GEOTHERMAL CEMENTING - THE STATE OF THE ART

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ABSTRACT

Much emphasis today is being placed on the drilling and completion of steam wells. Success or failure depends greatly on the cementing process, which requires not only the selection of competent and durable materials but also the complete understanding of placement techniques. Immobile muds, crooked holes, lost circulation, poor centralization, and the inability to move pipe are some of the major areas which contribute to good or bad results.

This presentation covers a "state of the art" of the various techniques, materials, and equipment being used in cementing steam wells in the United States and Mexico. Two new techniques which aid in achieving full hole coverage and in sealing lost circulation zones during cementing are highlighted.

DISCLAIMER

INTRODUCTION

Drilling and cementing techniques associated with the completion of over 2.0 million oil wells in North America have been adapted for use in many types of wellbores drilled for water wells, waste-disposal wells, mine shafts, and steam-producing wells [1].

All these holes are fairly shallow and rarely exceeding 6,000 feet except those drilled as steam-producing wells. In steam wells, wellbore and formation conditions are far more severe and unusual, therefore, both casing and cementing programs must be carefully planned.

Drilling techniques and cementing materials used for deep, hot oil wells where temperatures range upward to 500°F have made it possible to cement shallower geothermal steam wells having static bottom-hole temperatures in excess of 600°F. The hottest of these wells have been drilled in the Salton Sea area of California and in northern Mexico to depths in excess of 8,000 feet for the recovery of steam to power electric generators. Steam wells have also been drilled for the operation of steam generators to produce electrical power in Iceland, Italy, New Zealand, Japan, Philippines, and other parts of the world where large quantities of geothermal energy are found at shallow depths. One of the most publicized steam-recovery projects outside the U.S. is the Wairakei project in New Zealand and the steam areas of northern Italy [2-8].

Steam recovery projects were instituted in the U.S. as early as 1920 near San Francisco. Several hundred wells have been drilled there since 1957. These steam wells represent some of the hottest and deepest steam deposits found anywhere in the world. The temperature gradient - approximately 13°F per 100 ft. of depth - imposes rather unusual demands on drilling muds, casing, and cement used to bond the casing to the formation. Casing in steam wells is affected by temperature and undergoes creep or elongation by thermal expansion unless cemented to surface. Some of the earlier wells drilled for the recovery of geothermal steam used casing designed especially to withstand high temperatures [4,7]. For later wells, however, standard oilfield casing with special threads have been found satisfactory, particularly when casing was successfully cemented to surface.

Because of the extremely high temperatures in steam wells, drilling mud must be passed through cooling towers and circulated back into the well to reduce bottom-hole circulation temperatures as much as possible before cementing. Cement should be circulated to the surface on every string of pipe to reduce buckling and minimize casing creep. Also, the cement must be placed in such a way that the pipe cannot be blown out of the hole in some steam areas.

BASIC CEMENTING CONSIDERATIONS

In cementing casings, the objective is to provide a complete fill-up of cement in the casing hole annulus to resist specific environmental conditions and anchor the casings firmly to the ground and to each other. The hardened cement sheath must protect the casing against possible corrosion by thermal brines and gases and prevent the uncontrolled flow of thermal water and steam outside the casing [9-10] Figure 1.

The depths at which each casing string is to be set is influenced by geological conditions encountered and total depth to which the well is to be drilled. These programs vary, particularly for those casing strings below the surface casing the latter of which are controlled in some areas by regulatory bodies. The diameters of the holes drilled to receive the respective casings should be such that at least 1-1/2 inches thickness of cement surrounds the casing. If the annular space is too wide, it can result in difficulty in obtaining good casing centralization which may cause channeling of the cement during placement. When liners are run and cemented, this annular space may be reduced to 3/4 inches. Typical liner-hole combinations such as 7" liner in 8-5/8" hole have proven to be successful [11,12] Figure 2.

In geothermal drilling, the major difficulties in the cementing operations arise from high temperatures, lost circulation zones and contamination of the cement slurry with drilling fluids. The best way to overcome these difficulties is to diagnose and combat them as they arise using whatever techniques and materials are deemed necessary. Although this does not sound difficult, one will find that too often it becomes quite difficult as a result of poor planning and then overreacting.

High temperatures are expected and usually planned on. Some cementing compositions may exhibit a satisfactory compressive strength when first set, but will begin rapidly to lose this strength when continually exposed to high well temperatures [13, 14, 15]. As the compressive strength retrogresses, cement permeability will increase until the cement column may no longer prevent communication or flow of thermal waters between zones.

