3.2 Tools and Equipment used

Due to the nature of this project, no specific equipment is required apart from that offered in the office workstation. The followings Microsoft application software's were essential:

a) Microsoft Office
b) Microsoft Power Point
c) Adobe Acrobat reader
d) Internet Explorer

Besides these computers programs, reservoir simulation software was used. The reservoir simulator used was ECLIPSE100, which is used at the computer Laboratory at the university.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Results of Types of Water Injection Pumps

4.1.1 Water Injection Pumps

Water injection pumps are either of one of two general types:

a) Reciprocating Positive displacement (PD) pumps
b) Centrifugal Pumps.

4.1.2 PD Pumps

The Reciprocating PD pumps can be used for low pressure high flow rates for water injection and at constant rates for high injection pressures. Based on the literature reviewed, the common reciprocating PD pumps used are Duplex and Triplex Pistons or plunger Pumps. Triplex Pistons pumps fabricated by CAT Pumps, meet pressure ranges from 1,000 to 7,000 psi at flow rates from 5 to 320 GPM or 1,744.3 m^3/day.

4.1.3 Centrifugal Pumps (CP)

The following Centrifugal pumps can be used for High pressure high flow rates for water injection:

a) Horizontal multistage double casing (back to back design)
b) Horizontal multistage double casing (inline design)

Horizontal multistaged centrifugal pumps are high pressure pumps used for water injection at different rates and head according to the requirement of the field. The next section discusses more about these centrifugal pumps.

4.1.4 CP Horizontally Multistage Double Casing

Centrifugal pumps are the most practical and reliable water injection pumps used nowadays in the industry, due to their easy maintenance and easy to adapt at different requirements compared to reciprocating PD pumps. Centrifugal pumps are electric motor driven capable of generating water pressure up to 6,250psi with heads for about 8,280 ft. The Table 1 of the operating data summarizes the capability for this pump. These pumps are manufactured by many companies such as SULZER pumps, which is one the major player of this industry [17].

Table 1: CP Horizontal Multistage Pump Operating Data

Units	SI Units	U.S. Units
Capacities	Up to 590 m3/h	Up to 2,600 gpm
Heads	Up to 2,525 m	Up to 8,280 ft.
Pressures	Up to 425 bar	Up to 6,250 psi
Temperatures	-28 to 425 degree Celsius	-20o to 800 degree Far.
Speeds	Up to 7,200 RPM	Up to 7,200 RPM

From Table 1 we can see that these pumps are suitable for high pressure up to 6250 psi, speed up to 7,200RPM, temperatures up to 800^{o}F. The CP's rotating element is housed in horizontally split inner case, which is itself contained in a cast or forged outer barrel. This design provides for easy maintenance and element removal without piping disturbance. Suction and discharge nozzles are normally positioned at the top centerline, but can be rotated to meet specific application requirements.

For each injection pump, the discharged volumes at a pre-determined injection pressure well Head Injection Pressure (WHIP) should never exceed fracture pressure of the formation. Pumping Capacity is equal to the sum of all pumps capacity at that injection pressure. Most of Centrifugal pumps are designed for specific operating conditions and may not be suited for any other without loss of performance or damage.

PETRONAS Carigali's Angsi field uses four CP injection pumps, (see Appendix B).

These injections pumps are designed to provide flow rate of treated seawater 510 m^3/h at a back pressure of 11,800 kpa (1711.4 psi) with 3 units on line and one unit on standby, which is the maximum design of Angsi water injection management Plant. The water injection pump is taking suction directly from vacuum Deaerator which is design to locate at high level to provide NPSH require for the pump to prevent from pump cavitations. Other examples are the LL-5 Flank Waterflood at Lake Maracaibo (Venezuela) where each of eight injection wells has its own injection station capable of delivering 60,000B/D water. Many others fields from the Gulf of Mexico and the North Sea uses the split barrel multistaged centrifugal pumps [8].

4.1.5 CP Horizontal multistage Double Casing Design Features

a) Compliance with API 610 9th Edition (ISO 13709) requirements
b) Hot alignment feature for temperatures above 250°F (120°C) Forged outer case and end covers
c) Designed to accommodate temperatures between -20°F (-29°C) to 800°F (425°C)
d) Pump feet located on horizontal centerline
e) Inner bundle arrangement (rotating element & volute case) for Suction end closure design requires no heavy bolting ease of changeouts
f) Seal chambers for single/double seals to API 610 9th Edition (ISO 13709) Table 6
g) Tapered shaft extension per API 610 (ISO 13709)
h) Flanged stationary wear parts to control interstage leakage
i) Large shaft diameter with
j) Double volute inner case for radial thrust balance•
k) Replaceable or integral impeller hub and eye rings
l) Dynamically balanced impellers and rotating element
m) Rotation counterclockwise, as viewed from the driver

