CHAPTER 5
EXPLORATION AND EXPLOITATION

5.1 SEQUENCE OF SEARCH AND EXPLORATION WORK

Petroleum is basically a “Strategic Mineral”. In order to carry out the exploration in a new area, the mining lease of the area required has to be obtained. This job is done by the exploration company which carries out the exploration in that area. After the mining lease is obtained, the exploration activity in the area commences.

Before undertaking the task of petroleum exploration in any area, geological and geophysical surveys are done to find out the type of the rocks present, environment in which they have been deposited, thickness of the sediments in the particular area that could be expected in the sub surface, occurrence of suitable traps and presence of oil and gas seepages. If some positive results are obtained, then that area is recommended for exploration for oil and gas (Table 5.1 & Fig. 5.1). As is known, the oil well drilling is a very costly gamble and unless and until some positive indications are present, the particular area cannot be taken up for drilling. Even if the majority of the factors which are responsible for the generation and the accumulation of the petroleum being present, but if the formation of the trap takes place after the migration of the hydrocarbons, that structure, although, may be very good indicator. This could be knows only after the drilling in the area takes place. The different stages in oil/gas exploration are as follows: -

(I) Pre study of prospecting area
(II) Propose mining right negotiation
(III) Acquisition of mining right
(IV) Exploratory Survey- Geological Surveys, Remote Sensing and Geochemical Surveys, Gravity Survey, Magnetic Survey and Seismic Surveys
# TABLE NO. 5.1: SEQUENCE OF SEARCH AND EXPLORATION WORK

<table>
<thead>
<tr>
<th>Stage</th>
<th>Phase</th>
<th>Purpose of Investigation</th>
<th>Targets and Objectives</th>
<th>Estimation or Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SEARCH</strong></td>
<td>Preliminary Search (Regional investigations)</td>
<td>Comparative evaluation of petroleum potentialities; selection of the most promising areas for detailed search</td>
<td>Determination of main features of geological patterns and evolution of large territories, studies of sedimentary section 1st order to ascertain the position of source and reservoir rocks</td>
<td>Estimation of prognosticated resources</td>
</tr>
<tr>
<td></td>
<td>Detailed Search</td>
<td>Selection and preparation of areas for exploration</td>
<td>Detail study of promising areas to ascertain the presence of geological pre-conditions favorable for petroleum accumulation and oil &amp; gas injection</td>
<td>Estimation of prospective resources. If a pool is penetrated, the reserves of probable/possible category can also be estimated</td>
</tr>
<tr>
<td><strong>EXPLORATION</strong></td>
<td>Preliminary Exploration</td>
<td>Preparation of areas for detail exploration (commercial)</td>
<td>To ascertain the presence of oil &amp;/or gas accumulations in the area to prove their commercial value</td>
<td>Estimation of commercial reserves of Proved category</td>
</tr>
<tr>
<td></td>
<td>Detailed Commercial Exploration</td>
<td>Preparation of areas for development, transfer to development</td>
<td>Delineation of oil &amp; gas pools, their testing. Fields after tentative evaluation are considered to be of commercial value</td>
<td>Estimation of Commercial reserves</td>
</tr>
</tbody>
</table>
EXPLORATION AND EXPLOITATION SYSTEM

Figure 5.1: Flow-Chart of Exploration - Exploitation System.
(Courtesy: O.N.G.C. Ltd., Ankleshwar, Gujarat)
Pre Study of Prospecting Area

The characteristic features of pre study of any prospective hydrocarbon basins are as following:

(I) Direct and indirect evidences of presence of oil and gas
(II) Favorable tectonics and structures shows suitable structural/stratigraphic traps
(III) Metamorphism should be within reasonable limits so that the generated oil/gas may not be destroyed
(IV) Availability of favorable facies and lithological conditions
(V) Existence of suitable hydro-geological conditions
(VI) Cap rock for entrapment

Propose Mining Right Negotiation

Mineral leases on developed acreage are acquired either through bidding in public sales or through private negotiations with landowners. In either case, an initial acquisition cost is required to obtain a lease on these mineral rights.

Acquisition of Mining Right

The mineral rights are owned by the state. A mineral concession confers right to prospect or mine within acquired properties and the concession can be granted in the form of a prospecting license, mining lease, quarrying lease or permit. Under this system the operator (lessee) secures rights to extract and to acquire title to the mineral extracted as long as he fulfills the conditions specified by the lessor. These conditions are stipulated in the Mineral Concession Rules. When a mineral has been mined, it acquires a definite market value depending on grade, and also on market conditions. A portion of this value is shared by the lessor, in lieu of the privilege granted by him to the lessee for extracting the mineral.
(IV) METHODS OF EXPLORATION

The methods employed in exploration of petroleum are described as follows:

(A) GEOLOGICAL SURVEY

The geological exploration methods are applicable for those places where the outcrops are present. Surface feature such as elevations, dips, strikes of outcrops, lithological changes may be mapped as clues to sub-surface features. The value of surface mapping is generally limited to shallow beds, as deeper structures are not reflected by surface features.

RECONNAISSANCE SURVEY

These types of survey is conducted by trained geologists and consists of mapping of rock strata, exposed on the surface to find out their structure which may indicate deep seated oil and gas traps. The physical nature of the formation indicates in what part of major marine basin, the rocks have been deposited and also provide information about age. The superposition of the formation must be determined to provide information on the sedimentary thickness and act as basin for determination of the depths, which must be reached by the drilling.

(B) GEOCHEMICAL SURVEY

Geochemical exploration method is based on the assumption that hydrocarbons found in an oil pool tend to migrate upward, because of their having a lower density and some of their molecules may reach the surface. The methods generally used are:-

(I) Micro Gas Surveys
(II) Micro Core Surveys
(III) Micro Biological Surveys
(IV) Hydrochemical Surveys
(V) Bituminous Surveys
(VI) Sniffer’s Surveys for offshore areas
(C) REMOTE SENSING SURVEY

To facilitate locating sub-surface structures aerial photographs are often used, which are then mapped in detail by the field geologists.