Cements exhibiting strength retrogression have been found to contain two hydration products; calcium hydroxide and di-calcium silicate alpha-hydrate. These products appear together and sometimes singularly, depending on temperature and time. This begins at temperatures of 230°F and accelerates as temperatures increase. The process of using silica flour in concentrations of 30-80 percent by weight of the cement has provided a means of overcoming this. When silica flour is added to the cement, a portion of it reacts with the calcium hydroxide to form di-calcium silicate alpha-hydrate. The remaining silica reacts with the alpha-hydrates to form tobermorite. Tobermorite has a better cementing phase than alpha-hydrated di-calcium silicate and therefore brings about the desired improvements for high resistance in hot wells [13, 14, 15].

Cement samples taken from the annulus of 13-3/8"-20" casings nearly 1 year after completion of the well have been analyzed and found to contain alite, calcium hydroxide, kaolinite, quartz and calcite. The reason for these analyses was in attempt to determine the reasons for failure of the 13-3/8" casing. These products are not what would be expected to find unless a high water ratio filler type cement had been used in preference to an API Class "G" or "H" cement containing silica flour. Further investigations brought to light that this was the case and the well owner has since made changes in his cementing programs to prohibit this from occurring again. The apparent reason for having used this poor quality cement was to reduce the cementing costs.

The basic compositions currently available for cementing casings where temperatures in excess of 230°F is API Class "G" Cement with 30-80% silica flour. Cementing formulations of course will contain cement retarders, friction reducers and sometimes lost circulation materials. Table 1.

To determine which additive to add to this basic composition, it must be decided what properties are needed or required for the wellbore. The first basic need is sufficient fluid life, commonly referred to as thickening time, to place the slurry in the casing-hole annulus. Remember, this cementing composition is prepared at atmospheric conditions and then subjected to temperatures existing in the drilled hole which may be several hundred degrees hotter. As the slurry becomes hotter, it is also subjected to higher pressures and contamination with fluids in the hole. To either of these basic products, it is necessary to add retarders which are designed to keep the slurry a fluid for proper placement.

It is often necessary to reduce the density of the slurry to reduce the hydrostatic pressure or bridge fractures in the rock to control lost circulation. Weight reduction of cementing slurries has historically been accomplished by adding more water. To keep this water from breaking away from the slurry, it is necessary to add some additive which will tie it up. Bentonite, pozzolan and perlites and tiny glass beads are used for this application. Seldom is it necessary to increase the slurry density to contain the formation pressures to prevent a blow out. Reducing the water with cement dispersants or adding a weighting material is used to accomplish this. There are many additives which can be used with either of the basic cements and it would be rather difficult to completely cover all of these in this presentation [1]. Table 1.

Circulating cement to the surface on all casing strings is always desirable. Uncemented casing can have uncontrolled growth due to temperature and if it should be caught in some tight spot in the hole, it may buckle during idle periods or if allowed to cool, it may pull apart at a collar [10]. (Figure 3) Where liners are run, establishing full cement fill-up and assuring the lap is properly cemented by a squeeze cement job may be necessary.

One could cite many examples of casing failures, blow outs, corrosion problems and other undesirable facts which have and are continuing to occur in steam wells.

Quite often, it is necessary to do plugback cementing prior to running casing either for hole improvement, lost circulation during drilling or change in direction. This has proven to be a costly operation. Selecting any cementing composition without regard to conditions often leads to failure. Subjecting a neat portland cement slurry of 300-400°F in 5 to 15 minutes is a rather severe shock and can be disasterous. There are products and techniques to use which will save much money and time.

Following are various types of completions currently being used for geothermal wells in different areas of the world. Figures 4-8. Cementing compositions used on each of these may vary slightly but generally begin with basic API Class "G" or "H" Cement with 35-40% silica flour used as the temperature increases.

Factors Affecting Cementing Success. The basic cementing operation usually involves two parties, the service company and the well owner. The service company provides the pumping equipment and carries out the owner's instructions. Pre-planning conferences are always helpful and minimize foolish mistakes. Prior to performing the cementing job, depth, hole and pipe size, bottom hole static temperature, drilling mud properties and hole conditions are needed. The well owner stipulates where he wants to bring the top of the cement and usually indicates where and how much lost circulation has been encountered during drilling.

From this, one can determine what type and how much pre-flush to run ahead of the cement, what volume and type of composition to use, how much time will be required to do the job, should the job be staged in one, two or three stages and the volume of mixing water and displacement fluid the well owner should have available for the job. Wellbore hydraulics during the cementing operation, should be considered. Not often is it critical unless an unusually small annular space or lost circulation exists.