4.1.6 Pumps Selection Parameters

A number of Parameters enter into the choice of Waterflood pressure pumps, such as:

a) **Prime mover to be used,** there are several types of prime movers: Natural-gas-fueled, internal-combustion engines(either naturally aspired or turbocharged), electric motors, diesel or gasoline-fired engines; and natural-gas fired turbines
b) **Injection rates and Pressure required throughout the Waterflood life,** before reservoir fill-up, water is usually injected at low pressure and maximum achievable rates. As the flood progresses, the actual injection rate may decrease, in some cases to less than half the initial value.
c) **Future flood expansion,** this refers to the requirements of the reservoir for higher injection volumes in the future. So the current design must meet the future changes on the facilities.
d) **Injection-water quality,** asses the concentration of chemicals and substances not suitable for the water injection. Certain injection pumps are very sensitive to sand or other chemicals that can be found in the water.
e) **Space available for pump**

   The space for the facilities is very important especially for offshore operations. The space availability is limited due to the nature of the environment; therefore injection pumps that required less space are suitable. PD pumps take more space compared to CP with the same capacities.

f) **Pump efficiency**

   The efficiency of a hydraulic pump is the output power of the pump over the initial energy or power required to run the pump. The parameters that affect the efficiency of a pump are the flow rate, the density of the fluid and the head difference of the pump.

g) Maintenance Cost

The maintenance cost of the pumps is highly considered during the selection of the pump. The cost of maintenance of a Centrifugal pump depends on the Capacity of the pump, the fluid properties and the quality of the materials design for the pump. Generally CP pumps are cost saved of maintenance compared to their counterpart PD pumps.

4.1.7 Relationship of Injection Pumps and Reservoir Performance

Reciprocating positive displacement pumps and centrifugal pumps can be used for water injection based on the selection parameters mentioned. The reservoir performance will depend on the injection rates and the at desired head requirements. For high deepwater reservoirs flexibility on injection rates and pressure rates of the fluids injected are important parameters that the pumps need to meet for long production life of the reservoir. In addition to that the Maintenance cost of the pumps is also a critical parameter to select a suitable injection pump. One of the most important factor in oil and gas industry is to produce hydrocarbons efficiently at the lowest cost is possible. The cost of production comprises the initial cost of development of the field or capital expenditure, CAPEX and the Operation expenditures, OPEX. According to SPE (Ref.8) the Reciprocating PD pumps require frequent maintenance as compared to the centrifugal pumps. This makes these injection pumps very unsuitable for many oil corporations due to their high cost as result of the maintenance of the pumps. For same pressure rates and injection rates PD pumps have higher efficiency than the Centrifugal pumps

The investment for PD pumps is greater because of the higher unit weight and size. As a rule of thumb, the maintenance cost for a PD pump is about three times that of a centrifugal on a per-unit power basis. Most problems with a PD pump can be avoided by selecting a pump that will operate at conservative speeds, carefully designing the piping system, and using maintenance practices that preserve the alignment of the plunger and stuffing box. This alignment is important because packing problems can be significant. As with most equipment, operation problems can be significant [8].

4.1. 8 Pumping system Failure considerations

The Pumping system design for water injection must meet a desirable operations condition to avoid frequent downtime of the equipments. The downtime of the injection system due to a failure of the injection pump will have a serious impact on the reservoir if good maintenance methods are not been used. The downtime state of the pumping system will lead to a depletion of pressure of the reservoir if another alternative for pressure maintenance is not being implemented. For deepwater reservoirs this requirement is very critical, because the failure of the equipments will cause a reduction in the injection rates of the water into the reservoir, reduction of borehole pressure of the production wells and thus lead to a production decrease of the hydrocarbons.

In the 1950s and earlier, most floods used small PD pumps. Since then, design has tended toward use of a split-case multistage, centrifugal pump in large volume applications. Centrifugal pump usually are not competitive in high pressure, low rate applications. But a centrifugal pump is capable of a wide range of injection rates without changing the equipment. A PD pump, particularly when driven by an electric motor, has little flexibility without recycling water and consequently, wasting energy. Besides that a failure of a PD pump would cost higher. Whether a PD or a centrifugal is chosen, future expansion must also be considered [8]. The Operators of the pumps must have a high reliable system in order to response to any failure or downtime of the components of the injection system. One way of having a high reliable system to have a half or full back up system of the injection pumps while the system is online, in order to avoid greater pressure losses during production.