Chapter 10
Water Well Drilling, Well Construction and Well Development

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1 Introduction

Special ability of exploration and exploitation of resources available in nature is the key to the advancement of mankind. Though some of the resources are readily available in the surroundings, some of the resources are hidden; hence they need some devices and means to reach them.

Groundwater resource available beneath earth surface is excavated by mechanically powered equipment referred as Drilling Rig. Huge numbers of tube wells are drilled every year for irrigation, drinking water and also to meet industrial requirements. The type of well to be constructed depends on the (a) geological formation of the area, (b) intended use of the well, and (c) available financial resources.

2 Activities

Wells are drilled either for exploration or for exploitation. The object of exploratory well is to collect information of the hydro-geology of the underground aquifer or aquifer system. Apart from information gathered about geological layers encountered during exploratory drilling, the physical properties of aquifer are commonly assessed by conducting various tests.

Exploration of groundwater consists mainly of three steps: (a) site selection, (b) test drilling, and (c) bore hole logging.

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2.1 Site Selection

It is made by various hydro-geological and geo-physical studies followed by synthesis of data obtained from those studies.

Hydro-geological studies are mainly based on historical data of the area, hydro-geological information obtained from any government, non-government or local agencies, study of topography of the area etc. In some cases, if required, bail test or slug test are conducted. Bail test involves the instantaneous removal of measured volume of water from a borehole/dugwell followed by time measurement of water level recovery. A slugtest involves the injection of a measured volume of water into a borehole/dug well followed by time monitoring of the water level decay.

Geo-physical studies involve measurement of basic physical parameters to infer sub-surface condition. Many geo-physical techniques developed for oil exploration have also been adopted in groundwater exploration. Most common techniques (Dellur 1998) are:

(i) Electrical Resistivity: This technique is applied to determine depth to layer boundaries, fresh/saline water interface, and availability of water in fractures.
(ii) Seismic Refraction: This technique is used to determine depth to water table, number and depth of layer boundaries and bedrock.
(iii) Gravity: This technique is used to determine relative depth to bedrock and thickness of alluvium within an area

Thermal survey is useful to map high permeability zones for well location. This method is also helpful to identify area of shallow concealed bedrock and fault barriers.

Any one of the above technique or combination of more than one technique can be used to obtain adequate sub-surface information as a guiding factor for selection of site.

Synthesis of data is an important factor where soft skill is required. In this process, all information generated from various surveys and all results obtained from different tests are compiled. Now it is the responsibility of the concern scientist/engineer to derive a conceptual hydro-geological model that best fits the observed data.

From static water level measurement and historical well records, an idea can be drawn about the number and type of aquifers. From static water level and depth of various boundaries, aquifer thickness can be estimated. The investigator scientist/engineer must have some confidence on his predictions. Confidence level builds up with experience and number of success as well as failure studies.

2.2 Test Drilling

It is the method to obtain most authentic sub-surface information. There is a basic difference between test well drilling and production well drilling. The objective of test well drilling is basically to obtain sub-surface information to determine casing policy and design a production well. On the basis of the promising result, the test wells are often converted to a production well adopting necessary production well completion method.

Cable Tool drilling method is the best method to obtain most authentic formation samples. But this is very slow method as well as cost intensive. The test bore hole is usually a small diameter hole to reduce cost, but at the same time the hole-diameter must be large enough to conduct geo-physical logging wherever necessary.

In case of consolidated hard rock formations, the rock itself acts as a conduit and retains the bore hole. Only the top soil is cased by suitable pipe to prevent collapsing. In unconsolidated alluvium formation surface casing is used up to certain depth depending upon the looseness of the formation. Below that depth hydrostatic pressure of the drilling fluid filled in the bore hole maintains the bore hole and prevents from collapsing. As per Pascal's law hydrostatic pressure in the bore hole is directly proportional to the depth (Eq. 10.1).

$$P = h\rho g \tag{10.1}$$

where P = hydrostatic pressure at particular depth, h = depth, ρ = density of drilling fluid, g = acceleration due to gravity.

In case of unconsolidated boulder formation cable tool drilling is adopted and entire bore hole is cased to prevent the bore hole from collapsing. In such cases normal electrical logging is not possible and gamma-ray logging is recommended for such cased wells.

2.3 Logging

It is a very common word in drilling industry which means measurement of any parameter in respect of depth. In any test well, mainly three types of loggings are carried out to gather maximum information of the aquifer. They are: (i) litho-logical logging, (ii) time logging, and (iii) geo-physical logging.

(i) **Litho-logical logging:** We have already discussed about sampling of bore hole cuttings while test drilling. Tabulation of physical properties like colour, grain size, formation material of sample cuttings chronologically in respect of depth gives an ideal lithological log. From lithological log characteristics of aquifer is predicted.

(ii) **Time logging:** This is basically the measurement of rate of penetration in respect of depth at the time of test drilling. In usual practice time consumed for drilling every 3 m is monitored. In case any change in geology is observed during drilling, the frequency of measurement can be increased. From time log, depth-wise relative compactness of the formation can be judged. It is commonly found that availability of formation water is inversely proportional to its compactness. Alternately loose formation can contribute more water. So, time log is an important input towards first hand estimation of water availability.

(iii) Geo-physical loggings are sub-surface studies after completion of test well. Common geo-physical loggings in groundwater exploration are (a) electrical logging and (b) gamma-ray logging.

(a) Electrical logging: This logging refers to record of apparent resistivity of underground formations and spontaneous potential generated in bore holes. Both are plotted in respect of depth below ground surface. Electrical logging equipment can be a simple hand operated arrangement or it can be a truck mounted power driven equipment. Usually beyond 300 m depth, cable weight becomes so high that some mechanical device is required. Interpretation of electrical logging data is influenced by diameter of the bore hole, porosity of formation, amount of dissolved mud in the bore hole and mainly by the chemical quality of ground water. Resistivity of the formation inversely varies with the dissolved solid content in the formation water, for example, water with 600 mg/L dissolved solids will show half the resistivity than the water with 300 mg/L dissolved solids. A typical electrical logging arrangement is shown in Fig. 10.1.

(b) Gamma-Ray logging: Gamma-Ray logging is based on measurement of natural radiation of gamma-rays from certain radioactive elements that occur in sub-surface formations. Gamma-ray log is a diagram showing relative emission of gamma-rays (Fig. 10.1). The rays are measured in count per second and plotted against depth. The resulting curve is similar in appearance to the resistivity curve of an electric log. But probe and detecting devices are different in gamma-ray logging and suitable counter is used as down the hole sensing unit. At ground the counter is calibrated to convert electric pulses per second received from the probe into voltage. The voltage is continuously recorded on a film as the probe is pulled up the hole. Unlike electrical logging, gamma-ray logging is not influenced by the chemical quality of water. So gamma-ray logging can identify thickness of different formations. Gamma-ray logging can be conducted in both cased as well as uncased wells.