Items to be given critical attention which can significantly affect the outcome of the job are: (See Table II)

(1) Hole conditions - weak zones, etc.
(2) Mud condition after running casing.
(3) Casing centralization and movement during the cementing job.
(4) Waiting-on-cement time.

CASING DESIGN

The main consideration in designing a casing program for steam wells is to have sufficient strength to resist longitudinal, tensile, and compressive forces and the collapse and bursting forces to which they may be subjected. It was noted in early wells that collapse or tension failures occurred when the casing was not properly cementing in the hole and to the surface. It appeared that collapse failure was caused by heat expansion of undisplaced drilling fluid or excess water that had separated from the cement slurry and become confined in pockets in the annular space between casings. In more recent wells, fewer failures have been reported in completely cemented wellbore, even though thermal stresses are believed to be very high. Typical casing programs used in the steam wells are shown in Figures 4-8.

The effects of temperature on the modulus of elasticity of various grades of steel are shown in Figure 9. However, in most calculations the modulus of 30×10^6 is normally used. The modulus of elasticity for Grades J55, P110 and P105 appears to decrease slightly from room temperature through 700°F. Above 700°F, the modulus decreases rapidly for both P105 and P110 steels, but it appears to increase slightly for Grade J55. The modulus for the N80 steel was shown to decrease continuously with temperature from a value of 27.9 million psi at room temperature to 15.7 million psi at 900°F.

Casing design consideration, after diameter is selected, include [10,16]:

1. Use of low to moderate strength steels for maximum resistance to fluid, CO_2, and gas corrosion, work hardening and possible H_2S stress corrosion cracking.

2. Selection of weight and grade by basic tension, burst (internal yield) and collapse calculations, and

3. Use of API Buttress type couplings (or other premium couplings) to prevent failures, thermally induced stress fissures and, in the latter case, to eliminate coupling recesses for corrosion protection.

CEMENTING MATERIALS USED IN GEOTHERMAL STEAM WELL COMPLETIONS [9,17,18]

The selection of proper cementing compositions for steam wells has been researched by various companies, agencies, and committees. Comprehensive studies on cementing specimens actually stored in down hole steam environments have been documented in technical papers both in the U.S. and in Europe [19-22]. The same basic findings have been reported by both independent groups in Italy and California, i.e.:

1. All the slurries examined undergo a retrogression of the compressive strength when temperatures increase above 230^oF (110^oC).

2. At high temperatures, in the range 230^o-400^oF, when curing time increases, the compressive strength of the slurries rapidly decreases; only the Class "G" type cement with 40 percent silica showed sufficient compressive strength and durability with time. As far as mechanical strength is concerned, this mixture is the most suitable for the purpose of this work.

The other observations in these studies were noted:

1. API Class "G" Cement can be used up to about 170^oF (77^oC), whereas, at higher temperatures, up to 600^oF (300^oC), it is necessary to add a retarder depending on the temperature.

2. The fluid loss of this composition is more or less equal to the filtrate of a neat cement slurry which is in the area of 1,000 ml based on the API test. The addition of other products such as retarding agent, bentonite, mica and gilsonite, do not affect the fluid loss very much; filtration control agents, however, will reduce fluid loss values less than 60 ml.

3. The rheological characteristics of API Class "G" Cement with silica flour is not much different from those of a neat cement slurry, and are further improved by the addition of the retarding agent and/or friction reducing materials.

4. This cement-silica flour-water composition is capable of reducing the flow of water found in geothermal wells and is ideal for the purpose of bonding, sealing, and zonal isolation.

CASING EQUIPMENT USED IN GEOTHERMAL WELL COMPLETION - FIGURE 10

Floating equipment, cementing plugs, stage cementing tools, centralizers, and scratchers are mechanical devices commonly used when running casing and in the placement of cement in Geothermal Steam Wells [1]. Table III. Specifications covering such equipment are limited and variable, and standards are primarily the responsibility of the manufacturer.

Floating equipment is commonly used on the lower sections of casing to reduce derrick stress by allowing the casing to be floated into place, whereas a guide shoe functions to direct the casing away from ledges and to minimize sidewall caving as the casing passes through deviated sections of the hole.

This equipment is run on the first joint of casing and simply guides the casing through downhole irregularities. Circulation is established down the casing and out the open end of the guide shoe, or through side ports designed to create more agitation as the cement slurry is circulated up the annulus.

Float collars are normally placed one to three joints above the float or guide shoe in the casing string and serve the same functions as the float shoe. They contain a back pressure valve similar to the float shoe and provide a smooth surface or latching device for the cementing plugs.

