive maintenances. The package limit must be specified by the manufacturers, which state the limit before the pump stop functioning [7].

2.4.10 Utilities and Auxiliaries

Utilities/auxiliaries are addition parts to increase some efficiency.

i) Lubricating oil
ii) Cooling water

Lubricating oil reduces the friction of rotating parts and at the same time reduces the temperature of the equipment.

Pumps shall be equipped with mechanical seals and sealing systems in accordance with API 682 (refer Chapter 2.3), including pump and seal interface dimensions. The engineer shall specify the category of seal required. The purchaser should use the data sheets in API 682 for this purpose [7].

2.5 Pairwise Comparison Method

To use factor rating evaluation method, it requires weight of each criterion that is used. All alternatives criteria are gathered based on standards and ranked from the most important to least important.

Referring to 'Engineering Design, McGraw Hill', "A method of ranking alternatives on an ordinal scale is to use Pairwise Comparison. Each design criterion is listed and is compared to every other criterion, two at a time. In making the comparison the objective that is considered the more important of the two given is given a 1 and the less important objective is given a 0 [28]."

Based on what been described above, consider the evaluation where there are five design alternatives for example. The five criteria are Performance (P), Best Efficiency Point (BE), Differential Pressure (DP), Flowrate (F) and Material (M). In comparing Performance to Best Efficiency Point, it is considered Performance to be more important, and give it a 1. Same goes to others and at the end; a table is drawn as shown in Table 2.1 upon completion.

Table 2.1: Pairwise Comparison Table [28]

Design Criterion	P	BE	DP	F	M	Row Total
P	-	1	0	0	1	2
BE	0	-	1	1	1	3
DP	1	0	-	0	0	1
F	1	0	1	-	1	3
M	0	0	1	0	-	1
						10

A ratio scale is needed to establish meaningful weighting factors. Weight is expressed by row total number out of ten.

2.6 Factor Rating Evaluation Model

Several techniques exist that can be used as part of an evaluation method to determine the merits of prospective equipment. Evaluating often divide assessment of prospective equipment into macro and micro analysis. However, for this case the project focus on macro analysis. Macro analysis encompasses the evaluation of different general criteria includes the evaluation of particular specification and operating performance.

Karl Heil (2010) said that factor-rating systems are among the most commonly used techniques for choosing something especially in location strategy, because they analyze diverse factors in an easily comprehensible manner [26]. But here in equipment selection, factor-rating systems simply consist of a weighted list of the factors which considered the most important criteria needed in equipment and a range of values for each factor. Rate each criteria or specification with a value from the range based on how important the criteria must be in order to achieve better efficiency during operation, and multiply this value by the appropriate weight. These numbers are then summed to get an overall "factor rating." Then it can compare the overall ratings with some other alternatives equipment. This technique enables to choose equipment systematically based on the best rating.

The factor rating method flow is as Figure 2.5:

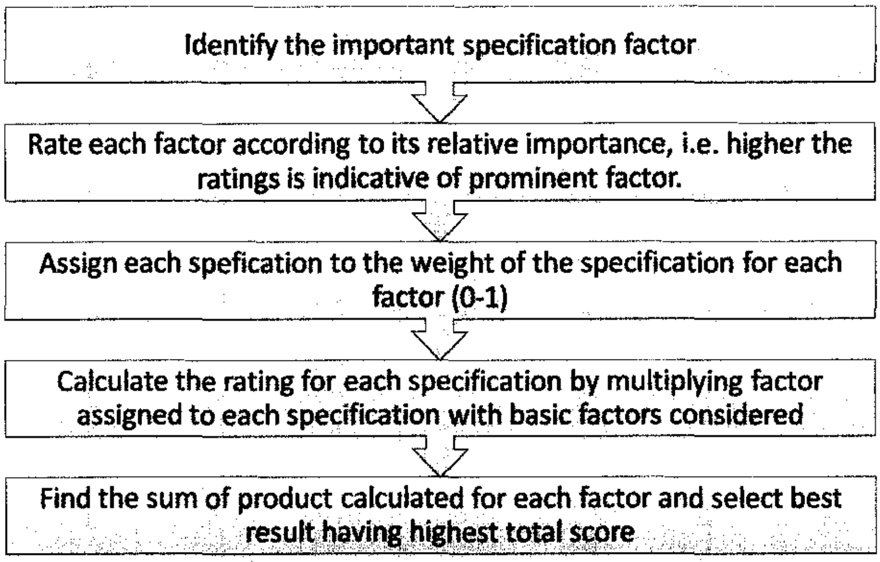

Figure 2.5: Factor Rating Methodology [26]

Figure 2.6 is an example of factor rating method that uses weight and scores to evaluate alternative equipment. Given the option of 100 points assigned to each factor, the Equipment 1 is preferable based on total product of weight and score.

		Score (out of 100)		Weighted Scores	
Key Factor/ Specification	Weight	Equipment 1	Equipment 2	Equipment 1	Equipment 2
Performance	0.22	70	60	(0.22)(70) = 15.4	(0.22)(60) = 13.2
Best Efficiency Point	0.2	50	60	10	12
Suction Pressure	0.14	85	80	11.9	11.2
Discharge Pressure	0.14	75	70	10.5	9.8
Flowrate	0.18	60	70	10.8	12.6
Material	0.12	80	75	9.6	9
Totals	1.00			68.2	67.8

Figure 2.6: Weight, Scores and Solution [27]

Jay Heizer and Barry Render (2008) mentioned in their book, 'When a decision is sensitive to minor change, further analysis of the weighting and the points assigned maybe be appropriate [27].'

Thus, weight with wide and variety of key factors which are equipment' specification and criteria is analyzed further to ensure appropriate result of best alternative equipment.

CHAPTER 3

METHODOLOGY

3.1 Overall Research Methodology

In order to achieve the objective of this project, there are many steps taken involving the acquisition of criteria and determine the importance of each criteria towards equipment design. The overall of research flow is shown in Figure 3.1.