3 Drilling Methods

Groundwater is in use since pre-historic time. Springs were the easily available source around which habitations developed. Subsequently dug wells were drilled in river-bed to excavate groundwater. Bucket and pulley arrangement to lift water from dug wells was developed in China. It is also believed that percussion drilling originated in China. In modern era it is recorded that a well was drilled in Paris in 1842. The first oil well was drilled in USA in 1859. Now a days drilling technology has developed to a large extent and it is possible to drill through any geological formation and up to any depth within the outer crust of the earth surface.

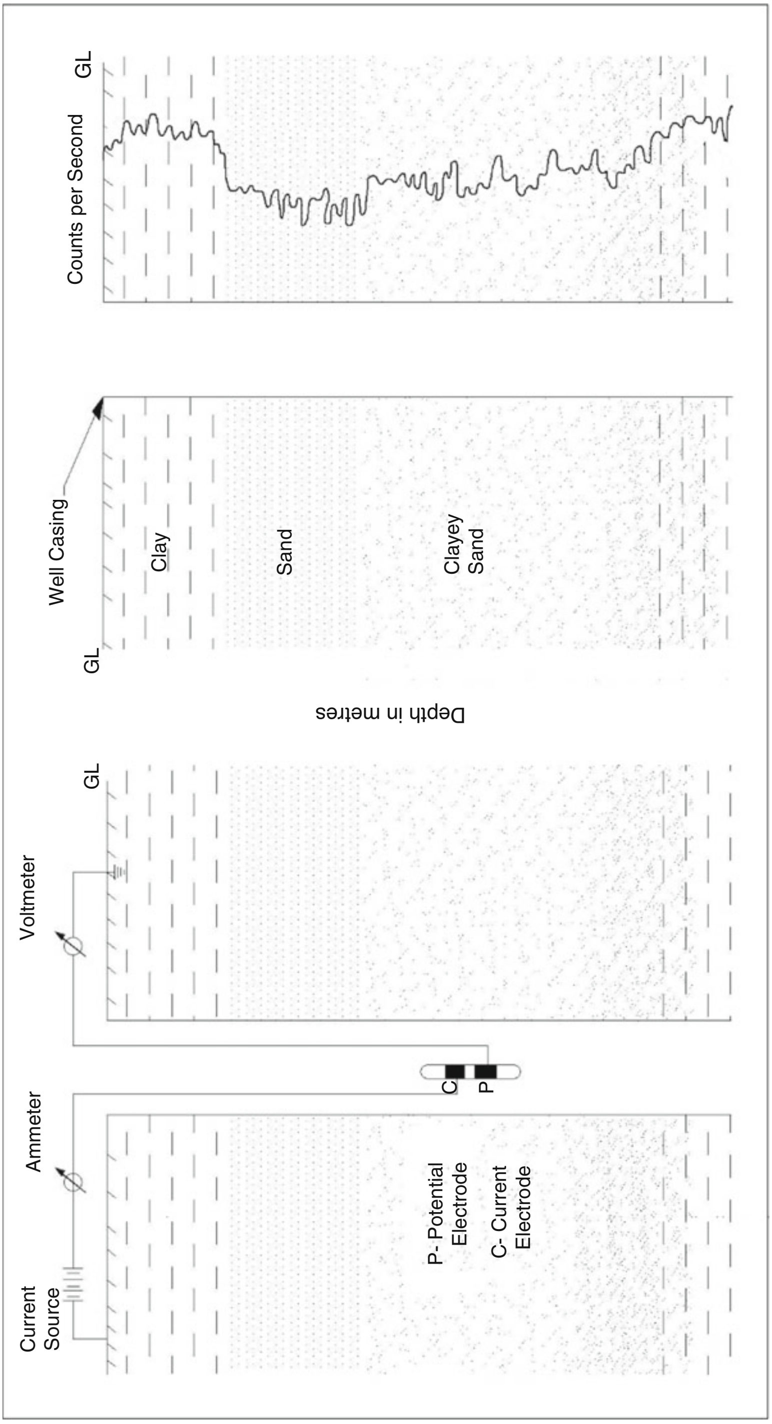

Fig. 10.1 A typical electrical log and a gamma log. (Adopted from CBPI, 1978)

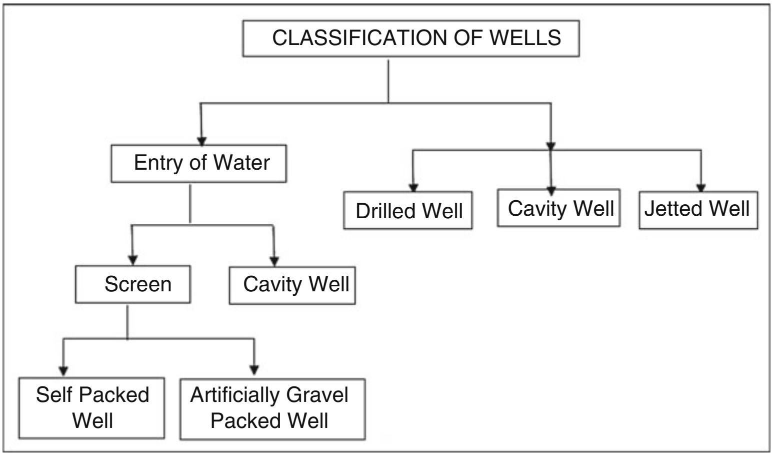

Fig. 10.2 Broad classification of water wells

3.1 Water Well

Water well is broadly a structure to extract groundwater but water wells are also used for water level monitoring purpose, domestic or stock use, community water supply, irrigation purpose, industrial purpose, injection purpose and dewatering in mines or construction site. Water wells can be classified on the basis of different parameters (Fig. 10.2).

In screen well a filtering device is provided in the intake portion of the well in unconsolidated or semi-consolidated aquifer which prevents in-rush of formation material in the well. Screen wells can be either artificially gravel-packed or self-packed. To prevent entering of finer particles of aquifer material in the tube well assembly, the annular space between drilled hole and tube well assembly is filled with coarse sand or gravel. These filler materials are smooth, uniform, clean, well-rounded and siliceous. Size of gravel is designed depending on average grain size of the aquifer material. In case average grain size of formation material is adequately large (>2 mm), no artificial packing is required. Larger particles of the aquifer material act as an envelope around the screen to prevent in-rush of finer particles of the aquifer material.

A cavity well is constructed by making an inner skin and an outer skin separated by a cavity. Both inner and outer skins are usually made out of brick or stone structures.

Drilled wells are those where formation material is cut or crushed manually or mechanically and cutting materials are taken out by some means to construct a well. Various methods of drilling and removal of cutting will be discussed in subsequent paragraphs. Drilled wells can be of any size and depth.