The spacing between the float collar and guide shoe allows for entrapment of contaminant cement or mud which may result from the wiping action of the top cementing plug. This spacing also prevents contaminated cement from being displaced around the shoe where the best bond is required.

Multiple stage cementing tools are for those conditions when it is desirable to cement two or three separate sections behind the same casing string or to cement a long section in two or three stages.

Stage cementing is used because of lost circulation zones found during drilling and the possibility of formation breakdown resulting in lost circulation from the pressure of a dense cement column and/or high displacement rates. Stage tools are installed just above the lost circulation zone at a specific point in the casing string as casing is being run into the hole. After the cement has been placed around the bottom of the casing (the first stage) the tool can be opened hydraulically with either a free falling opening plug dropped down the casing or with a plug pumped down the casing. When opened, fluid can be circulated through outside ports in the tool body until the first stage cement has set. Cement circulation is performed through these ports. When cement slurry displacement has been completed, a closing plug is displaced to close a sleeve over the side ports.

Although the two stage method of cementing is the most widely used, a three stage method can be used to distribute a cementing slurry over a long column when hole conditions will not allow circulation in one or two stages. The three stage cementing technique employs the same steps as the two stage technique except for one additional stage using the plug type method in the uppermost stage.

Cementing plugs are used to minimize contamination of the interface between the mud and cement in the casing; a bottom plug is pumped ahead of the cement slurry [23].

When released from its container, the plug wipes the mud from the casing wall as it moves down the pipe. When this plug reaches the float collar, differential pressure ruptures a diaphragm on top of the plug allowing the cement slurry to proceed through the plug and floating equipment and up the annular space between the pipe and hole. The top cementing plug reduces the possibility of contamination or channeling with the displacement fluid and results in a pressure buildup when landed at the float collar or float shoe.

The uniformity of the cement sheath around the pipe determines to a great extent the effectiveness of the seal between wellbore and casing. Since most holes are not straight, the pipe will generally be in contact with the wall of the hole at several places.

Centralizers have been the object of much research [24,25]; authors may differ in their approach to the ideal cementing job, but the one major single factor that receives unanimous agreement for success is that proper centralization of casing is essential.

The design of centralizers varies considerably with vendors and for different hole applications. For this reason, the API Specifications [24], as defined in Standards 10D, insure minimum strength requirements based on (1) restoring force and (2) starting force.

Scratchers or wall cleaners are mechanical cleaning devices that are attached to the casing to remove loose filter cake from the wellbore. They are most effective when used during the cement displacement operation.

Scratchers, like centralizers, aid the distribution of cement around the casing where a complete cement seal between the pipe and formation is essential. Casing scratchers are classified as:

1. Those used when the casing is reciprocated.
2. Those used when the casing is rotated.

The rotating scratcher is attached to the casing with the use of limit clamps or by welding.

Reciprocated type cleaners are also constructed of steel wires or cables and are installed on the casing with an integral or separate clamping device.

Rotating scratchers should be used where the pipe must be set at a precise depth and there is assurance that the pipe can be rotated.

Reciprocating scratchers are more effective where there is not depth limitation in setting casing and the pipe can be worked up and down after landing.

DISPLACEMENT - THE CRITICAL PERIOD

While much current research has been devoted to steam well cementing materials, one major area is frequently overlooked [25-30]. In any hole, drilling fluids receive much attention until the drilling objectives are reached. Filter cake on the wellbore makes it possible to achieve stability prior to the running of casing and pumping cement. Once the well is completed, the mud is no longer needed and the controlled properties during drilling may not be maintained. It is assumed that the pumping of cement slurry automatically will displace all the mud, but this may not always occur.

Effective displacement of drilling fluid by cement is a critical factor in successful completion of any well, particularly in hot steam wells. Primary cementing failures are predominantly created by channels of drilling fluid bypassed by the cement in the annulus. These channels are highly dependent upon the drilling fluid viscosity and the filter cake deposits upon the permeable wellbore wall. Any theoretical or model study may not adequately simulate the removal of or the thixotropic characteristics of the mud filter cake due to the lack of dynamic wellbore conditions in the laboratory. Because of this, any theoretical study of the actual displacement process requires great care in interpreting the results.

Field experience where casing or liner failures have occurred repeatedly need close examination. Items which are considered very valuable in diagnosing the problems include:

(A) Pump pressures at the cementing unit throughout the job.

(B) Close examination of the returns as they cross the shaker, particularly on jobs where cement returns are expected.

(C) Conditions of displacement fluid.