The sciences of 'Remote Sensing' from space platforms (Landsat Imagery) is a new powerful tool for mapping of the important geological structures connected either with the petroleum or mineral exploration. The main applications of this technique are,

I) Geological interpretation on a regional basis,
II) Correlation of mineral occurrences with linear or circular features and
III) Study of relationship between offshore data and onshore structural features detected on satellite imagery

In order to fulfill the above objectives, the digital processing techniques which allow enhancements of image quality and digital combination of spectral bands are required to be used. Various geological features, lineaments, stratigraphic boundaries, texture differences in addition to morphology, vegetation, etc., can be detected with the help of 'Landsat imagery'. This aids in locating suitable structures for petroleum.

(D) GRAVITY SURVEY

Gravity Survey method is based on Newton’s Hypothesis that every particle in the universe attracts each other. An instrument (Gravimeter) measuring minute changes in the vertical gravity intensity is run over the area of interest. It is a fact that dense rock mass will exert greater pull at the surface than a less dense rock mass at the same depth. Many structures suitable for entrapment of oil and gas contain a dense core. The pull of this core will show on a gravity reading as a ‘positive anomaly’.

Gravity Surveys in the alluvial tracts of the Cambay Basin, extending over 25,000 sq. km. have shown many interesting features. Excepting for about 200 stations surveyed with an Askania Gravimeter by Negi (1950) in the Gogha area, the rest of the region has been covered using Worden Gravimeters by him and later by the other
geophysicists of the O.N.G.C. Ltd. Khattri et al., (1964) have furnished a composite gravity anomaly map and a comprehensive account of the gravity surveys in the Cambay basin. In the central part of this region, especially near Borsad the gravity gradients are fairly steep, with many broad features. Sengupta (1967) has furnished a Bouger anomaly map of the Cambay Basin and pointed out the major tectonic elements which may be inferred from the gravity data.

As a large number of wells have been drilled in this basin, further detailed studies of the gravity anomalies by the “stripping method” proposed by Hammer (1963) may throw some light on the broader aspect of the subsurface geology relating to the Sub Trappean basement.

(E) MAGNETIC SURVEY

By this method anomalies in the earth’s magnetic field are mapped and correlated with underground structure. Sedimentary rocks are non-magnetic and hence any magnetic irregularities are attributed to depth variations of basement rocks. An instrument called the Vertical Magnetometer may be carried by a survey crew or flown in an aeroplane over the basin area. It measures the vertical changes in the earth’s magnetic field. In general, the changes are an effect of the depth of the original floor field.

In India, both ground and airborne, magnetic surveys have been employed extensively for oil exploration by the Geological Survey of India and Oil and Natural Gas Commission Limited and also by some of the private oil companies. Ground magnetometer surveys on a reconnaissance basis, over 25,000 sq. km. In the alluvial tracts of Gujarat were carried out by the G.S.I. This survey pointed out that the Deccan traps are faulted on the eastern and western edges of the Cambay basin and suggest that a fairly large thickness of Tertiary sediments could be expected in the central parts of the basin. The magnetic anomalies fluctuate very sharply on the eastern and western sides were attributed to Deccan trap occurring as outcrops or
concealed at very shallow depths. The smooth gradients in the central part indicates that the Deccan traps occur at much greater depths, suggesting deep basins conditions, with a large thickness of sediments. A rough estimate showed that the basin may be 3000 m deep in the middle portions.

Magnetic anomaly map of the Ankleshwar oil field has been one of the outstanding discoveries in India by geophysical methods. The magnetic high in south west of Ankleshwar roughly corresponds to the gravity and seismic highs. The magnetic high to the east of Ankleshwar corresponds to a gravity low. The occurrence of trapwacke below the Tertiary sediments influences appreciably the magnetic picture in this area.

(F) SEISMIC SURVEY

The seismography is the most successful and widely applied geophysical tool in exploration history. This method is based on the difference in propagation velocity of artificially induced elastic waves through various sub-surface strata.

Along surveyed lines, holes are drilled which are loaded with dynamite and exploded. Each explosion generates shock waves which travel down into sub-surface. Strata of different hardness reflect these waves back to the surface, where their time of arrival is recorded on sensitive instrument. Mathematical formulae may then be applied to construct a picture of the rock strata at depth. In this manner hidden deep seated structures can be found which may act as suitable traps for oil and gas.

Two basic seismic techniques exists namely- the refraction and reflection methods. In the refraction method, the wave traveling along a boundary between rocks of different elastic properties is utilized, while the reflection method uses the waves reflected from such boundaries. The reflection method is of principal importance, refraction shooting is used primarily as a reconnaissance tool to select areas and obtain interpretative data for the more detailed reflection method.
The difference between the refraction and reflection surveys lies in the distances from shot points to recorders. In refraction shooting spacing of two to eight miles are used while in the reflection technique, spacing is generally less than the depth to the first reflection bed, commonly less than one mile.

The reflection surveys carried out by the Geological Survey of India (GSI) during 1955-57 covered a west to east section of the Cambay basin from Dholera on the west to the Deccan trap outcrops on the eastern side. The Lunej structure at the head of the Gulf; about 12 km north-west of Cambay town was also discovered. This structure was drilled by the O.N.G.C. Ltd. and oil was struck in September, 1958. Subsequently the reflection surveys carried out by the O.N.G.C. Ltd. have covered almost the entire tract of Gujarat extending over some 20,000 sq. km. A detailed account of the seismic surveys in the Cambay basin has been furnished by Sastry (1964). The reflection surveys have also been extended into the off-shore regions of the Gulf of Cambay. As many as seventy structures, some very small, have been discovered so far by these surveys in the inland areas, and 12 in the off-shore area. The Lunej field has turned out to be a gas field while the Ankleshwar, Kalol, Nawagam and Mehsana structures are producing oil and associated gas.