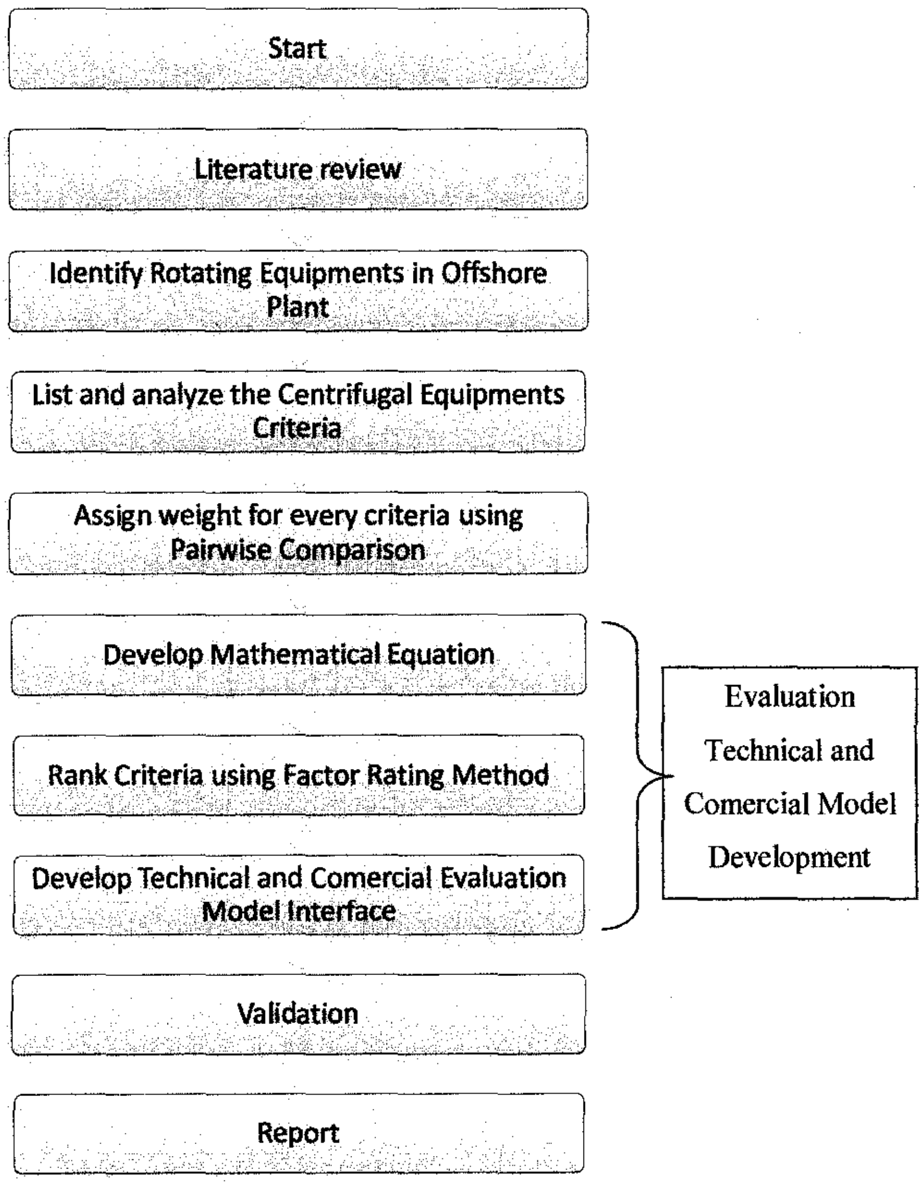

Figure 3.1: Overall Project Flow

3.2 Identify Rotating Equipment in Offshore Plants

In offshore plants, there are many static and rotating types of equipment. Thus it takes considerable time to study the whole system equipment. First step is listing down a number of equipment, which play main important role in the plant and study about those equipment. Refer to Havard Devold's (2009) Oil and Gas Production Handbook, in oil and gas plant, each equipment must has its own operation requirements based on its specific functions, especially rotating equipment. Thus, the project acquires findings of what equipment involve in the systems [12].

The project involved acquisition data of various specification and performance criteria of rotating equipment used at offshore process plant. The data have been categorized to enable it to be structured in the form evaluation algorithm. A visual basic program was developed which evaluate and select the most suitable equipment for particular process.

In order to meet the objectives of choosing the main equipment, the following steps were taken:

i) Identify and listing all the rotating equipment.

ii) Investigate and study the rotating equipment operations and functions theoretically.

iii) Determine design standard of each equipment and study based on that.

iv) Compare the available data and references for listed equipment for further researches.

3.3 Identify Design Criteria

To do offshore design, all the equipment must follow all the standards which available out there. The following are the major standards which relate to the offshore design and the project's model is based on these design standards:

i) American Petroleum Institute (API) Standard for rotating equipment.

ii) International Organization for Standardization (ISO)

The research is majorly based on only API Std 610 for centrifugal pumps and a little bit from other API standards which as follows:

i) API Std 674 Positive Displacement Pumps — Reciprocating
ii) API Std 675 Positive Displacement Pumps — Controlled Volume
iii) API Std 676 Positive Displacement Pumps — Rotary

Besides, there are some auxiliaries for each equipment including lubrications, sealing, installation, maintenance, coupling and protection systems which stated in another codes. Equipment needs auxiliaries in order to work in a complete system, moreover to increase the efficiency of the equipment itself.

i) API Std 682 Pumps—Shaft Sealing Systems

3.4 Development of the Technical Evaluation Model

The project proposes an evaluation model to aid the design work by selecting the best equipment in their particular system based on user input using factor rating method. The model needs to have the following basic functions:

i) The input is entered by user based on score of each criterion for every alternative.
ii) The result (equipment selected) technically accurate at least 90% as per API and ISO. This can be done by comparing this evaluation method with traditional selection method.
iii) An alternative result of second highest score also shown too as second alternative for engineer.

Steps of developing the technical evaluation model are as Figure 3.2 below:

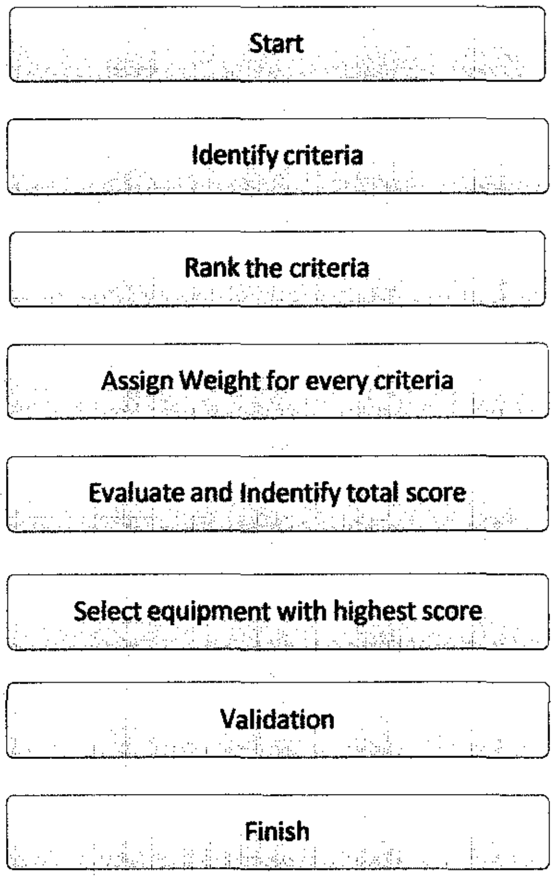

Figure 3.1: Technical Evaluation Model Flow

Using the Pairwise Comparison method which been discussed in Chapter 2.6, mathematical equation must be developed at first in order to create an evaluation model.