(D) Time required to mix and displace the cement.

After repeatedly having (1) a loss of returns and (2) subsequent casing or liner failures, two geothermal operators decided to examine their records in an attempt to identify what might be causing these two problems. The most significant and outstanding item found in this examination was the pump pressures at the cementing unit had increased - once the cement slurry entered the casing or liner-hole annulus - to twice or more what they should have been. When the pump pressure exceeded twice the mud circulating pressure observed during drilling, lost circulation occurred and was seldom recovered.

If the pump pressure increased less than twice the mud circulating pressure and cement returns were obtained, large amounts of rock cuttings from pea size to marble size were observed crossing the shale shaker.

Several occurrences of trouble were recorded in obtaining adequate volumes of displacement fluid at the desired rate. In most of these cases, the displacement mud was too thick to pump, requiring water dilution and agitation, slowing the displacement process dramatically--often resulting in cement being left in the casing or liner.

To eliminate or reduce the occurrences of these problems, the following steps have been employed and, if each is properly used, seldom is lost circulation encountered and casing or liner failures from buckling or collapse have ceased to occur:

(A) After reaching T.D., the hole is circulated through the drill string long enough to remove from the hole and drilling fluid cuttings large enough that might bridge in the casing or liner-hole annulus.

(B) The pump pressure, mud density, viscosity and temperature are recorded at 2-3 pump rates.

(C) Casing running speed should not exceed 1000 feet per hour.

(D) Break circulation every two hours while running casing or liner and circulate for a minimum of 15 minutes while reciprocating the casing.

(E) After the casing is on bottom, condition the mud and hole by circulating and, again, reciprocate the casing periodically such as 15 minutes out of every hour. Check the mud viscosity and temperature and continue circulating until both stabilize. Be sure to check for cuttings in the returns and try to reduce to less than 3%. This process usually requires four or more hours.

(F) Determine a maximum pump rate to be observed to keep from exceeding a pre-determined pump pressure. This pump pressure should not exceed twice the mud circulating pressure during drilling.

TYPICAL GEOTHERMAL CASING CEMENTING PROGRAM RECOMMENDATIONS

1. Prepare the mud and hole for cementing as previously indicated above.

2. Mix and pump a viscous spacer which is compatible with both the mud and the cement slurry, using a volume capable of filling at least 600-800 ft. per 2000 feet of casing-hole annulus. This spacer should be more viscous and heavier than the mud, but less viscous and lighter than the cement slurry.

3. Follow the spacer with 10 bbls. of fresh water.

4. Follow with 20-50 bbls. of FLO-CHEK™ hole conditioning agent.

5. Follow with 5-10 bbls. of Fresh Water.

6. Drop Bottom Plug if one is to be used.

7. Mix and pump cement at the correct density.

8. Pump as fast as possible but keep pump pressure below pre-determined maximum. Try to maintain a uniform rate.

9. Release top plug with 3-5 bbls. of cement slurry remaining in the pumps and lines. Switch to mud without shutting down and try to maintain a steady pump rate throughout the displacement.

10. Continue displacing until plug bumps or pump pressure reaches the pre-determined maximum. It's easier to drill out cement than it is to squeeze to repair a faulty or unsuccessful casing cement job, particularly if lost circulation is caused by continued pumping at too high a pump pressure.

11. Check to see if the floats are holding.

12. If the float fails to hold, close in the cementing head, but be sure the pressure inside the casing does not increase more than 200 psi above equalization pressure.

13. Give the cement adequate time to harden, usually 18-24 hours.

The important thing to remember is that displacement factors influence the displacement process in all wells, and that the condition of the drilling fluid is directly related to primary cementing success. Characteristics of the mud filter cake are dominant parameters affecting removal of the mud. Simply stated, if mud loses its fluidity, i.e., it becomes thick and viscous, it becomes very difficult to displace. Annular velocity is also an important factor affecting displacement. High flow rates, whether or not the cement is in turbulent flow, provide better displacement than plug flow rates. Other factors that cannot be overlooked are cement rheology and the flow energy of the cement, density differences, centralization, and pipe movement. In every displacement process there are two major opposing forces in cement/mud displacement, namely, a resisting force (the immobility of the drilling fluid), and a displacing force (the flow energy of the displacing fluid). Displacement may be improved by either decreasing the immobility of the drilling fluid by improving the mud properties, or by increasing the flow energy of the cement.