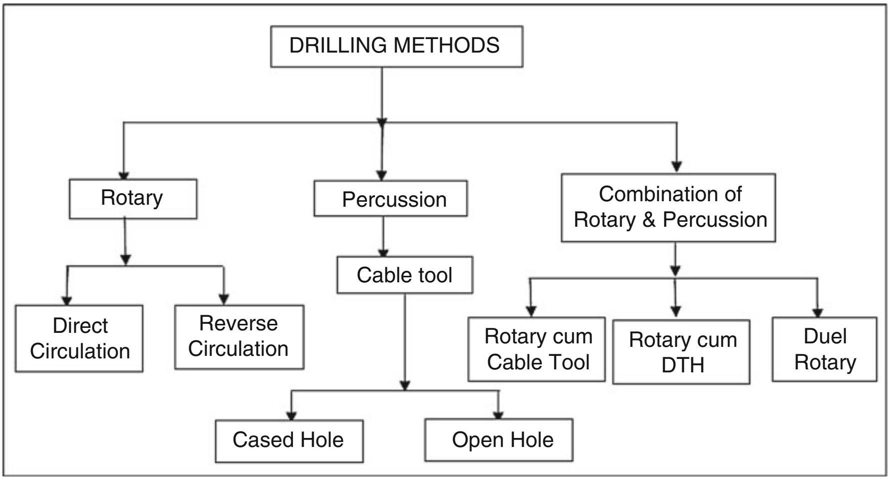

Fig. 10.3 Different types of drilling methods

Driven wells are suitable for unconsolidated sandy formations. Diameter and depth of driven wells are limited. Maximum 15 m can be driven mechanically by using very heavy hammer of 450 kg. In driven well, a hard conical shape metal is used to drive casing pipe. Casing pipe is used to protect well screen during driving. Once the screen is placed to the desired depth, the outer casing pipe can be unscrewed and removed.

Jetted wells are also suitable for unconsolidated formations. A 3–4 inch diameter borehole up to a depth of 50 m can be drilled by jetting method. A chisel-shaped bit is attached at the bottom of the drill pipe. Two nozzles are fitted on either side of the chisel. High pressure water is pumped through the drilled pipe which produces a jetting action through nozzle on the formation material. Cutting material comes out from the bore-hole along with the return flow of water.

Water wells can be drilled by different methods (Fig. 10.3) depending upon the following factors:

(a) Sub-surface geological formation to be encountered
(b) Expected yield from the well
(c) Size of well (depth as well as diameter)
(d) Accessibility of drilling machine and accessories.
(e) Available financial resource.

3.2 Rotary Drilling

In rotary drilling method, rotation is given to the bit attached at the bottom of the drill-string for cutting or crushing the formation material. Rotation is given to the bit either by means of Mechanical Rotary Table or Hydraulic Top-head Drive. Formation material is crushed or cut under heavy down pressure. Weight of the drill-string gives the required feed force to the bit. In top head drive rigs, weight can also be applied by hydraulic feed system. In rotary drilling, drilling fluid is used to remove the cutting materials with progress of bit in the bore-hole. Different types of drilling fluids are used in water well industry. The major types of drilling fluids are: (a) dry air, (b) clean water, (c) water with clay additive, (d) water with polymer additive, (e) foam etc. Combination of any of the above is also used as per requirement.

3.2.1 Direct Circulation Rotary

This method is commonly known as Direct Rotary drilling. In this method drilling fluid is pumped through drill pipe and the same drilling fluid comes out through the nozzles provided in the bit and removes the cuttings from the bottom of the bit. The spoil comes out of the bore-hole through the annular space between drill pipe and the bore-hole along with drilling fluid either by high return velocity of the drilling fluid or by suspending in drilling fluid due to its density and high viscosity depending upon the type of drilling fluid used.

In air rotary drilling, air compressor is a part of a drilling rig or a separate compressor unit is used where air, air-water mixture or air-water and foaming agent mixture are used as drilling fluid. Drilling with air has the advantage of reducing drilling cost by increased penetration rate, longer bit life and reduced well-development time. For effective drilling and removal of cuttings 20–30 m/sec up-hole velocity of return air is recommended. The up-hole air velocity is calculated by simple continuity equation (Eq. 10.2).

$$Q = A \times V \tag{10.2}$$

where Q is the volumetric capacity of the compressor, A is the area of annulus and V is the up-hole velocity.

For effective removal of drill cuttings, up-hole velocity of return air can be enhanced with same volumetric capacity compressor by reducing area of the annulus between the bore-hole and drill pipe. This can easily be done by reducing the size of drilling bit.

Direct circulation mud rotary drilling is very effective, hence popular drilling method. Almost all types of geological set-up can be negotiated by this method. Higher depth and larger diameter bore-holes can be drilled by this method (Fig. 10.4). Drilling process is similar to air rotary drilling. Only mud pump is used in place of air compressor. Water or water-bentonite clay mixture is used as drilling fluid in place of air. Water-bentonite clay mixture is commonly called mud. This circulating mud picks up the cuttings and flows upwards through the annular space between drill pipe and the bore-hole to the ground surface. At ground surface mud mixed with drill cuttings are allowed to pass through a settling pit. Drill cuttings

