CHAPTER III

BASIC THEORY

3.1. Oil Well Cementing

Oil well cementing is the process of placing a cement slurry in the annulus space between the well casing and the geological formations surrounding to the well bore. When a certain section of the depth of an oil or gas well has been drilled successfully, the drilling fluid cannot permanently prevent the well bore from collapsing. Therefore, oil well cementing was introduced in the late 1920s (Joshi and Lohita, 1997) with a number of objectives: (i) protecting oil producing zones from salt water flow, (ii) protecting the well casing from collapse under pressure, (iii) protecting well casings from corrosion, (iv) reducing the risk of ground water contamination by oil, gas or saltwater, (v) bonding and supporting the casing, and (vi) providing zonal isolation of different subterranean formations in order to prevent exchange of gas or fluids among different geological formations.

Strict control of the hardened cement mechanical properties and durability during the service life of the well are very important criteria, especially under such severe environments. Thus, a special class of cements called oil well cements (OWCs), has emerged and is specified by the American Petroleum Institute (API) (API Specification 10A, 2002). A number of additives have also been used to alter the chemical and physical properties of the oil well cement slurries as required for the flowability, and stability of the slurry and long term performance of wells.

3.2. Basic Cementing Process

A typical oil/gas well can be several thousand meters in depth, less than a meter in diameter (Lafarge, 2009), and is usually constructed using a metal casing surrounded by a special cement slurry mix that fills the annulus space between the outer face of the tubing and the wall formation of the hole. OWCs are sometimes pumped to depths in excess of 6000 m (20000 ft). At such depth the temperature may rise up to 205°C (400°F), but is normally reduced by the circulation of cooler drilling mud (Orchard, 1962). The cement slurry may also be subjected to very high pressures reaching over 200 MPa (Joshi and Lohita, 1997) depending on the height and density of the column of material above it. Thus, oil/gas well cementing operations face additional challenges in contrast to common cementing work above ground. Contaminations from the formations can pose additional problems. Thus, OWC slurries are pumped between the well bore and the steel casing inserted in the well to seal off all strata of the formation, except those that have oil so that gases and water do not contaminate the oil bearing strata.

After drilling the well to the desired depth, the drill pipe is removed and a longer string of casing is run into the well until it reaches its bottom. The circulatable completion fluids such as drilling mud must be removed and replaced with a hardened cement to ensure intimate contact and bonding of the cement with the casing and formation surfaces. Sufficient cement slurry is pumped down the inside of the casing and forced up the outside of the casing through the annular space between the casing and subterranean bore hole wall (Powers et al., 1977). Figure 3.1 is a schematic representation of a cemented well.

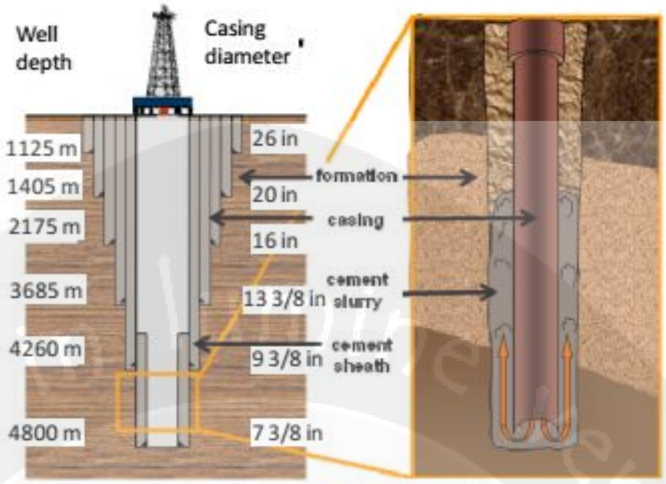

Figure 3.1. Schematic Representation of a Cemented Well (Anjuman, 2011)

3.3. Oil Well Cements

The productivity of an oil well is significantly affected by the quality of cementing between the well casing and the surrounding strata (Anjuman, 2011). Cement slurry flowability and stability are major requirements for successful oil well cementing. The properties of oil well cement slurries depend on its mixture design and the quality of its components.