The alluvial formation in the Cambay basin does not exceed 300-500 m. in thickness. The basin is tectonically a graben. The deepest part of the basin is over 5000m to the north of the Narmada River. The anticlinal structures are generally moulded on the Deccan trap basement highs. The reflections below the Trap are not consistent and the depth to the eventual crystalline basement has not been determined in any part of this basin; although in the Cambay field one well was drilled through 1000m of Trap, the basement was not met.

In the sedimentary section, there are three fairly prominent reflecting horizons at the top of the Miocene; the other at most consistent reflection zone is within the Eocene, which is traceable over large areas, both inland and off-shore. The Ankleshwar
structure is an elongated anticline trending east-north-east & west-south-west. The structure at Kosamba, south of Ankleshwar, is a large anticline plunging southwest, but has practically no closure. Some oil and gas have been found in these structures.

5.2 WELL PLANNING
The first step before taking spudding any well is the well planning. Drilling for oil and gas is a highly complex and expensive process that requires strict planning for success. Before the objective of any well plan is to minimize the cost of drilling and maximize the cost of drilling and maximize production and life of well. All aspect of drilling plan like type of rig, drilling days services required etc. are included in the well plan.

5.3 GEO TECHNICAL ORDER (GTO)
Before going to drill an exploratory or developing well a geo technical order (GTO) is prepared. It contains the tentative well programmed which is very important to the geologist working at the site. Geologist can anticipate what is likely to be encountered during drilling viz fresh water sands, high pressure zone, mud loss zones, pay-zones, probable caving etc. and may make certain changes during drilling as per the requirement of core.

The GTO is prepared from the following information.
1. The data acquired from the surface and subsurface exploration.
2. The lithologic, bio-stratigraphy, time units may be incorporated for correlation.
4. Prominent marks, lithological break, coal marker.
5. Possible reservoir rock, cap rock.
6. Their characteristics such as pressure, temperature.
7. Possible oil water/gas oil contacts.
The GTO which is prepared from the above information serves as a guide for drilling and comprises the following information:-

<table>
<thead>
<tr>
<th>General Data</th>
<th>Geological Data</th>
<th>Mud Parameter</th>
<th>Drilling Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Depth</td>
<td>Specific Gravity</td>
<td>Casing Policy and Rise of Cement</td>
</tr>
<tr>
<td>Longitude</td>
<td>Age</td>
<td>Viscosity</td>
<td>Meterage per Bit</td>
</tr>
<tr>
<td>Latitude</td>
<td>Formation</td>
<td>Static Flow Stress</td>
<td>Type of Drilling</td>
</tr>
<tr>
<td>State</td>
<td>Lithology</td>
<td>Sand%</td>
<td>Type and Size of Bit</td>
</tr>
<tr>
<td>Area</td>
<td>Interval of Coring</td>
<td>pH</td>
<td>Weight on Bit</td>
</tr>
<tr>
<td>Projected Depth</td>
<td>Electro-logging</td>
<td>Gel%</td>
<td>RPM of Rotary</td>
</tr>
<tr>
<td>Date of Spudding</td>
<td>Collection of Cuttings</td>
<td>-----</td>
<td>Stand Pipe Pressure</td>
</tr>
<tr>
<td>Well Number</td>
<td>Angle of Dip</td>
<td>-----</td>
<td>Discharge of Pump</td>
</tr>
<tr>
<td>Tentative Seabed</td>
<td>Oil/Gas shows</td>
<td>-----</td>
<td>Linear Size</td>
</tr>
<tr>
<td>Water Depth</td>
<td>Formation Pressure</td>
<td>-----</td>
<td>SPM</td>
</tr>
<tr>
<td>GL</td>
<td>Formation</td>
<td>-----</td>
<td>Rearing of Casing Line</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KB</td>
<td>Mud loss/ Cavings</td>
<td>-----</td>
<td>Remarks</td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>Drilling Time</td>
</tr>
</tbody>
</table>

### 5.4 DRILLING

Drilling is the most important operation in the entire process of exploration and exploitation. It is used to recover the oil and gas deposit from the surface. Oil well drilling is totally different from the domestic well drilling because the oil wells are penetrated upto 5000m depth or even more where the formation pressure becomes so high. Drilling is of two types: -
5.4.1 Drilling components

Various methods have been developed to drill different rock formation. Some of the important methods are
1. Cable tool method.
2. Rotary drilling.
3. Dyna drilling.
4. Directional drilling.
5. Offshore drilling.

Rotary drilling is generally used in onshore petroleum industry. All type of rotary drilling rigs usually has the same major components. These components are as following:-

(a) **Derrick**- To support the weight of the drilling equipment.
(b) **Power Supply System**- To provide power for running all machinery.
(c) **Hoisting System**- To raise or lower the drill string.
(d) **Rotating System**- To rotate the drill string.
(e) **Circulating System**- To circulate fluid down the pipe and throughout the hole.
(f) **Well Control System**- To maintain safety by controlling pressure imbalance in the well.

The following are the important assemblage of a drilling rig which is shown in fig. 5.2.

(I) **Derrick Floor**: - The steel frame tower which supports the tackle system for drilling, the drill pipe/ collar stands and running in and out of tools. The sizes of floor depend upon the capacity of rig.

(II) **Crown Block**: - Sheaves mounted on beams and set on the top of the derrick used for hoisting and lowering of string equipments during drilling.
(III) **Monkey Board:** - The platform in the derrick on which the top man work during running in and out of drill strings.

(IV) **Traveling Block:** - Block with sheaves to which load is connected for hoisting or lowering a drilling operation. It is suspended from the crown block sheaves by steel wire rope as in block and tackle system.

(V) **Swivel:** - A rotary joint under load through which mud is pumped under pressure and heavy rotating drill strings are suspended.