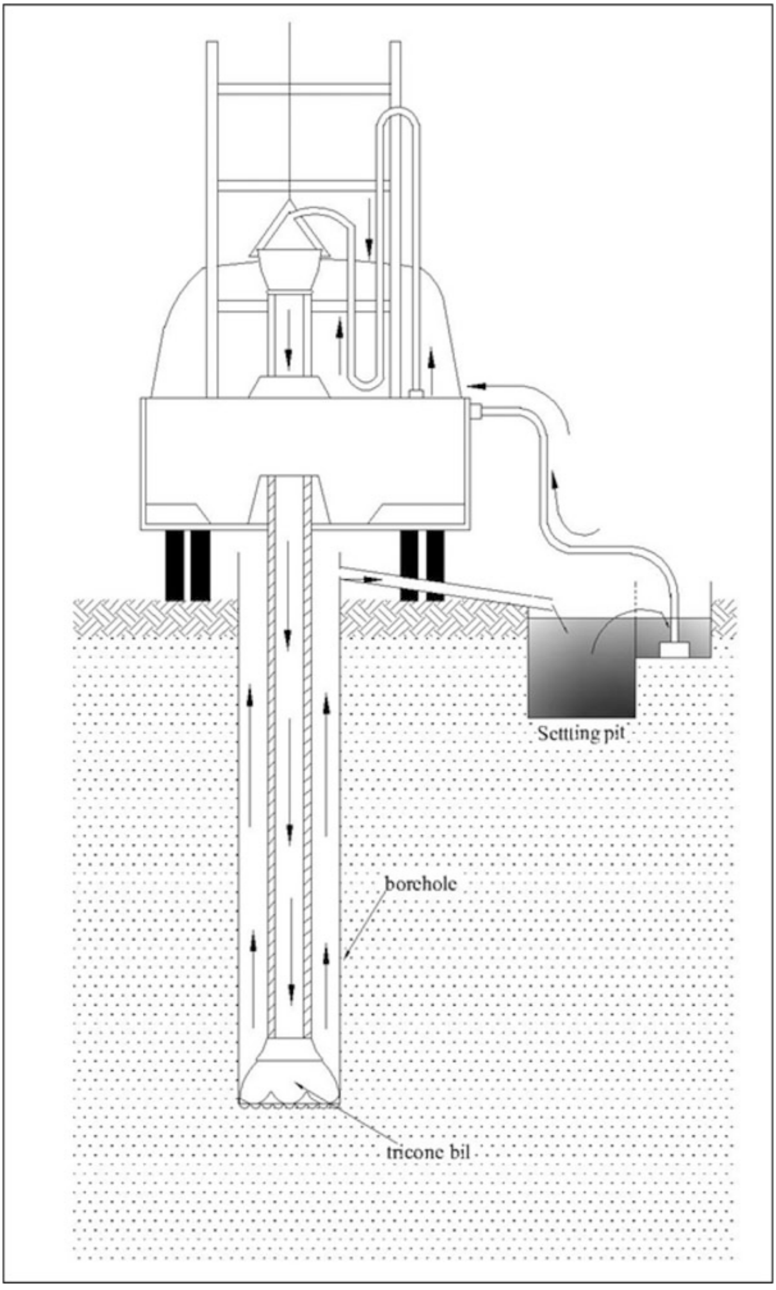

Fig. 10.4 Schematic diagram showing the process of rotary drilling. (Adopted from Dellur, 1998)

settle down at the bottom of the pit and only mud spills to the next pit from where it is again circulated through the mud pump.

In mud rotary drilling, selection of mud pump is very important. The major considerations are (i) mud volume requirement to develop required up-hole velocity for flushing cutting material and (ii) to develop adequate pressure to overcome pressure losses in drill string and surface equipment. Recommended up-hole velocity of drilling mud is 0.41–0.76 m/sec (80–150 fpm).

Next important factor in mud rotary drilling is preparation of mud and to maintain mud quality. Proper density and viscosity facilitate efficient removal of drill cutting. Formation water or formation clay makes the mud thin or thick in the process of circulation and effect the drilling process. Therefore a close observation on mud quality is must in mud rotary drilling.

3.2.2 Reverse Circulation Mud Rotary Drilling

This drilling method is commonly known as Reverse Rotary drilling. From the name itself it is clear that the direction of circulation of drilling fluid is reverse to that of Direct Circulation Mud Rotary drilling. In direct rotary, drilling mud is pumped through drill pipe to the bottom of the hole and the same mud comes out of the bore-hole along with drill cuttings through the annular space between drill pipe and the bore-hole. But in reverse rotary drilling fluid is allowed to enter the bore-hole through the annular space and reach the bottom of the hole by gravity. Subsequently the drilling fluid along with drill cuttings is pumped out through drill pipe. In reverse rotary drilling usually a centrifugal pump is used in place of mud pump used in direct rotary drilling. Reverse rotary drilling is suitable for unconsolidated formations. Bit and drill pipes are differently designed than that of direct rotary drilling so that drill cuttings are allowed to pass through them. In this method higher up-hole velocity can be achieved with a less capacity pump as the space through the drill pipe is much less than that of the annular space. Large diameter bore-holes can be achieved by this method. For drilling to a deeper depth compressor is used to airlift the fluid. When an airlift is used, the air is introduced in to the drill string at an appropriate depth by a small diameter pipe externally fitted with the drill pipe.

3.3 Cable Tool Drilling

Cable Tool Drilling is the oldest percussive drilling method developed in China about 4000 years ago. The method is still in practice with various technical and material improvements with the passage of time. Cable tool rig are also called Spudder Rig. Repeated lifting and dropping of heavy drilling tool into the bore-hole crushes formation material. This repeated lifting and dropping action is obtained mechanically by vertical motion of the spudding beam. The loosen material or drill cutting is mixed with the fluid in the bore-hole. Since no drilling fluid is circulated to remove drill cutting, the same is removed by bailing or by sand pump at relatively short drilling intervals. In this method, drilling and removal of drill cutting are alternative processes. Bailer or sand pump are mechanical devices to remove drill cutting at a regular interval (1–3 m of drilling). Bailer is a section of pipe with a one-way valve at the bottom. When the bailer is dropped, drill cuttings push the one-way valve and enter in to the bailer. While lifting the bailer, the one-way valve gets close due to the weight of the drill cutting accommodated in the bailer. The bailer is taken out and drill cuttings are removed from the bailer on the surface. Sand pump is a bailer fitted with a suction pipe and plunger. The plunger creates vacuum, which opens the one-way valve fitted at the bottom of the bailer and sucks drill cuttings into the bailer. Drill cutting size is a function of formation material and its hardness. They range from fine crushed rock to chips and particles. Small pebbles and gravels come out intact in the bailer.

Cable tool drilling method (Fig. 10.5) is a slow method as removal of cutting is done intermittently by stopping drilling action, but any geological formation can be negotiated by this drilling method. Since no foreign material is used as drilling fluid, most accurate sample of drill cutting can be obtained directly in this drilling method. Large diameter bore-hole can be obtained by this method. This method is still popular for drilling through unconsolidated boulders. Casing can be driven up to the bottom of the bore-hole simultaneously with drilling to prevent the bore hole from collapsing due to unconsolidated loose formation. Therefore this drilling is also termed as Cased Hole drilling**.** These casing pipes are retrieved after lowering the designed tube well assembly through the casing pipes by jacking. Since driving casing pipe up to the bottom and retrieving of entire quantity of casing pipe is a time taking process and more inventory is to be maintained at side, Open Hole drilling practice has been developed in cable tool drilling. In this process, casing is driven up to certain depth depending upon the characteristics and looseness of the formation and rest of the well is filled with water. Hydrostatic pressure of water in the bore-hole prevents from it collapsing. The hydrostatic pressure in the bore-hole increases directly with depth and takes care of the stability of bore-hole at higher depth. Circular hollow bits are used to minimize buoyancy effect in open-hole drilling, where bore-hole is filled with water.

3.4 Combination of Rotary and Percussion Drilling

Different drilling methods have got specific advantages and limitations over one another. To satisfy specific requirement, faster operations and better economy various improvises have been made in drilling methods. Therefore, combination of different drilling methods has been adopted popularly in drilling industry.