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TABLE I SUMMARY OF OILWELL CEMENTING ADDITIVES[1]

Type of Additive	Use	Chemical Composition	Benefit	Type of Cement
Accelerators	Reducing WOC time Setting surface pipe Setting cement plugs Combatting lost circulation	Calcium chloride Sodium chloride Gypsum Sodium silicate Dispersants Sea water	Accelerated setting High early strength	All API Classes Pozzolans Diacel systems
Retarders	Increasing thickening time for placement Reducing slurry viscosity	Lignosulfonates Organic acids CMHEC Modified lignosulfonates	Increased pumping time Better flow properties	API Classes, D,E, G, and H Pozzolans Diacel systems
Weight-reducing additives	Reducing weight Combatting lost circulation	Bentonite-attapulgite Gilsonite Diatomaceous earth Perlite Pozzolans	Lighter weight Economy Better fillup Lower density	All API Classes Pozzolans Diacel systems
Heavy-weight additives	Combatting high pressure Increasing slurry weight	Hematite Ilmenite Barite Sand Dispersants	Higher density	API Classes D, E, G, and H
Additives for controlling lost circulation	Bridging Increasing fillup Combatting lost circulation	Gilsonite Walnut hulls Cellophane flakes Gypsum cement Bentonite-diesel oil Nylon fibers	Bridged fractures Lighter fluid columns Squeezed fractured zones Minimized lost circulation	All API Classes Pozzolans Diacel systems
Filtration-control additives	Squeeze cementing Setting long liners Cementing in water-sensitive formations	Polymers Dispersants CMHEC Latex	Reduced dehydration Lower volume of cement Better fillup	All API Classes Pozzolans Diacel systems
Dispersants	Reducing hydraulic horsepower Densifying cement slurries for plugging Improving flow properties	Organic acids Polymers Sodium chloride Lignosulfonates	Thinner slurries Decreased fluid loss Better mud removal Better placement	All API Classes Pozzolans Diacel systems
Special cements or additives				
Salt	Primary cementing	Sodium chloride	Better bonding to salt, shales, sands	All API Classes
Silica flour	High-temperature cementing	Silicon dioxide	Stabilized strength Lower permeability	All API Classes
Mud Kil	Neutralizing mud-treating chemicals	Paraformaldehyde	Better bonding Greater strength	API Classes A, B, C, G, and H
Radioactive tracers	Tracing flow patterns Locating leaks	Sc 46	-	All API Classes
Pozzolan lime	High-temperature cementing	Silica-lime reactions	Lighter weight Economy	-
Silica lime	High-temperature cementing	Silica-lime reactions	Lighter weight	-
Gypsum cement	Dealing with special conditions	Calcium sulfate Hemihydrate	Higher strength Faster setting	-
Hydromite	Dealing with special conditions	Gypsum with resin	Higher strength Faster setting	-
Latex cement	Dealing with special conditions	Liquid or powdered latex	Better bonding Controlled filtration	API Classes A, B, G, and H

TABLE II — FACTORS AFFECTING PRIMARY CASING CEMENTING

Personnel
- Well owners responsibility, service company responsibility

Drilling Rig Operations
- Running time of casing, rate of running casing, fracture gradient, position of collar on landing joint, circulating time after running casing

Drilling Fluid
- Composition, weight, viscosity, water loss and filter cake, gel strength, admixes

Bore Hole
- Diameter, depth, straightness, formation characteristics

Casing
- O.D. casing versus hole size, depth of casing set versus total depth

Special Tools
- Guiding and floating equipment (shoes, collar), centralizers, scratchers, stage cementing, casing movement (reciprocating vs rotation)

Cementing Materials
- Slurry volume required (caliper survey, estimate), type of cement (API classification, admixes), mixing water (supply, impurities, temperature), slurry weight (volume - cu. ft./sack, volume to be mixed)

Mixing and Pumping of Cement Slurry
- Plugs (bottom, top, location of top plug, compression of fluid), spacers-flushes (water, special fluid), time (mixing, displacement), mixing units (number, type, mixer)

Cementing Head and Connections
- Swage, quick change, plug container, opening in head, valves on head, floor manifold

TABLE III

DIGEST OF CEMENTING EQUIPMENT AND MECHANICAL AIDS[1]