(VI) **Kelly:** - A hollow square / hexagonal stem stacked to the top most drill pipe of the drill string which is rotated by the rotary table during drilling.

(VII) **Draw Works:** - A hoisted which is used for handling drill pipes, casing, tubing and other tools used in drilling. It is usually placed on the derrick floor and wire rope of the crown block is wound on its drum.

(VIII) **Rotary Table:** - A heavy geared circular steel having a hole at its centre into which square or hexagonal hole bushing cab be fixed for engaging and rotating the drill string by Kelly. The table rotates in the horizontal plane and is normally driven by chains / carbon shaft from the draw works

(IX) **Sub-Structure:** - The steel frame work on which the derrick draw works and engines are installed.

(X) **Flow Nipple:** - The Hollow Steel pipe through which the return of mud received in to the channels.

(XI) **Collar:** - An excavator under the derrick designated to accommodate the well head fittings.
(XII) **Blow Out Preventer (B.O.P):** - An equipment to control the sudden outburst of gas, oil or water under high pressure encountered during drilling. It can either completely close the bore holes or close the annulus when drill string is inside the bore hole.

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**Figure 5.2: Drilling Rig and Its Components. (Courtesy: Google.com)**
(XIII) **Cat Head:** - A small spool retreated by the draw works on which a manila steel line is wounded and is used for making up or breaking off the driving drilling equipments on the derrick floor.

(XIV) **Shale Shaker:** - A device on the rig to separate formation cuttings from the drilling and it comes out of the well.

(XV) **Brake Arm:** - The lever which monitors the movement of the draw works driven.

### 5.4.2 Process

During rotary drilling three operations carried out simultaneously are i) a string of drilling pipe rotated with cutting bit; ii) the bit is lowered as the formation drills out and iii) the bit is cooled and lubricated.

The drilling rig is powered by ‘diesel engines’. The essential piece of equipment of a rotary drilling rig is a derrick. The purpose of the derrick is to hold the travelling block assembly which holds the drill pipe. When a trip is made the derrick furnishes a most convenient place to stack the drill pipe vertically. When they are temporarily out of the hole, the depth capacity of drilling rig depend primarily on the size of draw works, which provide hoisting and rotating action, power from engine is transmitted to the draw works, then to the rotary table which rotate the kelly. The top of the kelly is attached to the swivel. Swivel allow the drill string to rotate while drill fluid passed through the crown block down to the draw works, drilling mud is passed through the bit with a jetting action. It assists the bit in cutting the hole. The fluid clean and cool the bit, cutting are carried by it through the annulus from which it passes over the shale shaker which separates the mud from cutting. The cutting goes into the pit and mud is recycled.
As the hole is drilled deeper additional length to the drill pipe is added by tool joints at derrick floor. The choice of the bit is an important factor to carry out drilling smoothly. Mostly diamond and tungsten carbide type of bit are being using in project area.

The rate of penetration depends on type of bit and bit rotation or pump pressure. The diameter of well is not kept always constant through out due to economic factors. The drilling is started with the 20” bit and in each casing diameter is reduced gradually. Finally 12.25” diameter hole drilled up to Cambay Shale and sometime up to Deccan Trap.

5.4.3 Drilling Fluid

The drilling fluid is normally called as mud. The mud is continuously pumped with high pressure into the well through drill pipes. It reaches the bottom of the well and comes out through the jets or nozzles of the bit; from there it takes the cuttings, makes its way (back) upwards through the annular space to the surface. Then it is passed into shale shaker to separate cuttings and other material. Shale Shaker or Vibrating Screen is built of two metal frames inclined at an angle of 12º-18° to the horizontal. A screen is fixed over each frame set on helical springs and resting on a firm footing. The screen is made of stainless wire. Generally 12-16 mesh screens are used. The frames are fixed with shaft. The vibration of screen destroys the thixotropic structure of the mud. Before going to shale shaker, the mud goes to gas separator, where the gas coming with mud is separated. Other items included in the fluid circulating systems are the de-sanders and de-silters. These are vortex cones which centrifugally removes undesirable materials that are fine enough to pass through the screen on the shale shaker.

After this, mud cleaner cleans the mud (remove clay size particle) and then passes it to the agitator or storage tank. In the storage tank barite powder, bentonite clay or
mica etc. are added to mud to increase its density, viscosity etc. and then again goes to well and the process is continuously run during drilling.

In this system, liner is placed. The liner is comprised of two valves. Through one valve the mud is sent in to the well, while through the other valve, the mud comes out from the well. It works as a piston. At a time only one valve is opened. This is Mud Circulation System (Fig. 5.3).

Figure 5.3: Mudflow System (Courtesy: O.N.G.C. Ltd., Ankleshwar, Gujarat)
5.4.3.1 Functions of Drilling Fluids

The important functions of drilling fluid (mud) are as following:

(I) To clean the bottom of the hole, remove the cuttings and carry them to surface.
(II) To cool and lubricate the drill bit and string.
(III) To plaster the wall with mud cake and preventing the hole from caving.
(IV) To hold the cuttings and weight material in suspension while circulation is stopped.
(V) To support the weight of drill pipes and casing.
(VI) To transmit hydraulic horse power to the bit,
(VII) To acts as a medium of electrical well logging.
(VIII) To ensure the maximum information about the formation penetrated.
(IX) Preventing corrosion of drill pipe.

5.4.3.2 Composition of Drilling Fluid

Main components of drilling fluid are as following:

(a) Liquid Base: Water or oil.
(b) Colloidal Particles: It is used for a sedimentation stability of the system due to its transformation into a gel and also capable of plugging up pores and fine fractures in rocks.
(c) Weighting Material: To ensure pre assigned density of the fluid.
(d) Chemical Reagents: To regulate physico-mechanical chemical protecting adverse effect of environments.
(e) Miscellaneous: Act as thinners, lost circulation materials, calcium removers, corrosion inhibitors, defoamers, emulsifiers etc.