In rotary-cum-cable tool drilling method, rotary table is attached with the rig. Mud pump and drill pipes are also used to carry out direct rotary drilling in addition

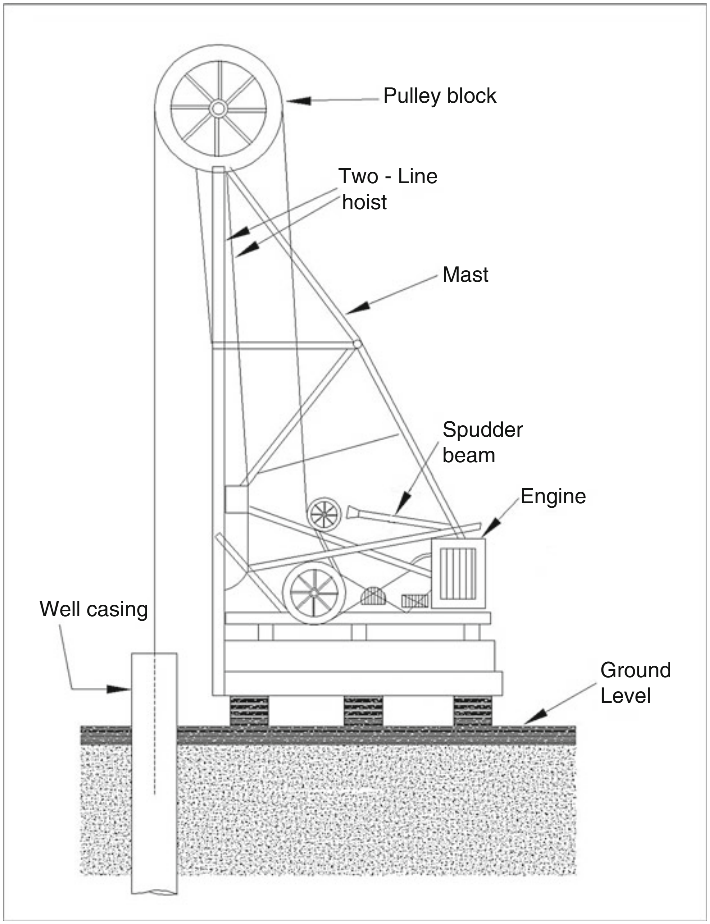

Fig. 10.5 Schematic diagram showing the process of cable tool drilling. (CBPI 1978)

to cable tool drilling. In such method, conventional cable tool drilling is initiated and drilling is continued to cross the boulder bed to case the boulder formation. Below that depth direct rotary drilling is resumed by engaging rotary table, drill pipes and mud pump. This method of drilling is much faster than that of conventional cable tool drilling. In this combination of drilling methods higher depths can be achieved.

Down the Hole Hammer (DTH) drilling is a popular drilling method for drilling through consolidated hard rock formations. Drill bits are known as DTH button bits. The buttons are usually made out of High Carbon Steel. Sometimes the buttons are made out of Tungsten-Carbide or diamond tipped to negotiate through harder materials like non-weathered quartz etc. In this drilling, the bit is attached with a pneumatically operated hammer and fitted at bottom of the drill string. Compressed air passes through the drill pipe to the hammer. The compressed air actuates the hammer and produce high frequency strokes by the bit to crush the rock formation. Drill cuttings are periodically flushed by blowing compressed air at the bottom of the bore-hole through drill pipe, hammer and bit so that bit can strike directly to the formation material. In DTH drilling, compressor is the most important component as it actuates the hammer and maintains adequate up-hole velocity to flush out drill cutting from the bore-hole. Though the hammers usually actuate at 100–110 psi pressure but for efficient removal of drill cutting and to maintain adequate up-hole velocity at least 200 psi pressure is required. Recommended up-hole velocity is 900 m/min or more. Volume of air requirement depends on the size of the bore-hole. Hammer produces 80–120 strokes per minute depending on their design factors. Button bit is attached with the hammer. The hammer imparts blows on the bottom of the bore-hole which is a percussive action. But at the same time the bit also rotates at the rate of 15–30 rpm to maintain the bore-hole annular. Therefore it is a combination of percussion and rotary action simultaneously.

Among all the drilling methods, DTH drilling is the fastest method. Various advancements and improvisations have been made in this method. Provision for bore-hole enlargement or simultaneous casing drive can be attached to this type of drilling machine to case the loose top soil over the compact rock formation.

Dual rotary drilling is a very advance technique getting popular for drilling through unconsolidated boulder. Drilling and casing driving through boulder by conventional cable tool drilling is a time taking method. After completion of well, retrieving of casing pipes by jacking is another time taking process. In this process, due to high friction with side wall of the bore-hole, casing pipes sometimes snaps from the joint. In such case, fishing out of remaining pipes from the bore-hole is further vigorous and time consuming process. These limitations have been taken care in dual rotary drilling method. In this method one rotary device is used to lower casing pipe. This device gives continuous rotation and up and down movement to the casing pipe. Due to this continuous movement casing pipes do not get stuck and become easy to retrieve. Retrieval of casing pipe can be done by the drilling machine instead of jacking which is a time taking process. Through the casing pipe DTH drilling is usually taken up to obtain faster penetration by using suitable air compressor. In this process return air comes out through the casing pipe which acts as a conduit and return air do not come in contact with the side wall of the bore hole. Hence there is no possibility of air loss in the bore hole and comparatively less capacity compressor can also perform. In this method, mud rotary drilling can also be resumed through the casing pipe by using a suitable capacity mud pump instead of air compressor. Therefore, it is obvious that Dual Rotary drilling method is more flexible and improvised method to obtain higher penetration rate and easy casing retrieval in unconsolidated boulder and gradually getting popular.

3.5 Drilling Fluid

Over the years, drilling fluid technology has developed to a great extent in water well industry. Beside water, other fluids like mud, air, air-foam mixture and polymers are popularly used in water well drilling. However the most commonly used drilling fluid is mud which is a colloidal solution of water and bentonite. Bentonite is finely ground clay free from any abrasive material or any toxic chemical. Circulation of drilling fluid is essential to remove drill cuttings from the bottom of the bore-hole to the surface and keep bottom of the hole clean so that bit can directly come in contact with the formation material for penetration.

Common functions of the drilling fluids are:

- Remove drill cuttings from bottom of the bore-hole and carry the same to the surface.
- Hold cutting material suspended in the fluid when circulation is stopped for the time being.
- Make temporary impermeable mud-cake on the wall of the bore-hole.
- Cooling and lubricating bit which suffers vigorous friction with formation material during drilling.
- Encounter sub-surface pressure.
- Support part of the weight of drill string and casing due to its buoyancy factor.

While performing the above duty, drilling mud should not cause the following adverse effects.

- Adversely affect the formation adjoining to the bore-hole
- Reduce rate of penetration
- Allow continuous suspension circulation of abrasive drill cuttings
- Require excessive pumping pressure for desired circulation
- More time to remove mud cake and excess washing or development of well.

Therefore, it is important to maintain proper drilling fluid properties for efficient completion of the well.

4 Well Construction

Tube well is an intake structure to draw groundwater from the aquifer. Tube wells can also be used for artificial recharge of non-committed surface water to the aquifer after proper treatment. Well completion basically comprises some distinct operations like: (i) drilling, (ii) installation of casing, (iii) placing of well screen and filter pack, if required, (iv) grouting of well to prevent dislocation of well assembly and to avoid seepage of contamination from surface and (v) development to ensure maximum intake of sand free water in the well. Well structure consists of two major elements (a) well casing and (b) intake portion.