Cementing Equipment and Types	Application	Placement
Floating Equipment		
1. Guide Shoes	Guides casing into well *Minimizes derrick strain*	First joint of casing
2. Float Collars	Prevents cement flow back Create pressure differentials to improve bond Catches cementing plugs	1 joint above shoe in wells less than 6,000 ft 2-3 joints above shoe in wells greater than 6,000 ft
Automatic Fill-Up Equipment		
1. Float Shoes	Same as Float Collars and Shoes except fill-up is controlled by hydrostatic pressure in annulus	Same as Float Collars or Guide Shoes
Formation Packer Tools		
1. Formation Packer Shoes	Packer expands to protect lower zones while cementing	First joint of casing
2. Formation Packer Collars		As hole requirements dictate
Cementing Stage Tools		
2 Stage 3 Stage Full Opening Tools	When required to cement two or more sections in separate stages	Based on critical zones and formation fracture gradients
Plug Containers		
1. Quick Opening 2. Continuous Cementing Heads	To hold cementing plugs in string until released.	Top joint of casing at surface of well
Cementing Plugs		
1. Top and Bottom Wiper Plugs 2. Ball Plugs 3. Latch Down Plugs	Mechanical Spacer between Mud and *cement* (bottom plug) and cement and displacement fluid (top plug)	Between well fluids and cement
Casing Centralizers		
Variable Types	Center casing in hole or provide minimum stand-off to improve distribution of cement in annulus, prevent differential sticking	Straight hole—1 per joint through and 200 feet above and below pay zones; 1 per 3 joints in open hole to be cemented Crooked hole—Variable with deviation
Scratchers or Wall Cleaners		
1. Rotating	Remove Mud cake and circulatable mud from well bore.	*Place through producing* formations and 50 to 100 feet above. Rotate pipe 15 to 20 RPM
2. Reciprocating	Aid in creating turbulence Improve cement bond	Placement is same as rotating Reciprocate pipe *pipe 10 to 15 feet off bottom*