In Engineering Design, George E. Dieter, Chapter 10 state that "The components of a system are represented by idealized element that have the essential characteristic of the real components and whose behavior can be described by mathematical equations"[6].

In this research, the components represent criteria of equipment were evaluated. Mathematical equations have been developed based on Pairwise Comparison table. An example of the first in the making of mathematical equation is shown below.

Table 3.1: Simplified Pairwise Table

	Criteria1	Criteria2	Criteria3	.	.	.	Cn
Criteria1	X_{11}	X_{12}	X_{13}	.	.		X_{1n}
Criteria2	X_{21}	X_{22}	X_{23}	.	.	.	X_{2n}
Criteria3	X_{31}	X_{32}	X_{33}	.	.	.	X_{3n}
.	.						.
.	.						.
.	.						.
Cn	X_{n1}	X_{n2}	X_{n3}				X_{nn}
Total							

From Table 3.1, next step was creating another table which satisfies the development of mathematical equation. There are some limitation or declaration have to be made before proceed to next step. The limitations or declarations are:

i. The value of comparison between two criteria only 1 or 0.

ii. No comparison between same criteria.

iii. The mathematical equation must ideal and support infinite comparison data (criteria).

After that, some justification must be made in order to complete the mathematical equation.

The input $X_{i,j}$

$X_{1,1}, X_{2,2}, X_{3,3}$, or which $X_{i=j}$ = no value

$X_{i,j+1} = 0$ or 1

$X_{i+1,j} = 0$ or 1

For the first row, which comparison of criteria1 (C1) with other is represented by this Equation 3.1:

$$\sum_{j=1}^{n} Xij \text{ , } i = 1 \text{ and if } i = j, \text{no value} \qquad 3.1$$

Same equation applies for second row for criteria 2 (C2) which represented by:

$$\sum_{j=2}^{n} Xij \text{ , } i = 1 \text{ and if } i = j, \text{no value} \qquad 3.2$$

The different is only j=2, which represent the row of the criteria. For infinite comparison, which j=n the equation is like Equation 3.3 below:

$$\sum_{j=n}^{n} Xij \ , i = 1 \ and \ if \ i = j, no \ value \qquad 3.3$$

All these three Equation 3.1, 3.2 and 3.3 are the basic calculation of finding the total input (0 or 1) for Pairwise comparison table for every row. In Chapter 2.6 mentions, in order to get the weight, total for every criteria must be divided with total of overall criteria in the table. Assuming the total number of criteria is 'n', equation is developed to calculate overall criteria point. The equation is like Equation 3.4 below:

$$\sum_{i=1}^{n} \cdot \sum_{j=n}^{n} Xij \qquad 3.4$$

The total point for each row of criteria is divided by total of overall point in the table. The Equation 3.5 shown below made first row as an example:

$$\frac{\sum_{j=1}^{n} Xij \ , i = 1 \ and \ if \ i = j, no \ value}{\sum_{i=1}^{n} \cdot \sum_{j=n}^{n} Xij} \qquad 3.5$$

Then, for idealized equation which weight of every criteria is obtained by converting j=1 by j=n for infinite comparison and applicable for every row.

$$\frac{\sum_{j=n}^{n} Xij \ , i = 1 \ and \ if \ i = j, no \ value}{\sum_{i=1}^{n} \cdot \sum_{j=n}^{n} Xij} \qquad 3.6$$

The final comparison table is as Table 3.2 which integrates with the mathematical equation.

	C1	C2	C3	.	.	.	Cn	Total	Weight
C1	X_{11}	X_{12}	X_{13}				X_{1n}	$\sum_{j=n}^{n} Xij$, $i = 1$ and if $i = j$, no value	$\frac{\sum_{j=n}^{n} Xij\ ,\ i = 1 \text{ and if } i = j, \text{ no value}}{\sum_{i=1}^{n} \cdot \sum_{j=n}^{n} Xij}$
C2	X_{21}	X_{22}	X_{23}				X_{2n}		
C3	X_{31}	X_{32}	X_{33}				X_{3n}		
.	.			Xij, which i=j, no value.			.		
.	.						.		
.	.						.		
Cn	X_{n1}	X_{n2}	X_{n3}				X_{nn}		
Total								$\sum_{i=1}^{n} \cdot \sum_{j=n}^{n} Xij$	

3.5 Development of the Comercial Evaluation Model

As discussed in Chapter 2.1.1, Present worth analysis is calculating something in future, and everyone cannot see futures. It is difficult to solve a problem if you cannot see it. Thus, the easiest way to approach problems in economic analysis is to draw a picture as shown in Figure 3.3. The picture should show three things [29]:

a) A time interval divided into an appropriate number of equal periods

b) All cash outflows (deposits, expenditures, etc.) in each period

c) All cash inflows (withdrawals, income, etc.) for each period

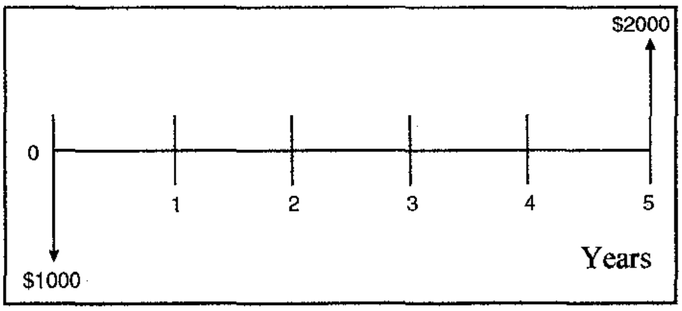

Figure 3.3: Cash Flow Diagram [29]

Figure 3.3 is an example of cash-flow diagram showing an outflow or disbursement of $1000 at the beginning of year 1and an inflow or return of $2000 at the end of year 5. Centrifugal pumps in offshore plant have been specified by API Std 610 to have their own design life of 20 years as discussed in Chapter 2.4.7. Annual expenses such as maintenance and operating cost are adapted to the Cash Flow diagram.