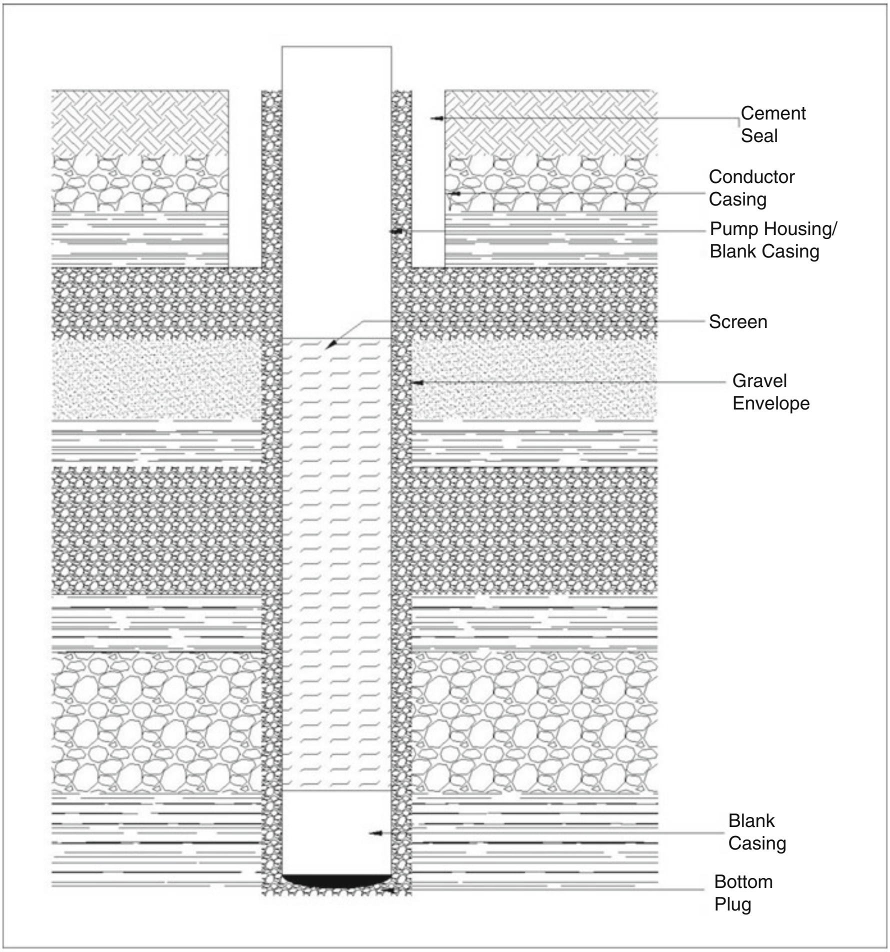

Fig. 10.6 Diagrammatic representation of a typical well assembly. (Adopted from Roscoe Moss 1990)

Well casing is again of two types, one is drive pipe and other one is well assembly casing pipe. The pipe used to support the bore-hole during drilling in case of cable tool drilling method is known as drive pipe. Drive pipe is taken out with the lowering of assembly pipe and shrouding of gravel. These drive pipes are re-used and not a part of the tube well assembly. Well assembly (Fig. 10.6) casing is part of the tube well structure which holds the intake portion of the well in proper position. Diameter of the casing pipe depends on the size of the bore-hole which in turn will depend on the capacity of the well and depth of aquifer tapped. The upper portion of the casing pipe used for pump setting is conventionally termed as Housing pipe.

Intake portion is the most important part of the well. Through this part of the tube well water enters the well from aquifer. In case of unconsolidated formations, the intake portion consists of screen or perforated pipes through which water flows into the well. Design of intake requires careful consideration of hydraulic parameters which influences performance of well. In case of consolidated hard rock formation only the top soil or over burden is cased and rest of the bore-hole is kept naked. Water from the fractures and fissures accumulates in the bore-hole. Due to consolidated nature of the formation, the hole remains intact. In case of unconsolidated water bearing formations, screen is provided to allow sand free water enter into the well freely and also to restrict the formation material to rush in. This part of the tube well requires proper design from various hydraulic considerations and that influence the performance of a well.

5 Well Design

A good water well design is to ensure an optimum combination of performance, longevity and economy (Driscoll 1986). The basic inputs required to design water well are:

- Expected yield and intended use of the well.
- Geological set up of the entire depth drilled.
- Character, thickness and sequence of potential aquifer.
- Size and gradation of aquifer materials.
- Water level condition and seasonal fluctuation.
- Quality of water.

In addition to the above basic inputs, some local information are also important like design and construction feature of previously constructed wells in that area and also operation and maintenance history of previously constructed well in that area.

Important steps for proper design of a well are:

- Determination of diameter and depth of casing.
- Mechanical analysis of formation material for screened well.
- Selection of water bearing strata to be screened and fixing the length of screen.
- Design of well screen i.e. diameter, length, percentage of screen opening and material.
- Selection of type of well i.e. naturally packed or artificially gravel packed well.
- Determination of gravel size.

5.1 Design of Casing

Diameter of casing is very important because it affects significantly the cost of structure. Housing part of the well casing must be large enough to accommodate the

Table 10.1 Recommended diameter of housing pipe

Anticipated yield of well (lps)	Nominal size of pump (mm)	Optimum size of housing pipe (mm)
< 6	100	150
5–11	125	200
10–25	150	250
22–40	200	300
37–56	250	350
53–82	300	400

Source: CGWB 2011

pump with proper clearance for installation and operation. The recommended diameter of the housing pipe is given in Table 10.1.

Diameter of the rest of the casing must be such as to ensure hydraulic efficiency. It can be calculated from the simple relation as follows (Eqs. 10.3 and 10.4):

$$a = Q/v \tag{10.3}$$

where a = Area of cross-section of casing pipe in meter, Q = Expected discharge of the well in cubic metre per second and v = Entrance velocity of water into the well (ideally, 3 m per second).

$$again, \quad a = \pi d^2/4 \tag{10.4}$$

where
d = Diameter of casing pipe in metre.

From the above relations diameter of casing pipe can be determined.