Type I/II ordinary portland cements can provide adequate strength and durability for common applications. However, some demanding applications may require the use of other cements to meet specific performance criteria. For instance, the need for high-early strength cements in pavement repairs, the use of blended cements with aggregates susceptible to alkali-aggregate reactions, and the use of oil well cements in the exploration and production of oil and gas in onshore as well as offshore wells are examples of such applications. Although slightly modified Type I, II and III portland cements can be used for cementing around the steel casing of gas and oil wells having depths not exceeding 1800 m (6000 ft), deeper wells usually require special oil well cements (Popovics, 1992).

3.4. Classification of Oil Well Cements

Oil-well cements are usually made from portland cement clinker or from blended hydraulic cements. OWCs provide a base ingredient in the slurry mix that is pumped into the interior metal casing of the well and forced back toward the surface from the base of the borehole filling the annulus (Powers et al., 1977, Calvert, 2006). Initially, only one or two types of oil well cement were available. As oil/gas wells became deeper and subjected to more adverse environments, the more stringent performance criteria could not be satisfied by those cements. With the advent of the API Standardization Committee in 1937, improved OWCs were developed (Smith, 1987). The API Specifications for Materials and Testing for Well Cements (API Specification 10A, 2002) include requirements for eight classes of OWCs (classes A through H).

a. Class A: Used from surface until the depth of 6000 ft (1830 m) with the temperature 0-80°C and it is not resistant with sulphate. Only available in Ordinary (O) type, used in a normal condition where there are no special requirements for the OWCs. (Equal with ASTM C-150 type I).
b. Class B: Used from surface until the depth of 6000 ft (1830 m) with the temperature 0-80°C with the condition of the formation contain a lot of sulphate. Only available in Ordinary (O) and Moderate Sulfate Resistant (MSR) type. (Equal with ASTM C-150 type II).

c. Class C: Used from surface until the depth of 6000 ft (1830 m) with the temperature 0-80°C with the requirement of quick OWCs setting time. Available in Ordinary (O), Moderate Sulfate Resistant (MSR), and High Sulfate Resistant (HSR) type. (Equal with ASTM C-150 type III).
d. Class D: Used for the depth from 6000 ft (1830 m) until 10.000 ft (3050 m) with the condition of moderate pressure and temperature from the formation (between 80–130°C). Available in Moderate Sulfate Resistant (MSR) and High Sulfate Resistant (HSR) type.
e. Class E: Used for the depth from 10.000 ft (3050 m) until 14.000 ft (4270 m) with the condition of temperature (130–145°C) and high formation pressure. Available in Moderate Sulfate Resistant (MSR) and High Sulfate Resistant (HSR) type.
f. Class F: Used for the depth from 10.000 ft (3050 m) until 16.000 ft (4880 m) with the condition of temperature (130–160°C) and very high formation pressure. Available in Moderate Sulfate Resistant (MSR) and High Sulfate Resistant (HSR) type.
g. Class G: Used from surface until the depth of 8000 ft (2440 m) with temperature up to 90°C. With the addition of additive, this class of cement could be used in the higher temperature and pressure and deeper depth. Available in Moderate Sulfate Resistant (MSR) and High Sulfate Resistant (HSR) type.

h. Class H: Used from surface until the depth of 8000 ft (2440 m) with temperature up to 95°C. Available in Moderate Sulfate Resistant (MSR) and High Sulfate Resistant (HSR) type. (Smith, 1976)

OWCs are classified into grades based upon their C3A (Tricalcium Aluminate) content: Ordinary (O), Moderate Sulphate Resistant (MSR), and High Sulphate Resistant (HSR). Each class is applicable for a certain range of well depth, temperature, pressure, and sulphate environments. Class A, Class G and Class H are the three most commonly used oil well cements. Class A is used in milder, less demanding well conditions, while Class G and H cements are usually specified for deeper, hotter and higher pressure well conditions (Lafarge, 2009). Conventional types of portland cement incorporating suitable additives have also been used. API Class G and H are by far the most commonly used OWCs today.