Regarding Present Worth analysis, there are some essential components that have been identified. The components are as follows:

ii) Beginning investment cost
iii) Equipment lifecycle or total period
iv) Annual cash flow e.g maintenance cost or operation cost
v) Interest calculations
vi) Continuous cash flow
vii) Gradients

So, the commercial evaluation model flow chart is generated as shown in Figure 3.4 below.

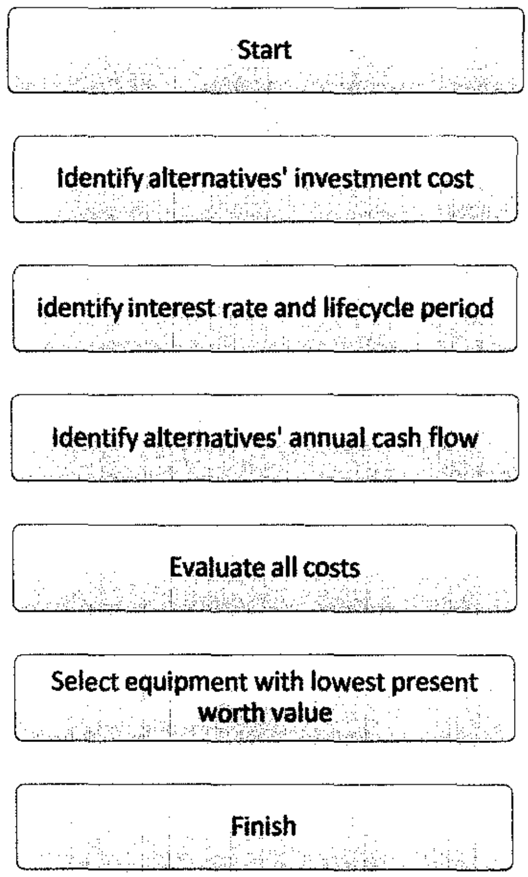

Figure 3.4: Commercial evaluation model flow chart

Beginning investment cost is the cost buying the equipment itself. The cost normally provided in the commercial proposal which prepared by vendor upon bidding or during FEED period as discussed in Chapter 1.1.3. The equipment cost are one of the essential components for commercial evaluation.

Equipment lifecycle period is total years which the equipment are meant to stand for operations in the offshore plants. As discussed in early Chapter 3.5, design life shall up to 20 years of operation.

Annual cash flow is the annualized total cost involved in order to keep the equipment running on the offshore plants. All maintenance costs are identified from the manufacturers' maintenance history of the respective equipment.

Interest for Present Worth analysis generally called Minimum Attractive Rate of Return. Discount future amounts to the present by using the interest factor as shown in Equation 3.7 below:

$$PW = \sum_{k=0}^{n} Fk(1+i)^{-n} \qquad 3.7$$

Where,

- i = effective interest rate, or MARR per compounding period
- k = index for each compounding period
- F_k = future cash flow at the end of period k
- N = number of compounding periods in study period
- $(1+i)^{-n}$ is the interest factor or =(P/F,i%,n)

From Equation 3.7, beginning investment cost is at n=0, which,

$$PW = investment\ cost \qquad 3.8$$

However, if there is expected upgrade which request by manufacturer for example at tenth years of operation, Equation 3.7 is applied as the upgrade cost is bring to present value.

According to Office for National Statistics of United Kingdom (1999), they assuming that investors in oil and gas companies receive an 8% real rate of return on the capital invested [30].

Continuous cash flow perhaps the most useful function of continuous interest is its application to situations where the flow of money is of a continuous nature. The other word is expenses are constant or equivalent along the equipment lifecycle period. For example, the maintenance cost for centrifugal pump A is RM10000 every year. It's called continuous cash flow due to the cost is bared every year until 20 years of operation.

The interest factor for this kind of uniform series of present worth is shown in Equation 3.9 which later added into Equation 3.8 to get more detail cost analysis of Equation 3.10.

$$(\mathrm{P/A}, i\%, \mathrm{n}) = \frac{(1+i)^{\mathrm{n}}-1}{i(1+i)^{n}} \qquad 3.9$$

$$PW = investment\ cost + annual\ cost(P/A, i\%, \mathrm{n}) \qquad 3.10$$

Gradient is slightly different with continuous cash flow. It occasionally becomes necessary to treat the case of a cash flow which regularly increases or decreases at each period. Such patterned changes in cash flow are called gradients. They may be a constant amount (linear or arithmetic progression), or they may be a constant percentage (exponential or geometric progression). The interest factor for gradient case is shown in Equation 3.11 and Equation 3.12 shows the equation integrated with investment cost, annual continuous cash flow and gradient increment.

$$\left(\frac{\mathrm{P}}{\mathrm{G}}, i\%, \mathrm{n}\right) = \frac{(1+i)^{\mathrm{n}}-1}{i^{2}(1+i)^{n}} - \frac{\mathrm{n}}{i(1+i)^{\mathrm{n}}} \qquad 3.10$$

$$PW = investment\ cost + annual\ cost\left(\frac{P}{A}, i\%, \mathrm{n}\right) + gradient\ (\mathrm{P/G}, i\%, \mathrm{n}) \qquad 3.11$$

For further interest factor, refer to Appendices 4.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Centrifugal Pump Evaluation Criteria

After several studies have been done for centrifugal pump, the project has arrived at criteria that are very important in designing a centrifugal pump. Most of the criteria have been extracted from process datasheet which approved for offshore plant (refer Appendices 3) and API 610. The major criteria are as below:

Table 4.1: Selected Criteria of centrifugal pumps

No.	Criteria
1	Maintenance
2	Design Life
3	Guarantee / Warranty
4	Spare Part List (after years operation)
5	Protection and rust Prevention
6	Package Limit
7	Operating Condition (NPSH)
8	Weight
9	Size
10	Design Temperature and head
11	Coupling and Guard
12	Shaft type (deflection)
13	Flow rate
14	Utilities/auxiliaries
15	Material of Construction
16	Impeller type and size
17	Type of seal
18	Driver Type
19	Power and Voltage
20	Capacity
21	Best Efficiency Point (BEP)
22	Bearing Type

4.2 Assign Weights for Technical Evaluation Model

From the findings as in Chapter 2, books and standards, the Pairwise Comparison tables are developed to assign weight to each criterion. The total of comparison between two criteria is divided with total of comparison of every criterion respectively. Then the weight is included in the factor rating table.