5.4.4 MUD LOGGING

One of the most important problems encountered during drilling for hydrocarbons is the determination of fluid content of the porous formation opened by the bit, so that no oil or gas formations are overlooked. Geologging often referred to as mud logging
in oil industry is a continuous monitoring system of the various parameters, like drilling rate, absence and type of gas in the mud system, mud loss/gain, examination of the drill cuttings, cores etc. for detecting presence or absence of hydrocarbons. The principal application of the geologging has been in drilling of wild cat or exploratory wells, where there is very little or no geological control. However the mud logging is helpful in gaining reliable qualitative information on the occurrence of hydrocarbons and this in connection with logging and interpretation derived from that, helps in giving more positive information about fluid contents of formations penetrated.

**Principle**-
During drilling, mud is continuously pumped through the drill pipe to the bottom and out through the bit. It is then come back to the surface through annulus. While comes upto the surface it carries the cuttings and other drilled material. The mud is normally passed over a shale shaker where cuttings are separated. The chips are washed thoroughly and carried for further studies by the well site geologist. The studies are as follows: -

(I) Evaluates the formation penetrated and the hydrocarbons shows encountered.

(II) Determination of subsurface contacts, lithological units for using the data on subsurface mappings.

(III) Determination of physical characteristics of the sediments.

(IV) Interpretation of stratigraphy for using local and regional problems in sedimentology, structure, hydrocarbons accumulation.

**5.4.5 Well logging**
Well logging operating are generally carried out in wells of all, either a wildcat well, exploratory, developing or producing well to know the various parameters of the well. Logging offers a way of gathering information's needed for both economic analysis and production planning. The geologist used to know the stratigraphy of the formation, the structural and sedimentary features and the mineralogy of the formation. The geo-physicist needs to know and to relate seismic references to
specific horizons encountered in the drill section. The reservoir engineer needs to know the vertical and lateral extents of the reservoir, its porosity (type), permeability, the fluid content and its recoverability.

Logs provide either a direct measurement or indication of porosity both primary and secondary, permeability (to some extent), water saturation and hydrocarbon mobility, hydrocarbon type (oil and gas condensate), lithology, formation dip and structure, sedimentary environment, travel time of elastic wave in the formation.

Logging techniques in cased holes can provide much of the data which needs to monitor primary production and also to gauge the applicability of water flooding and monitor its progress when installed. In producing wells logging can provide measurement of flow rates, fluid type, pressure temperature, oil &/or gas saturation, points of fluid entry. Simply say logging when properly applied, can answer many questions ranging from basin geology to economics.

**5.4.6. WELL COMPLETION**

When drilling is completed, a well is prepared and filled with control equipments so that the well may safely produced oil/gas. This operation is known as well completion.

The well completion is the most important operational phase in the life of a well. This is the only way of communication with reservoirs. The effectiveness of communication with reservoir is main factor which control the reservoir drainage and economic life of well. The well completion involve the perforation of casing, well testing and activation of well through work over job.
5.4.6.1 DRILL STEM TEST

The drill stem test is used primarily to determine the fluids present in a particular formation and at the rate which they can be produced. The test is done in a bore hole filled with drilling mud. Pressure exerted by the drilling mud in the well prevents flowing out of fluid from the reservoir rock into the well. The drill stem has two expandable devices, called packers around it. The drilling stem is lowered into the well until one packer is just above the formation to be tested and other below. The packers are then expended to close the well above and below the formation. Sealing the well around the formation eliminates the pressure exerted by drilling mud on the formation. Water, gas or oil can flow out of the formation and in to the well. A trap door is opened on the drill stem and the formation fluids flow into and up the drill step (Fig. 5.4).

![Figure 5.4: A Drill Stem Test. (Courtesy: Hyne, 1984)](image)

5.4.6.2 CASING AND CEMENTATION

The first step in completing the hole is Casing. Casing is steel pipe that runs down the hole (Fig. 5.5). Cement (slurry) is then pumped between the casing and sides of the well. Casing has three purposes. It stabilizes the well and prevents the sides from caving into the well. Casing protects fresh water aquifers that are often found near the surface. Casing seals off these reservoirs from pollution by mud during drilling and
also petroleum during production. The casing also prevents the petroleum from being diluted by water from other formations during production. In completion of wells four types of casing are used. The size of casing and bit are as follows and as shown in fig 5.6 and 5.7.
(I) Production casing - casing size = 5.5 inch; bit size = 8.5 inch
(II) Intermediate casing – casing size = 9.62 inch; bit size = 12.25 inch
(III) Conductor casing – casing size = 13.62 inch; bit size = 17.5 inch
(IV) Surface casing – casing size = 18.62 inch; bit size = 26 inch.

Several items like guide shoe, float collar, centralizers and scratchers etc. are required. Guide shoe allows the movement of the casing tube down the hole and it is attached to the first joint of the casing. After running the joint halfway through the floor a centralizer is added (Fig. 5.8 A) and after running through full floor length another centralizer is added. Like this there may be 3 or 4 centralizers added to the drill string. Float collar is placed at a much higher height than the shoe and contains one way valve. The valve allows the casing to float down the hole so that the drilling fluid is prohibited entering the casing. After running the casing in the hole, filling fluid is essential to counter the buoyant effect and prevent damages caused by hydraulic pressure. Drill string often bounces while cutting hard rock. This causes damage to drill bit and drill string. To prevent such damages shock are kept on the drill bit. This absorbs all the shocks over this a drill collar is placed. Stabilizers are placed at 2 or 3 places at a distance of 30 fit, centralizers and scratchers (Fig. 5.8 A & B) help in holding the casing away from the wall of the hole and abrades the mud when the casing tube is reciprocated. This procedure ensures proper distribution of cement around the pipe facilitating good bonding among pipe, cement and formation.