3.5. Admixtures for Oil Well Cementing

Typical admixtures for OWC slurries can be categorized into eight groups: set accelerators, set retarders, extenders, weighting agents, dispersants, fluid-loss control agents, lost circulation control agents, and other specialty additives (antifoam agents, fibers, etc.). The OWC slurry may incorporate retarders or accelerators to control the setting behavior, weighting agents are light-weight systems to increase the density of the OWC slurry system, and extenders to lower the density of the cement system and increase its yield. Similarly, different admixtures are used as dispersants or viscosifiers to control the viscosity of the slurry. For instance, fluid loss additives are used to control the loss of the aqueous phase of the OWC slurry to the geological formation and to maintain constant water to solid ratio in cement slurries, while lost circulation control agents are used to control the loss of the cement slurry to weak or regular formations (Nelson et al., 2006).

In addition to chemical admixtures, a number of mineral additives such as fly ash, silica (α-quartz and condensed silica fume), diatomaceous earth, gilsonite, powdered coal (Nelson et al., 2006), etc, have been used to alter certain properties of OWC slurries. A new generation of engineered cement set control (ECSC) additive has been developed and successfully used to cement long casing sections. The ECSC overcomes the well integrity problems due to huge temperature differential exist between the bottom and the top of a long cement column (Sorgard and Viali, 2007).

3.6. Shrinkage, Expansion and Dimensional Stability

The expansion of OWC slurries is important to improve the quality of the well cementing sealing. Expansion should take place after pumping cement slurry into the annulus and the process should begin after the formation of the hardened cement structure starts but not after the formation of a rigid crystalline structure, as it can cause fracturing and adversely affect the porosity. On the other hand, if the expansion takes place too early, i.e. when the suspension is in a liquid state, the quality of formation isolation get worsens. The well casing is in an expanded state during the initial setting of the cement slurry due to the heat of hydration. Subsequent internal temperature reduction resulting from mud circulation may cause the casing to contract and destroy the cement/casing bond partially or entirely (Rubiandini, 2005). Expanding additives can overcome this problem as they tend to expand after the initial set, thus maintaining the bond between formation, cement and casing during pressure and temperature changes.

3.7. Calcium Carbonate

Calcium carbonate is composed of the crystalline mineral, calcite, which occurs naturally in the form of chalk, limestone or marble. Dolomite is also a naturally occurring crystalline mineral. Most ground calcium carbonate on the market contain more than 85 % $CaCO_3$ and are controlled on their alkali–silica reactivity if they contain more than 4 % SiO_2. They also have less than 0.20 % organic material. They are ground from well-known rock; marble as used for statues, tables etc., medium hard crystalline limestone and soft chalk, known from blackboard use.

The benefit of using calcium carbonate in addition to cement mixture could give an improvement in shear bond strength because of the contribution of calcium carbonate in hydration process. It has namely been noticed that additive with higher $CaCO_3$ content produce a higher shear bond strength.

Hydration of C_3S or Portland cement in the presence of $CaCO_3$, results in the production of some calcium carbosilicate hydrate that contributes in the improvement of shear bond strength of the cement (Paramatatya, 2014).

3.8. Silica Fume

The silica used as a mineral additive in cementitious products can be originated from several sources such as microsilica, also called or silica fume, a very finely spheres of non-crystalline silica, a byproduct of electric furnaces used for obtaining silicon and silicon alloys.

Silica fume is a byproduct of silicon metal and ferrosilicon alloy product. By-products of the production of silicon metal and the ferrosilicon alloys having silicon contents of 75% or more contain 85-95% non-crystalline silica. The by-product of the ferrosilicon alloy having 50% silicon as much lower silica content and is less pozzolanic. Silica fume usually contain of 90% SiO_2 (Souza et al., 2012).

In the hydration process of cement slurry, primary chemical reactions produce two chemical compounds: calcium silicate hydrate (C-S-H), which is the strength producing crystallization, and calcium hydroxide (CH), a by-product also called free lime which is responsible for pores within the cement when it is hardened. By the addition of silica fume, it will react with CH and producing additional C-S-H which is provides the improvement of the compressive strength of the cement (Rubiandini, 2005).