Then, all criteria are list down in the table. Note that, in order to increase the accuracy of the comparison result, the criteria are separated into two tables. The two tables are divided based on general and operation design criteria of centrifugal pumps. They are shown in Table 4.2 and Table 4.3 below:

Table 4.2: General Equipment Design Criteria

No.	Criteria	Codes
1	Maintenance	A1
2	Warranty	A2
3	Spare Part List (after years operation)	A3
4	Protection and Rust Prevention	A4
5	Weight	A5
6	Size	A6
7	Coupling and Guard	A7
8	Shaft type (deflection)	A8
9	Utilities/ Auxiliaries	A9
10	Material of Construction	A10
11	Impeller Type	A11
12	Type of Seal	A12
13	Driver Type	A13
14	Bearing Type	A14

Table 4.3: Operation Equipment Design Criteria

No.	Criteria	Codes
1	Design Life	B1
2	Package Limit	B2
3	NPSHr & NPSHa	B3
4	Design Temperatures	B4
5	Flow rate	B5
6	Power and Voltage	B6
7	Capacity	B7
8	Best Efficiency Point (BEP)	B8

After all the criteria have been tabulated, they were analyzed and their importance in a system are identified based on API standard, equipment maintenance journals and design book as main references. Then, with prioritization that stated of API standard and journal, all the criteria are evaluated using Pairwise Comparison. Refer Table 4.2, and 4.3 for simplified Codes which used in the Table 4.4 and Table 4.5 to gain their weight ratio before proceed to factor rating method.

The score sheet of factor rating for centrifugal pump is shown in Table 4.6. The score terminology is to be determined within specific range of available recent pump.

The 0-1 score in Table 4.4 and Table 4.5 is based on project research and findings or what was stated in Chapter 2 and Chapter 3. Thus, as a justification, the factor rating weight developed in this project was developed by non-expert engineer but based on project findings. The main focus is the methods of developing of the weight rating and validation process by experts is preferable to enhance the reliability.

Table 4.4: Pairwise Table for General Equipment Design Criteria

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	Score	Weight
A1	-	0	1	0	1	0	0	0	1	0	0	0	0	0	3	3/112
A2	1	-	1	1	0	0	0	0	0	0	0	0	0	0	3	3/112
A3	0	1	-	1	0	0	1	1	1	0	1	1	1	1	9	9/112
A4	1	1	1	-	0	0	1	1	1	1	1	0	1	1	10	10/112
A5	1	1	1	1	-	1	1	1	1	1	1	1	1	1	13	13/112
A6	1	1	1	1	1	-	1	1	1	1	1	1	1	1	13	13/112
A7	1	1	0	0	0	0	-	1	1	1	1	1	1	1	9	9/112
A8	1	1	0	0	0	0	1	-	1	0	1	1	1	1	8	8/112
A9	1	1	1	0	0	0	0	0	-	0	0	0	0	0	3	3/112
A10	1	1	0	0	0	0	0	1	1	-	1	0	0	0	5	5/112
A11	1	1	0	0	0	0	1	1	1	0	-	1	1	1	8	8/112
A12	1	1	0	1	0	0	1	1	1	1	1	-	1	1	10	10/112
A13	1	1	0	0	0	0	1	1	1	1	1	1	-	1	9	9/112
A14	1	1	0	0	0	0	1	1	1	1	1	1	1	-	9	9/112
Total Score															112	

Table 4.5: Pairwise Table for Operation Equipment Design Criteria

	B1	B2	B3	B4	B5	B6	B7	B8	Score	Weight
B1	-	1	0	0	0	0	0	1	2	2/35
B2	1	-	0	0	0	1	0	0	2	2/35
B3	1	1	-	1	0	1	0	0	4	4/35
B4	1	1	1	-	1	1	1	1	7	7/35
B5	1	1	1	1	-	1	1	1	7	7/35
B6	1	0	0	0	0	-	0	0	1	1/35
B7	1	1	0	0	1	1	-	1	5	5/35
B8	1	1	1	1	1	1	1	-	7	7/35
Total Score									35	

Based on above Pairwise comparison result, the criteria weights are transferred into another table which is Factor Rating score sheet as shown in Table 4.6.

Table 4.6: Score Sheet Centrifugal Pump- Factor Rating Method

No.	Key Factor	Weight Rating
	General Design	
1	Maintenance	0.0268
2	Warranty	0.0268
3	Spare Part List (after years operation)	0.0804
4	Protection and rust Prevention	0.0893
5	Weight	0.1161
6	Size	0.1161
7	Coupling and Guard	0.0804
8	Shaft type (deflection)	0.0714
9	Utilities/auxiliaries	0.0268
10	Material of Construction	0.0446
11	Impeller type	0.0714
12	Type of seal	0.0893
13	Driver Type	0.0804
14	Bearing Type	0.0804
	Total	1.0000
	Operation Design	
15	Design Life	0.0571
16	Package Limit	0.0571
17	NPSHr & NPSHa	0.1143
18	Design Temperature	0.2000
19	Flow rate	0.2000
20	Power and Voltage	0.0286
21	Capacity	0.1429
22	Best Efficiency Point (BEP)	0.2000
	Total	1.0000

Next is to transfer all those data, weights and mathematical equations into an interface to include input as part of the calculation to provide best alternative solution. The interface is developed user friendly and be tested its reliability.

4.3 Commercial Evaluation Model

As discussed in Chapter 3.5, the essential components that needed in order to use present worth analysis method. The components are listed in Table 4.7 below:

Table 4.7: Components of Commercial Evaluation model

No.	Components	
1	Investment cost (purchasing cost)	
2	Annual cost	Maintenance cost
3		Operation cost
4		Upgrade cost if any
5		Labor cost if any
6	Gradient	
7	Interest Rate = 8%[30]	
8	Lifecycle Period = 20 years[7]	

Same as technical evaluation model which commercial evaluation model interface is developed using Microsoft Excel to integrate the components with calculations. Thus the lowest value will be chosen as best alternatives.

4.4 Evaluation Model in Microsoft Excel

The next step is to develop the interface itself. All the data, mathematical equations and criteria compliances are integrated in an interface. For time being, Microsoft Excel being used in developing that model.

According to Jay Heizer, Professor and Barry Render, Professor, (2008), the weights do not need to be on 0-1 scale or total to 1. The method can use a 1-10 scale, or 1-100 scale for more detail, or any other scale is still acceptable [27]. As a result, every specification or criteria are scored with scale of 1-10 based on its compliance to the requirements. The table is shown in Figure 4.1 and Figure 4.2 below.