Figure 5.8: (A) Centraliser & (B) Scratcher
(Courtesy: Hyne, 1984)
The cementing procedure also varies depending on the depth of the well. This informs the number of stages required for filling the annular space between casing and hole. The volume of cement to be pumped is calculated to ensure the filing of the annular. When the cement has set, the drill pipe can be run back and deepening of the hole can take place as usual.

Surface casing extends from the surface to 200 to 1500 feet deep depending on the area. It protects fresh water aquifers and prevents loose surface rock from caving into the well. Surface casing has a large diameter, for example, 13.62 inch outside diameter (OD). Intermediate casing is used to seal off problem formation such as salt or abnormal high pressure zones. It has a smaller diameter, for example, 8.62 inch OD. Production casing or oil string is run down to the producing formation. It has a smallest diameter, for example, 5.5 inch OD. The total length of a particular type of casing is called as string. A large diameter bit is used to drill the near surface portion of the well. After the surface casing string is run into the well, a small diameter bit is used to drill the next portion of the well. The well bore and casing become progressively are smaller with depth.

If the well bottoms out in the producing formation, a open hole completion can be used (Fig.5.9). The well is cased down to the top of the producing formation and left open below that. If the reservoir is loose sand, a screen, gravel pack or slotted liner is often put on the bottom of a well to prevent the well from becoming clogged. A cased well can also be completed with perforations (Fig. 5.10 A & B). Multiple completions on several reservoir rocks in a same well are done by perforations (Fig. 5.11). The casing is run down the length of the well and a casing shoe closes off the bottom. A perforating gun is lowered into the well until adjacent to the reservoir rocks. The gun has either bullets or shaped explosive charges that are detonated to blow holes (perforations) in the casing, cement and reservoir rocks (Fig. 5.12). This makes a very clean system; only fluids from the reservoir rock can flow into the well.
Figure 5.9: Open Hole Completion. 
(Courtesy: Hyne, 1984)

Figure 5.10: (A) & (B) Cased Hole Completions. 
(Courtesy: O.N.G.C. Ltd., Ankleshwar, Gujarat)
Figure 5.11: Multiple Completion. (Courtesy: O.N.G.C. Ltd., Ankleshwar, Gujarat)

Figure 5.12: Perforating Operation. (Courtesy: O.N.G.C. Ltd., Ankleshwar, Gujarat)
5.4.6.3 TUBING

Small diameter pipe called tubing is run into the well to conduct the petroleum to the surface. Tubing ranges from 1.25 to 4.5 inches in diameter. It is suspended in the well from the surface down to just above the bottom. The pressure on oil in many reservoir rocks is enough to force the oil into the well but not to the surface. A pump is usually suspended in the well from the bottom of the tubing.

5.4.6.4 SURFACE COMPLETION

In most oil wells, the oil has to be pumped to the surface through the tubing. The pumping unit (Fig. 5.13) is powered by an engine or prime mover that is usually electrical or diesel operated. The engine causes the walking beam to pivot up and down. As the end of the walking beam is raised and lowered a sucker rod is raised and lowered in the well. The sucker rod operates the pump at the bottom of the well. The oil or gas from the formation come and raises in tubing and goes to separator. Here oil and gas from the formation are separated out and oil is collected in tanks.

Figure 5.13: A Surface Pumping Unit. (*Courtesy: Hyne, 1984*)
5.4.6.5 ACTIVATION OF WELL

After a well is perforated, it is activated to include flow of formation fluid into the well. The activation of well can be done by following method such as;

(a) Swabbing

(b) Injection of compressed air or mixture of water and air down the annular.

(c) Injection of nitrogen gas at high pressure down to the annular.

5.4.6.6 TESTING

After the well has been completed, a potential test can be run. This test will show the maximum gas and oil potential that the well can produce in a 24 hours period.

A Productivity test is run to determine the effect of different production rates on pressures in the reservoir rocks. This is done by measuring the fluid pressure at the bottom of the well when it is not producing and then at several different rates of production. The test is used to calculate the maximum production rate of a well without damaging the reservoir.

5.4.6.7 DEVELOPING OF FIELD

It is well known that for the development of oil field, the drilling of development wells is necessary. For optimum number of wells, the following criteria has been used:

(a) There should be minimum interference between the wells.

(b) The wells should be spaced in such a manner that they could be utilized in future for pressure maintenance or for enhanced oil recovery.

(c) The wells should be placed considering the isopay map, at the place where effective thickness is good and well may produce so much oil as to recover its cost etc.

Oil well spacing is often either 10, 20, 40 or 160 acres. Gas well spacing is often 160, 320 or 640 acres. A well spacing of 40 acres means that only one can be located on each forty acres of surface above the field.
5.5 DRILLING PROBLEM AND WORK OVER

During the drilling, casing, well completion or when the well is flowing, several problems may arise which will be overcome by the work over. The following problems have been solved:

If a tool is lost or the drill string breaks, the obstruction in the well is called as junk or fish. Special grabbing tools are used to retrieve the junk in a process, called Fishing (Fig. 5.14). In extreme cases explosives can be used to blow up the junk and then the pieces can be retrieved with a magnet.

Some reservoir rocks can be damaged by forcing drilling mud into them. This can be caused by using too heavy an overbalance while drilling. The drilling mud clogs the pores or causes chemical or physical changes in rock. This decreases the rock’s permeability near the well bore. Formation damage prevents or reduces production from the reservoir rock when the well is completed.

Lost circulation occurs when a very porous and permeable formation is encountered in the subsurface. The drilling mud flows into the formation without building up a filter cake (Fig. 5.15). During lost circulation, more mud is being pumped down the well than is flowing back up. The level of mud in the mud pits falls and a float senses that there is a lost circulation problem.
To solve these problems, fine grained fibrous materials such as mica flakes, ground pecan hulls, sugarcane hulls, shredded cellophane, and even shredded paper money pumped down into the well. The material got into the pores spaces of the lost circulation formation and swelled up, closing off the formation and solves the lost circulation problem.