Length of casing is determined in such a way that most of the aquifer thickness is utilized by intake portion of the well, resulting in higher specific capacity (discharge per unit draw down). However, depth of the housing pipe is guided by the following relation (Eq. 10.5):

$$\begin{aligned}\text{Depth of housing pipe} = {} & \text{Water table below ground level} + \text{Length of the pump} \\ & + \text{Drawdown} + \text{Seasonal water level fluctuation} \\ & + \text{Allowance for submergence of pump}\end{aligned} \tag{10.5}$$

5.2 *Design of Well Screen*

Screen is the most important component of a well and hence must be carefully designed. Life of a well is mainly governed by the life of the screen. An efficient well screen is required to (i) offer minimum resistance to flow water in the well,

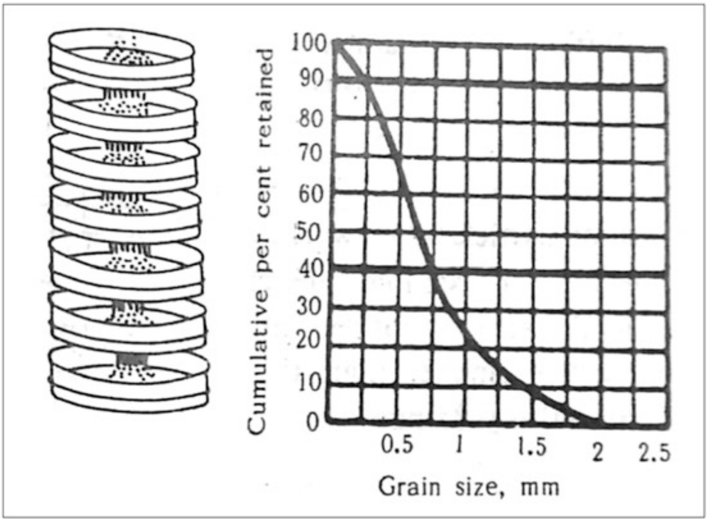

Fig. 10.7 An overview of sieve analysis. (Adopted from CBPI, 1978)

(ii) prevent movement of formation materials in the well, (iii) be strong enough to prevent collapse, and (iv) resist corrosion and incrustation.

However, for proper design of screen length, diameter, percentage opening and for determining corresponding gravel size, mechanical analysis of sample cuttings obtained from different depths is essential. Sieve analysis (Fig. 10.7) is one of such mechanical analysis of sample cuttings.

Preparation of sample is required before conducting sieve analysis. In this process, sample cuttings are properly washed and made free from any foreign material like mud etc. Then the sample is properly dried by heating up to 110 °C. In slandered procedure of sieve analysis, a set of sieve conforming to IS: 460–1962 or standard set by individual country is used. The weight retained in each sieve is measured. These weights are then expressed as a percentage of total weight of the sample. On the basis of the sieve size grain size of the sample can be determined. A graph is plotted by keeping grain sizes in X-axis and percentage retained in Y-axis (Fig. 10.7).

Uniformity Co-efficient (C_u) is a ratio expressing the variation in grain size (Eq. 10.6). It is usually measured by the sieve aperture that passes 60% of the material divided by the sieve aperture that passes 10% of the material.

$$\begin{aligned} C_u &= d_{60}/d_{10} \\ &= 60\%\text{pass or } 40\%\text{retained}/10\%\text{pass or } 90\%\text{retained} \end{aligned} \tag{10.6}$$

Generally, if the grain size is classified as uniform then the C_u is less than 2. For fairly distributed grain size the C_u lies between 2 and 3 and for heterogeneous grain size the value of C_u is greater than 3. This uniformity co-efficient is the guiding factor for selection of strata to be screened.

Effective Size (d_{10}) is defined as formation particle size, where 10% of the grains pass through the sieve and 90% of the grain is retained. This effective size of the grain is the guiding factor for selection of slot opening.

Selection of aquifer to be screened is carefully done after proper grain size distribution analysis. Permeability of aquifer is proportional to the square of the effective grain size $d_{10.}$ In case two sets of sample is having same effective size, the sample having lower Uniformity Coefficient is more permeable. The well screen length is determined on the basis of the characteristics of the aquifer and available drawdown. In any case drawdown should not be allowed up to the depth of screen. For different aquifer conditions different guidelines are followed.

For homogeneous confined aquifer, 70–80% of the aquifer thickness is screened depending upon thickness of aquifer. If aquifer thickness is less than 7.5 m, then 70% aquifer is tapped. If aquifer thickness is between 7.5 and 15 m, then 75% of aquifer is tapped. If aquifer thickness is more than 15 m, 80% of aquifer is screened. For non-homogeneous confined aquifer**,** it is best to screen most of the permeable or productive zone. This zone can be identified from the mechanical analysis of drill cutting sample as well as from electrical logging.

In case of homogeneous unconfined aquifer**,** the bottom one-third of the aquifer is usually screened. However, to obtain higher specific capacity (discharge per unit drawdown) more length, even up to 50% of the aquifer length can be screened. In case of non-homogeneous unconfined aquifer, the same principle is followed that is followed in the case of non-homogeneous confined aquifer. Only one consideration is taken care in such case, that is, the screen is placed at the lower most portion of the most productive zone. This is to obtain maximum available drawdown.

To maintain minimum turbulence at the entrance, the screen entrance velocity is maintained at 3 m/sec or less. This results in (i) minimum friction loss at the screen opening, and (ii) minimum rate of corrosion and incrustation. To determine the well screen diameter Eqs. (10.3) and (10.4) are used.

The size of the slot opening and percentage of open area of the screen is another important aspect of well screen design. As discussed earlier the ideal slot opening is the d_{10} size of the aquifer material. It means the slot size of the screen should be such that it can retain 90% of the formation material and may allow 10% of the formation material to pass through the slot. If formation material is of finer grade, it is recommended that V-wire screen is used in place of conventional slot pipe. It is difficult to cut slot less than 1.4 mm in normal MS pipe, whereas 0.5 mm opening can be obtained in V-wire screen.

For slotted pipes, the recommended maximum percentage of open area of the screen is 20%. It is not only difficult to design more slot per unit area but it is also not recommended from the strength point of view to have more percentage of open area in case of slotted pipe. However, for V-wire screen 70% of open area can be obtained.

5.3 Gravel Pack Design

In naturally packed wells (naturally developed wells), the fine material in the formation surrounding the screen is removed by development of the well to create more permeable zone around the screen. In such wells higher slot openings are used so that 60% of the formation materials are removed and 40% retained during development.

In artificially packed well, the zone immediately surrounding the screen is made more permeable by removing 10% of the formation material and replacing it by artificially graded coarser material (gravel).

In either case, the net hydraulic result is an increase in the effective diameter of the well and an increase in permeability around the screen. The mean size of the pack material is related to the mean gravel pack ratio (Fig. 10.8) which is given in Eq. (10.7) (Michael and Khepar 1989).

$$\text{PA Ratio} = 50\%\text{size of gravel} \div 50\%\text{size of formation} \tag{10.7}$$

The Central Board of Irrigation and Power (1967), based on a series of laboratory experiment, recommended the following criteria for PA Ratio:

(a) For uniform aquifer material ($C_u \leq 2$)

d_{50} of pack material $\div$ d_{50} of formation material should lie between 9 and 12.5.

(b) For graded aquifer material ($C_u > 2$)

d_{50} of pack material $\div$ d_{50} of formation material should lie between 12 and 15.5.