The criteria or basically key factors are listed down at the most right of the table in the Microsoft Excel. These criteria are evaluated with alternative equipment as shown in the Figure 4.1. The answer for every criterion is; range of 1-10 as how much the alternatives comply with requirements as discussed deeply in Chapter 3 and 4.

No.	Key Factor	Weight	Centrifugal Pump 1		Centrifugal Pump 2	
			Score	Weighted Score	Score	Weighted Score
	General Design					
1	Maintenance	0.0268				
2	Warranty	0.0268				
3	Spare Part List (after years operation)	0.0804				
4	Protection and rust Prevention	0.0893				
5	Weight	0.1161				
6	Size	0.1161				
7	Coupling and Guard	0.0804				
8	Shaft type (deflection)	0.0714				
9	Utilities/auxiliaries	0.0268				
10	Material of Construction	0.0446				
11	Impeller type	0.0714				
12	Type of seal	0.0893				
13	Driver Type	0.0804				
14	Bearing Type	0.0804				
	Operation Design					
15	Design Life	0.0571				
16	Package Limit	0.0571				
17	NPSHr & NPSHa	0.1143				
18	Design Temperature	0.2000				
19	Flow rate	0.2000				
20	Power and Voltage	0.0286				
21	Capacity	0.1429				
22	Best Efficiency Point (BEP)	0.0804				
	Totals (Operation + Equipment)			0.0000		0.0000

Figure 4.1: Excel Technical Evaluation Model

Then for an example, insert some figures into the table to calculate scores for each alternative. The score of each criterion which ranged 1-10 is multiplied with its weight ratio to calculate the weighted score. Then, the total weighted score are identified at the end of the model.

No.	Key Factor	Weight	Centrifugal Pump 1		Centrifugal Pump 2	
			Score	Weighted Score	Score	Weighted Score
	General Design					
1	Maintenance	0.0268	8	0.2143	8	0.2143
2	Warranty	0.0268	10	0.2680	8	0.2144
3	Spare Part List (after years operation)	0.0804	6	0.4824	8	0.6432
4	Protection and rust Prevention	0.0893	7	0.6251	8	0.7144
5	Weight	0.1161	5	0.5805	9	1.0449
6	Size	0.1161	7	0.8127	7	0.8127
7	Coupling and Guard	0.0804	1	0.0804	6	0.4824
8	Shaft type (deflection)	0.0714	3	0.2142	9	0.6426
9	Utilities/auxiliaries	[illegible]	[illegible]	2144	9	0.2412
10	Material of Constructio	[illegible]	[illegible]	2230	8	0.3568
11	Impeller type	[illegible]	[illegible]	4998	7	0.4998
12	Type of seal	[illegible]	[illegible]	7144	6	0.5358
13	Driver Type	0.0804	6	0.4824	6	0.4824
14	Bearing Type	0.0804	5	0.4020	6	0.4824
	Operation Design					
15	Design Life	0.0571	8	0.4568	8	0.4568
16	Package Limit	0.0571	9	0.5139	9	0.5139
17	NPSHr & NPSHa	0.1143	6	0.6858	8	0.9144
18	Design Temperature	0.2000	7	1.4000	10	2.0000
19	Flow rate	0.2000	8	1.6000	8	1.6000
20	Power and Voltage	0.0286	7	0.2002	7	0.2002
21	Capacity	0.1429	8	1.1432	9	1.2861
22	Best Efficiency Point (BEP)	0.0804	7	0.5625	5	0.4018
	Totals (Operation + Equipment)			12.3760		14.7405

The highest total weighted score is the best alternatives

Figure 4.2: Excel Model with Weight Rating and Score

From total weighted score, then the best alternative can be identified based on highest score numbers. In Figure 4.2 shows that alternative B is higher than alternative A thus, alternatives B is awarded better alternative in term of technical wise.

For commercial evaluation model, the model with two alternatives is shown as Figure 4.3 which the model integrate the components with mathematical equation as discussed in Chapter 3.5.

No.	Components	Cost					
		Centrifugal Pump 1	Factor	Present Worth	Centrifugal Pump 2	Factor	Present Worth
1	Lifecycle period (years)	20					
2	Interest rate (%)	0.08					
3	Purchasing cost		1	RM0.00		1	RM0.00
4	Annual Maintenance cost		9.8181	RM0.00		9.8181	RM0.00
5	Annual Labor cost		9.8181	RM0.00		9.8181	RM0.00
6	Annual Operation cost		9.8181	RM0.00		9.8181	RM0.00
7	Upgrade		0.2145	RM0.00		0.2145	RM0.00
8	Gradient		69.0898	RM0.00		69.0898	RM0.00
	Total cost	RM0.00			RM0.00		

Figure 4.3: Commercial Evaluation Model

And as the value inserted as an example of the commercial model is shown in Figure 4.4 below which the lower cost is selected as the best alternatives:

The lowest total cost is the best alternatives

No.	Components	Cost					
		Centrifugal Pump 1	Factor	Present Worth	Centrifugal Pump 2	Factor	Present Worth
1	Lifecycle period (years)	20					
2	Interest rate (%)	0.08					
3	Purchasing cost	RM100,000.00	1	RM100,000.00	RM150,000.00	1	RM150,000.00
4	Annual Maintenance cost	RM10,000.00	9.8181	RM98,181.47	RM8,000.00	9.8181	RM78,545.18
5	Annual Labor cost	RM10,000.00	9.8181	RM98,181.47	RM8,000.00	9.8181	RM78,545.18
6	Annual Operation cost	RM8,000.00	9.8181	RM78,545.18	RM9,000.00	9.8181	RM88,363.33
7	Upgrade	RM20,000.00	0.2145	RM4,290.96	RM18,000.00	0.2145	RM3,861.87
8	Gradient	RM1,000.00	69.0898	RM69,089.79	RM1,000.00	69.0898	RM69,089.79
	Total cost	RM448,288.88			RM468,405.34		

Figure 4.4: Example Comercial Evaluation Model with values

From Figure 4.4, which PW_A (i) < PW_B (i) thus alternatives is chosen as the best alternatives.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Project Conclusions

In this project, researches have been done to produce on evaluation method to select the best alternative equipment of rotating and static equipment for offshore plant. Two approaches of selection methods which are Pairwise comparison to find the weight ration and factor rating method were adopted for the model. Compares the alternative equipment in term of score thus the highest weighted score (weight rating x score) which will be chose as the preferable equipment. These weight rating is the main roles of developing the evaluation model for this project.