An unexpected abnormally high temperature in the subsurface can cause a blow out. The overbalance is lost and the fluids flow out of the subsurface rocks into the well, is called as ‘kick’. As the water, gas, or oil flows into the well, it mixes with the drilling mud, causing it to become even lighter and exert less pressure on the bottom of the well. The diluted drilling mud is called gas cut, salt-water cut or oil cut. The blows out preventers are immediately thrown to close the hole. The kick can be dangerous if it is caused by flammable natural gas or poisonous hydrogen sulphide gas. Sometimes the blowout occurs so fast that the drillers do not time to throw the blowout preventers and the result are disastrous. Slides and cables are located on the rig to evacuate the crew in such an emergency. If the blowout preventers are thrown in time, heavier drilling mud is pumped into the well through choke manifold to circulate the kick out. Abnormally high pressure is caused by the compaction of sediments.

Figure 5.15: Lost Circulation caused by drilling mud flowing into a porous and permeable rock layer without building up a filter cake.
(Courtesy: Hyne, 1984)
A kick and possible blowout is detected by several different methods during drilling. As subsurface fluids enter the well during the kick, more fluids will be flowing out of the well than are circulating into the well. The sudden increase of fluid flow out of the well or rise of fluid level in the mud pit is detected by instruments. The drilling mud can also be continuously monitored for sudden changes in weight, temperature or electrical resistivity that would indicate the mud being cut by subsurface fluids. Another method is based on the principle that shale should become dense and less porous with depth as it is compacted. The density and porosity of shale can be determined from both well cuttings and well logs. If the shale density increases and porosity decreases are less than predicted from computations based on normal conditions, abnormally high pressure can be expected.

A blow out can also be caused by raising the drilling string out of the well. The drill string displaces a volume of drilling mud in the well. As the drill string is raised, the level of drilling mud falls in the well and the pressure is increased in the well, overbalance could be lost and a blow out could occur.

5.6 PRODUCTION AND TRANSPORTATION
After casing and perforation due to the natural forces the well flows by its own and in course of time the forces are decreases and the rate of production also decreases. The following methods are used for further production.

(A) SELF FLOW WELL
During first phase the well flow on its own, due to the forces that exist in the reservoir. These self flow wells are of only gas wells or oil-gas wells, known as Christmas Tree (Fig.5.16). The production rate of these well are generally decreases with time due to declining of reservoir forces. The production is so adjusted that the time period of production is maintained to certain period after that the well needs to be produced by an Artificial lift.
ARTIFICIAL LIFT:

After the first phase of production i.e. self flow stage the pressure of the reservoir decreases so you have to exert certain pressure to produce oil. There are two types of mechanism which are employed.

(I) SUCKER ROD PUMP (SRP):-

Sucker rod pump is similar to the domestic ground water pump. In this method, a pump is connected to a rigid rod is lowered down the tubing to the bottom. Sucker rod pumps are recovering oil in Gandhar area (Fig. 5.17).

(II) SCREW TYPE:-

In this type a long rotating rod with blades is fitted into the well. Due to the rotation the blades lift the oil from depths and the well contains one or more pumps at different levels to lift the oil.
5.7 COLLECTION OF OIL AND GAS FROM THE WELL
Oil and gas are produced from the well and are transported through the pipe lines and road tankers. Oil and gas collected at well itself or collected at those place where number of wells are gathered at centrally located unit called Group Gathering Station. The essential features of production installation are mentioned below.

(A) WELL HEAD INSTALLATION
A well head installation handle about 30-40 tonnes of oil per day, produced from one well. The installation consists of an oil and gas separator and water both. Oil is separated and collected in horizontal tank and transported by road tankers.

(B) GROUP GATHERING STATION
This is centrally located unit where flow line from various productions well is connected to the manifold platform. In this unit oil, water and gas are separated individually and different separators separate the gas from crude oil. This crude oil is
further pumped down to central tank form. There are several group gathering stations in Gandhar oil field (Fig. 5.18).

(C) CENTRAL TANK FORM

This is the storage unit for crude oil received from different GGS. The capacity of storage tank in the unit is over 1000 cubic meter. The oil and gas are totally separated from each other. The oil is then stored at central tank form and pumped through pipeline to the refinery and gas is sent gas collecting stations.

Central tank form unit is situated in Gandhar oilfield (Fig. 5.19). The working flow chart from CTF is shown in Fig. 5.20 a & b.
CENTRAL TANK FORM

SCHEMATIC LAYOUT OF GAS HANDLING

0.5 Atmospheric gas → 6 Atm. → 16 Atm. → 26 Atm. → LPG
1st stage compression → IInd stage compression → IIIrd stage compression → Plant

6 Atm. field gas → Separator

16 Atm. field gas → Separator

20 Atm. field gas → Separator

Figure 5.20a: Flow Chart of Central Tank Form of Gas Handling. (Courtesy: O.N.G.C. Ltd., Ankleshwar, Gujarat)

SCHEMATIC LAYOUT OF OIL HANDLING

Field Oil from GGS → Horizontal Separator → 0.5 Atm. gas to compress. → 1st Wash Tank 5000 m³ → Oil / Water

Intermediated Tank 2000m³ → Intermediate Tank 2000m³

Oil for Vadodara Refinery → Storage Tank 800m³ → IInd Wash Tank 2000m³

IIIrd Wash Tank 2000m³ → Effluent to Sea

Figure 5.20b: Flow Chart of Central Tank Form of Oil Handling. (Courtesy: O.N.G.C. Ltd., Ankleshwar, Gujarat)
GAS COLLECTION STATION

Gas collection station called LPG plant. It is situated near the central tank at Gandhar. Gas is soluble in oil and separated from pressure. Some reservoirs have dry gas or free gas with high pressure. The high pressure gas obtained from gas well collected at gas collecting stations. The gas is passed through separators to separate gas and condensate, the later is piped to storage tank where as gas at high pressure (40-60/cm²) is sent down pipe line to consumers (Fig. 5.21). The gas consists of 80-90% of methane which is highly inflammable.