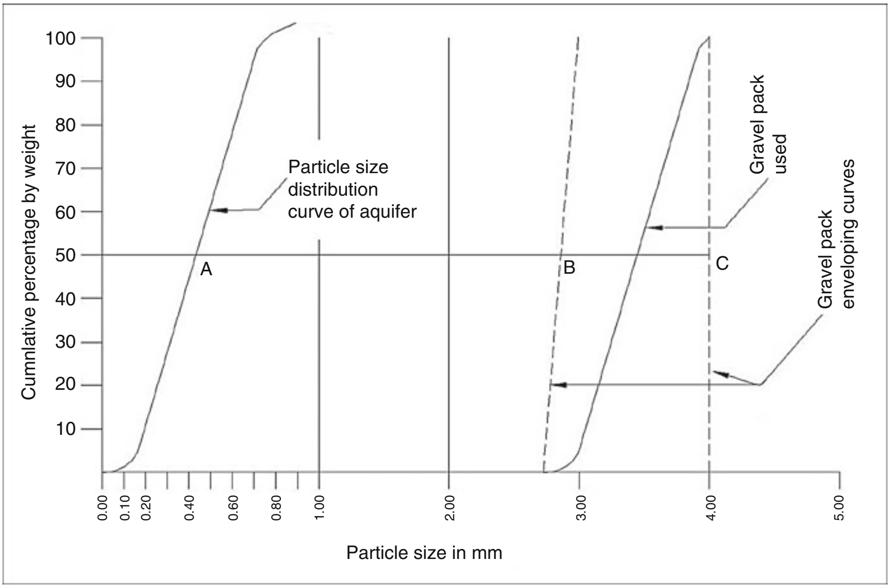

Fig. 10.8 Analysis for choosing appropriate gravel size based on grain size distribution of aquifer material

5.4 Material for Construction of Well

ERW Mild Steel (MS) pipes are commonly used for construction of well for any size and depth. But alternative materials are also used under different conditions such as size of formation material, water quality and last but not the least, the cost factor. Since the screen portion is the weakest portion of the well assembly, it is prone to fail early than any other part of the well. To avoid corrosion and incrustation Galvanized Iron pipes (GI) or High Density Polyvinyl Chloride (HD-PVC) pipes are used. But for large diameter and deeper wells MS pipe is recommended although stainless steel pipes have distinct advantages, but not very cost effective. To arrest fine formation material brass strainers or V-wire screens are used. Brass strainers are not cost-effective for deep and larger diameter bore holes and stainless steel V-wire screens are cost intensive than conventional low carbon galvanized steel (LCG Steel) V-wire screen.

6 Well Development

During drilling operation, normal setup of the geological formation is damaged or disturbed. Moreover, foreign materials like mud etc. are used during drilling which ultimately clog the water bearing aquifer. Mud cakes are also formed on the side wall of the bore-hole during drilling to prevent collapse of the unconsolidated formation. Therefore, after completion of the construction part, the tube wells are developed to remove those foreign materials from the well and repair the formation from the damage occurred during drilling.

The basic objectives of well development are:

- To remove the mud cake formed on the wall of the bore-hole.
- To clear the permeable zone.
- To remove desired quantity of formation material surrounding the screen for better yield of sand free water.
- To minimize skin effect and maximize well efficiency.

6.1 Development Methods

6.1.1 Back Washing

In this process fresh water is pumped in the well with pressure which comes out through the screen and agitates the area surrounding the screen. As a result not only the mud cake around the screen is broken, gravels and formation materials are also segregated. Back washing is usually done by mud pump and through drill pipe to the desired depth.

6.1.2 Hydraulic Jetting

In this method, high velocity fresh water is injected in the well. This water jet cleans the tube well assembly from inside. At the same time part of the jetting through the screen strikes the mud cake around the screen. For jetting, usually mud pump is used. Jetting tools are commonly fabricated from a section of blank pipe slightly less than the diameter of screen. Four straight holes are drilled at 90° apart. If nozzles are used in place of drilled hole, better hydraulic efficiency can be obtained. Simultaneous use of air lift pump with jetting is very effective development technique.

6.1.3 Mechanical Surging

In this process, fresh water is forced into the formation. The surge block moves up and down in the tube well assembly and acts as a plunger. This up and down movement of the plunger also creates suction inside the tube well assembly; as a result the fresh water forced into the formation is again sucked in along with mud and fine formation particles present around the screen.

6.1.4 Compressed Air Development

This is the most commonly used method. This is basically pumping by air-lift method. In air-lift pumping, compressed air is forced in the well and all the fine formation particles, mud etc. present in the tube well assembly is pumped out. Air-lift pump also creates suction around the screen portion and helps to clean the formation around the screen. In air-lift pump, air-line is placed inside a larger diameter eductor pipe. The eductor pipe is lowered against the bottom most screen. Air-line is lowered within the eductor pipe up to a maximum possible depth according to the capacity of compressor. But in any case air-line should not be lowered beyond the depth of eductor pipe. If air-lift pumping is combined with mechanical surging, better result can be obtained.

6.1.5 Chemical Treatment

If more time is consumed in drilling or there is a time gap between well construction and development, mud cake may become hard and conventional development methods may not break it. Also in case of hard-rock wells, sometime fractures may get clogged by clay or any softer material which restricts the hydraulic continuity and inflow of water in the well; in such cases chemical treatments are required. The commonly used chemicals – polyphosphates which act as dispersion agents for clay – are sodium tri-polyphosphate ($Na_5P_3O_{10}$), sodium pyrophosphate ($Na_4P_2O_7$) or sodium hexa-meta-phosphate {$(NaP_2)_6$}.

Apart from chemical treatment, acid treatments are also done to dissolve acid soluble material present in the formation for permitting higher flow rate in the well. Commonly used acids are hydrochloric acid (HCl), sulfamic acid (H_3NO_3S) etc.

A measured quantity and dilution of chemical or acid is poured in the well and a reaction time is given. But the most important function is to remove these foreign materials completely from the well and from the aquifer where these chemical/acid has propagated.

6.1.6 Hydro-Fracturing

This method of development is adopted in specific wells in hard rock formation. In this method of development a section of well is isolated by using packers and then fresh water is injected at high pressure (120–140 bars) to that isolated zone. In this process, drill cuttings or any softer material clogging the fractures will get cleared and due to better hydraulic continuity, yield of the well will increase. One hydro-fracturing unit consists of (a) one plunger type reciprocating pump to deliver about 3000 lph at about 180 bar pressure, (b) one water tanker of 9000–10,000 l capacity along with a pump to fill up the tanker from available source, (c) single and double packer units to isolate the required section of well where hydro-fracturing is to be conducted, and (d) different fittings and fixtures to fix packers to the desired depths and apply high hydraulic pressure to the selected area. This method of development is not recommended for all types of wells.

6.1.7 Over Pumping

This is the simplest method of development to remove the fine particles from the aquifer. In this method, a tube-well is pumped at a higher rate than the actual rate of pumping during its normal operation. Though a very effective method but usually adopted as a final development after using other development methods. This is because if the water is not fairly cleared by other development methods, the test pump may get easily worn out while pumping unclear water that contains formation sand which is abrasive in nature. The pump is normally set above the screen. When pump is in operation, water flows from formation to well but when pump is stopped the water in the column pipe gives a return pressure to the formation. Thus, by periodically running and stopping the pump, formation around the screen is stabilized. This method of development is not recommended for developing shallow wells with short length of screen.

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