Based on results and discussion, Weight rating was successfully developed and with Factor rating method the best alternative pump was chosen based on highest total weighted score. Thus the objective of the project is achieved to develop a technical and commercial evaluation model for rotating equipment.

5.2 Recommendations

The recommendations for future project work development of technical and commercial evaluation model for rotating equipment for offshore plant are:

1. Increase the number of design criteria of equipment which involving more operating conditions, utilities, auxiliaries and sizing in order to have accurate results.
2. Improve the Pair Wise method by involving experts in making the decision of 0-1 score comparison, thus improve weight rating accuracy.
3. Validate the evaluation model itself by experts or real case study. Either the criteria are sufficient enough or add on should be applied to increase the accuracy of the result. Thus, the model can be applied in real design world.

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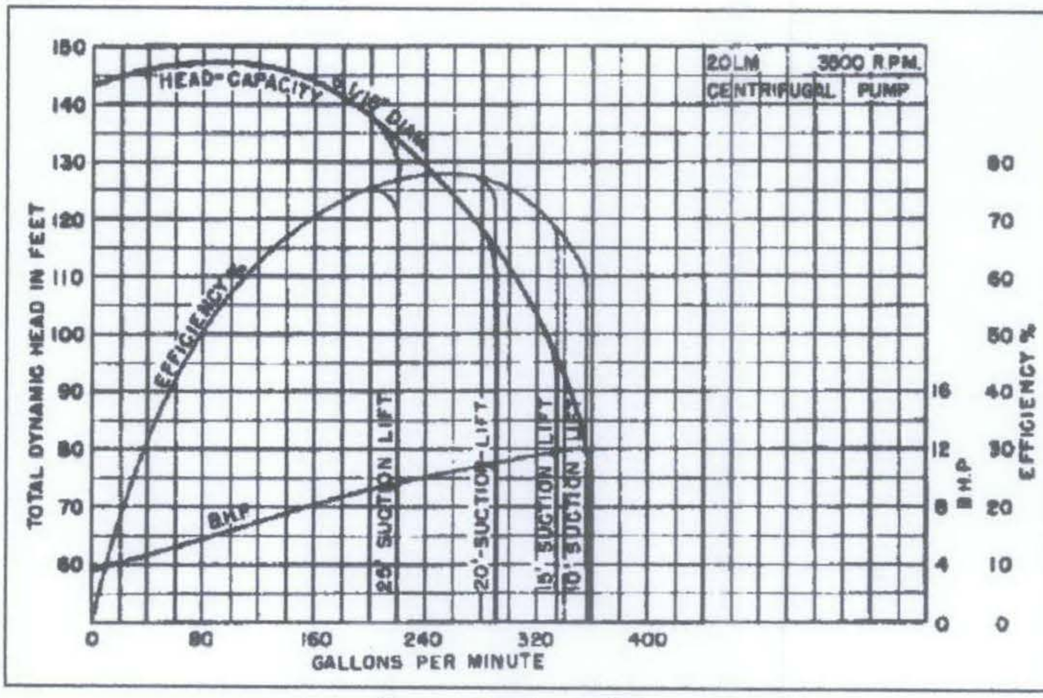
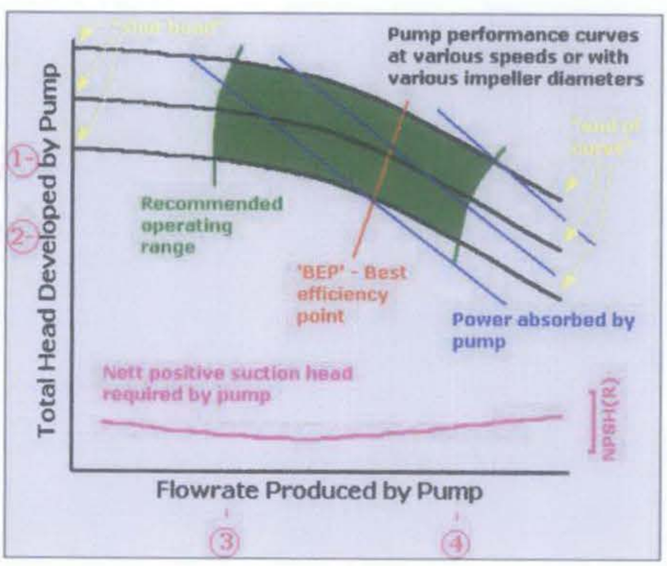
APPENDICES



Appendices 1: Head vs Efficiency [13]



1. Maximum recommended head.
2. Minimum recommended head.
3. Minimum recommended flow.
4. Maximum recommended flow.

Appendices 2: Characteristic Curve for Centrifugal Pump

Centrifugal pump process data sheet — SI units

PAGE 1 OF
JOB NO. ITEM NO.(S)
REQ. / SPEC. NO. /
PURCH. ORDER NO. DATE
ENQUIRY NO. BY

APPLICABLE TO: ○ PROPOSALS ○ PURCHASE ○ AS BUILT
FOR UNIT
SITE SERVICE
NOTES: INFORMATION BELOW TO BE COMPLETED: ○ BY PURCHASER □ BY MANUFACTURER ○ BY MANUFACTURER OR PURCHASER

○ DATA SHEETS						REVISIONS		
ITEM NO.	ATTACHED	ITEM NO.	ATTACHED	ITEM NO.	ATTACHED	NO.	DATE	BY
PUMP	○		○		○	1		
MOTOR	○		○		○	2		
GEAR	○		○		○	3		
TURBINE	○		○		○	4		
APPLICABLE OVERLAY STANDARD(S):						5		

○ OPERATING CONDITIONS (5.1.3)

FLOW, NORMAL (m³/h) RATED (m³/h)
OTHER
SUCTION PRESSURE MAX./RATED / (MPa)
DISCHARGE PRESSURE (MPa)
DIFFERENTIAL PRESSURE (MPa)
DIFF. HEAD (m) NPSHA (m)
PROCESS VARIATIONS (5.1.4)
STARTING CONDITIONS (5.1.4)
SERVICE: ○ CONT. ○ INTERMITTENT (STARTS/DAY)
○ PARALLEL OPERATION REQ'D (5.1.13)

○ SITE DATA (5.1.3)