ENHANCE OIL RECOVERY

When natural driving forces are declined, these leaves a considerable amount of oil in reservoir, to recover this amount of oil secondary methods are adopted which is called enhance oil recovery. Water injection and gas injection is most important enhanced oil recovery methods which are used in Gandhar area. The EOR methods are of following types:-

GAS INJECTION

Gas injection is the commonly used technique for secondary recovery of oil. In this case carbon dioxide and nitrogen etc. gases are injected into the well with high
pressure. This gas tends to come out along with oil. Nitrogen and liquid nitrogen gas injection wells are recovering the oil from Gandhar area. Gas injectivity in Gandhar well no. 94 in GS4 sand has been tested in November 1990.

(b) WATER INJECTION
Water Injection is the most important method for injection of well. In this case, water is injected below the oil water contact. The injectivity of well depends upon the permeability of the formation. The injecting water sweeps the remaining oil through the reservoir to the producing well.

(c) WATER ALTERNATE GAS (WAG)
Water Alternate Gas is used first in Gandhar offshore field. WAG is introduced in reservoir zone (Fig. 5.22). In reservoir zone, water and gas are injected alternatively. In place of carbon Dioxide, 98% methane gas is injected.

(d) POLYMER FLOODING
Conventional water flooding can often be improved by the addition of polymers to injection water (Fig. 5.23) to improve (decrease) the mobility ratio between the injected and in place fluids. The polymer solution affects the relative flow rates of oil and water sweeps a large fraction of the reservoir than water alone, thus containing more of the oil and moving it to production wells. Polymers currently in use, are produced both synthetically (poly cryl-amides) and biologically (poly-saccharides).
Figure 5.22: Water and Gas Injection and Production of Oil. 
(Courtesy: O.N.G.C. Ltd., Ankleshwar, Gujarat)

Figure 5.23: Polymer Flooding. 
(Courtesy: Sahay, 1994)
e) **SURFACTANT FLOODING**

Surfactant flooding (Fig. 5.24) is a multiple slug process involving the addition of surface active chemicals to water. These chemicals reduce the capillary forces that trap the oil in the pores of the rock. The surfactant slug displaces the majority of the oil from the reservoir volume contacted, forming a flowing oil/water bank that is propagated ahead of the surfactant slug. The principle factors that influence the surfactant slug design are interfacial properties, slug mobility in relation to the mobility of the oil/water bank, the persistence of acceptable slug properties and integrity in the reservoir and cost.

![Diagram of Surfactant Flooding](image)

**Figure 5.24: Surfactant Flooding.**
*(Courtesy: Sahay, 1994)*
ALKALINE FLOODING

Alkaline flooding (Fig. 5.25) adds inorganic alkaline chemicals such as sodium hydroxide, sodium carbonate or sodium orthosilicate to flood water to enhance oil recovery by one or more of the following mechanisms—interfacial tension reduction, spontaneous emulsification, or wettability alteration. These mechanisms rely on the in situ formation of surfactant during the neutralization of petroleum acids in the crude oil by the alkaline chemicals in the displacing fluids. Since the content of natural petroleum acids is normally higher in lower API gravity crude oils, this process seems to be applicable primarily to the recovery of moderately viscous, low API gravity, naphthenic crude oils.

Figure 5.25: Alkaline Flooding.
(Courtesy: Sahay, 1994)
(g) ALKALINE-SURFACTANT POLYMER FLOODING (ASPF)

An important method to increase the recovery of reservoirs is ASP flooding to lower the IFT (interfacial tension) between the crude oil and displacing fluid to an ultra low value to increase the displacement efficiency and at the same time to increase the viscosity of the displacing fluid in order to increase the volumetric sweep efficiency. Therefore, natural gas is added to the ASP fluid to form ASP foam (ASPF) displacing fluid. This ASPF fluid should have the characteristics of an ultra low IFT. High displacement efficiency and also low mobility should increase the volumetric sweep efficiency also.

(h) MICROBIAL ENHANCE OIL RECOVERY (MEOR)

The microbes are cultured artificially. Crude oil has different contents of materials. These materials are settled in the reservoir zone and chock the reservoir rock so the migration of oil is slow. To clean the reservoir rocks, microbes are injected in the reservoir rocks. These microbes eat the unwanted material and clean the reservoir rocks and the flow of oil takes place freely. This is microbial enhance oil recovery. The microbes are alive at 60°C, but by some technique it is increased up to 90°C. It decreases the interfacial tension, viscosity of oil and improves permeability of rocks.

(i) DOWN HOLE OIL WATER SEPARATOR

Downhole oil water separation (DOWS) separates oil and gas from produced water at the bottom of the well and re-inject some of the produced water into another formation or another horizon within the same formation, while the gas and oil are pumped to the surface.
(j) **IN-SITU COMBUSTION**

In-situ combustion is normally applied to reservoir containing low gravity oil. Heat is generated within reservoir by injecting and burning part of the crude oil. This reduces the oil viscosity and partial vaporizes the oil in place. The oil is driven forward by a combination of steam, hot water and gas drive. The relatively small portions of the oil that remains after these displacements mechanism have acted become the fuel for the in-situ combustion process. Production is obtained from well offsetting the injection locations. In some applications, the efficiency of the total in-situ combustion operation can be improved by alternating water and air injection (Fig. 5.26). The injected water tends to improve the utilization of heat by transferring heat from the rock behind the combustion zone to the rock immediately ahead of combustion zone.

![Figure 5.26: Wet In-Situ Combustion.](https://example.com/figure526)

*(Courtesy: Sahay, 1994)*