LOCATION: (5.1.30)
○ INDOOR ○ HEATED ○ OUTDOOR ○ UNHEATED
○ ELECTRICAL AREA CLASSIFICATION (5.1.24 / 6.1.4)
CL GR DIV
○ WINTERIZATION REQ'D ○ TROPICALIZATION REQ'D.
SITE DATA (5.1.30)
○ ALTITUDE (m) BAROMETER (MPa)
○ RANGE OF AMBIENT TEMPS: MIN./MAX. / (°C)
○ RELATIVE HUMIDITY: MIN. / MAX. / (%)
UNUSUAL CONDITIONS: (5.1.30) ○ DUST ○ FUMES
○ OTHER

○ DRIVER TYPE

○ INDUCTION MOTOR ○ STEAM TURBINE ○ GEAR
○ OTHER

○ MOTOR DRIVER (6.1.1 / 6.1.4)

○ MANUFACTURER
□ (kW) □ (r/min)
□ FRAME ○ ENCLOSURE
○ HORIZONTAL ○ VERTICAL ○ SERVICE FACTOR
○ VOLTS/PHASE/HERTZ / /
○ TYPE
○ MINIMUM STARTING VOLTAGE (6.1.5)
○ INSULATION ○ TEMP. RISE
○ FULL LOAD AMPS
○ LOCKED ROTOR AMPS
○ STARTING METHOD
○ LUBE
BEARINGS (TYPE/NUMBER):
□ RADIAL /
□ THRUST /
□ VERTICAL THRUST CAPACITY
UP (N) DOWN (N)

○ LIQUID (5.1.3)

LIQUID TYPE OR NAME
○ HAZARDOUS ○ FLAMMABLE ○ (5.1.5)

	MIN.	NORMAL	MAX.
PUMPING TEMP (°C)			
VAPOUR PRESS. (MPa)			
RELATIVE DENSITY (SG):			
VISCOSITY (mPa·s)			

SPECIFIC HEAT, Cp (kJ/kg·K)
○ CHLORIDE CONCENTRATION (6.5.2.4) (mg/kg)
○ H_2S CONCENTRATION (mol fraction) WET (5.12.1.12c)
CORROSIVE / EROSIVE AGENT (5.12.1.9)

MATERIALS (5.12.1.1)

○ ANNEX H CLASS (5.12.1.1)
○ MIN DESIGN METAL TEMP (5.12.4.1) (°C)
○ REDUCED-HARDNESS MATERIALS REQ'D. (5.12.1.12)
□ BARREL/CASE IMPELLER
□ CASE/IMPELLER WEAR RINGS
□ SHAFT
□ DIFFUSERS

○ PERFORMANCE:

PROPOSAL CURVE NO. □ r/min
□ IMPELLER DIA. RATED MAX. MIN. (mm)
□ IMPELLER TYPE
□ RATED POWER (kW) EFFICIENCY (%)
□ MINIMUM CONTINUOUS FLOW:
THERMAL (m³/h) STABLE (m³/h)
□ PREFERRED OPER. REGION TO (m³/h)
□ ALLOWABLE OPER. REGION TO (m³/h)
□ MAX. HEAD @ RATED IMPELLER (m)
□ MAX. POWER @ RATED IMPELLER (kW)
□ NPSHR AT RATED FLOW (m) (5.1.10)
○ MAX. SUCTION SPECIFIC SPEED: (5.1.11)
○ MAX. SOUND PRESS. LEVEL REQ'D (dBA) (5.1.16)
○ EST. MAX. SOUND PRESS. LEVEL (dBA) (5.1.16)
○ EST. MAX. SOUND POWER LEVEL (dBA) (5.1.16)

○ UTILITY CONDITIONS (5.1.3)

ELECTRICITY	VOLTAGE	PHASE	HERTZ
DRIVERS			
HEATING			

SYSTEM VOLTAGE DIP ○ 80% ○ OTHER (6.1.5)

STEAM	MAX. PRESS.	MAX. TEMP.	MIN. PRESS.	MIN. TEMP.
DRIVERS				
HEATING				

COOLING WATER: (5.1.19) SOURCE
SUPPLY TEMP. (°C) MAX. RETURN TEMP. (°C)
NORM. PRESS. (MPa) DESIGN PRESS. (MPa)
MIN. RET. PRESS. (MPa) MAX. ALLOW. D.P. (MPa)
CHLORIDE CONCENTRATION: (mg/kg)

Appendices 3: Centrifugal Pump - Process Datasheet (courtesy of DPS Consultant (M) Sdn Bhd)

factor name	converts	symbol	formula
single payment compound amount	P to F	$(F/P, i\%, n)$	$(1+i)^n$
single payment present worth	F to P	$(P/F, i\%, n)$	$(1+i)^{-n}$
uniform series sinking fund	F to A	$(A/F, i\%, n)$	$\frac{i}{(1+i)^n - 1}$
capital recovery	P to A	$(A/P, i\%, n)$	$\frac{i(1+i)^n}{(1+i)^n - 1}$
uniform series compound amount	A to F	$(F/A, i\%, n)$	$\frac{(1+i)^n - 1}{i}$
uniform series present worth	A to P	$(P/A, i\%, n)$	$\frac{(1+i)^n - 1}{i(1+i)^n}$
uniform gradient present worth	G to P	$(P/G, i\%, n)$	$\frac{(1+i)^n - 1}{i^2(1+i)^n} - \frac{n}{i(1+i)^n}$
uniform gradient future worth	G to F	$(F/G, i\%, n)$	$\frac{(1+i)^n - 1}{i^2} - \frac{n}{i}$
uniform gradient uniform series	G to A	$(A/G, i\%, n)$	$\frac{1}{i} - \frac{n}{(1+i)^n - 1}$

Appendices 4: Interest Factor Formula

No.	Detail/Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1.	Selection of project							Mid- Semester Break								
	- research for project background															
	- submission of Form01															
2.	Research work															
	- collect literature review															
	-preliminary interpretation															
	- submission of Preliminary Report															
3.	Project work															
	- study on theory, operations and functions															
4.	Progress Report and Seminar															
	- interpretation of data															
	- submission of Progress Report															
5.	Project work continues															
	-Study on environmental conditions															
	-study and relate the impacts towards equipment															
6.	Interim Report															
	- evaluation and discussion of data															
	- submission of Interim Report															

Appendices 5: Gantt Chart FYP 1

No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
8	Project work continue								Mid- Semester Break							
	-literature review															
	-start doing the model															
9	Progress Report 1															
	- preparation of report															
	- submission of report															
10	Project work continue															
	- Final interpretation															
11	Progress Report 2															
	- Preparation of Report															
	- Submission of Report															
12	Project work continue															
	- preparation of dissertation															
	-conclusion and recommendations															
14	Submission of Dissertation															

Appendices 6: Gantt Chart FYP 2