Reprint from SPE Monogram

FIGURE 1

TYPICAL PRIMARY CEMENTING JOB

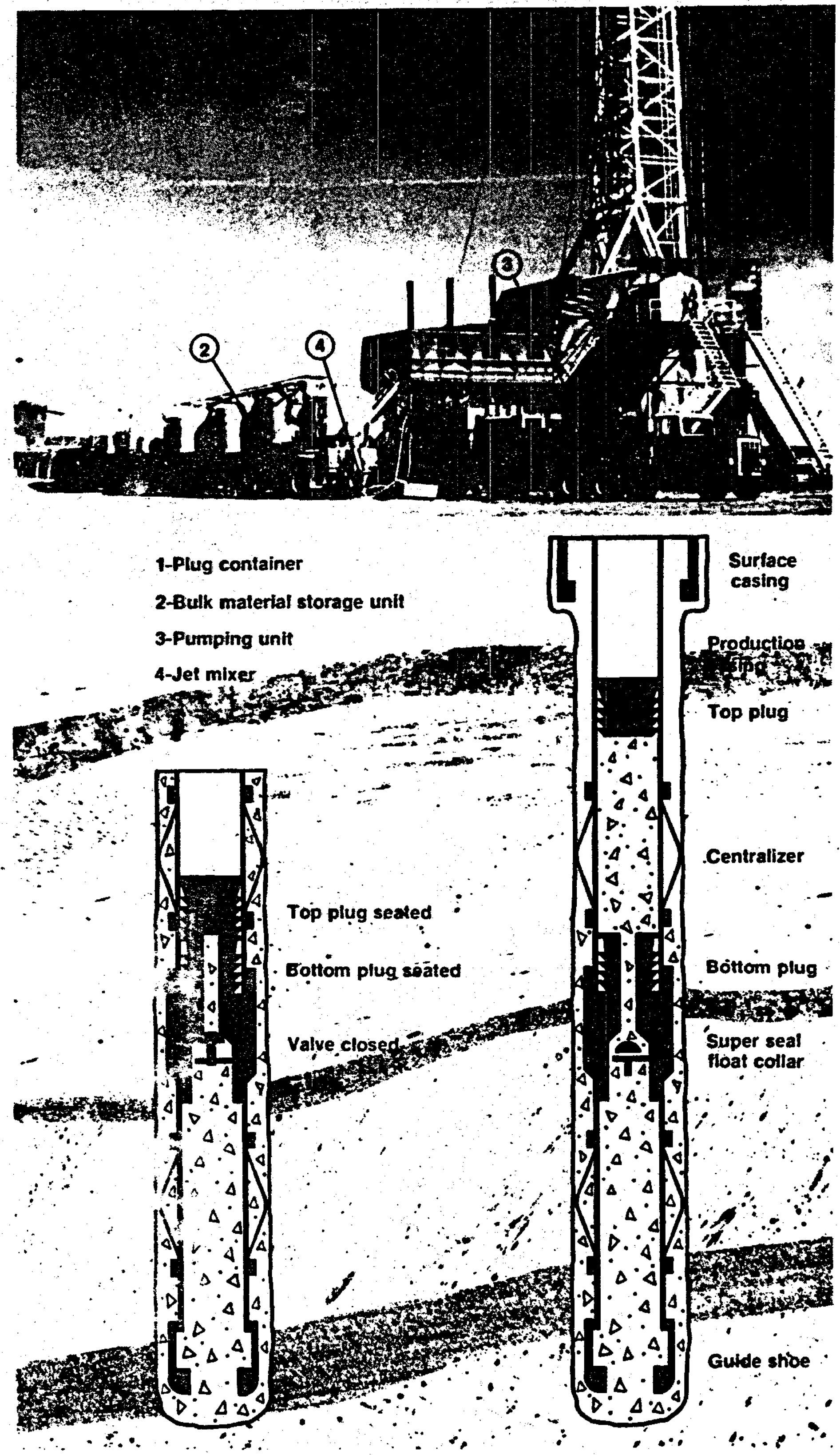


FIGURE 2

TYPES OF LINERS USED IN WELLS

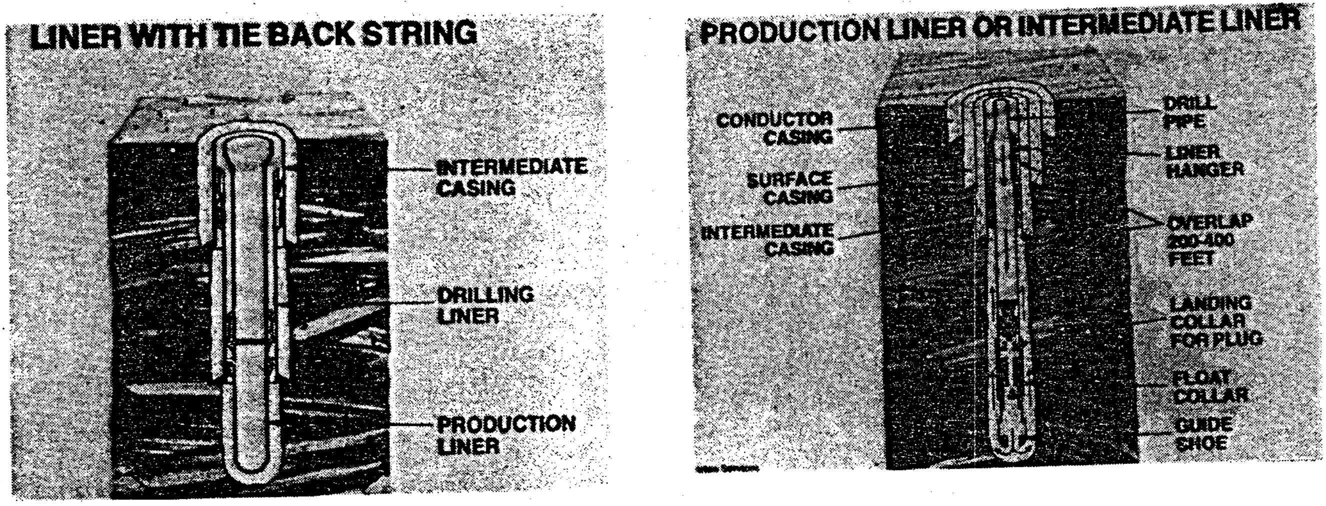
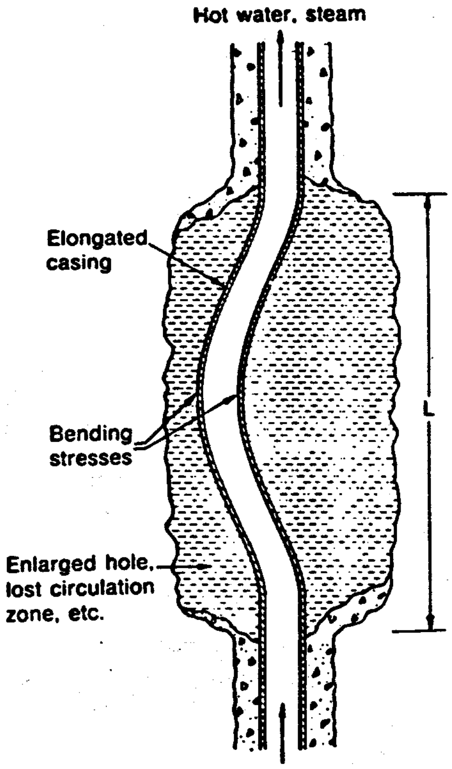


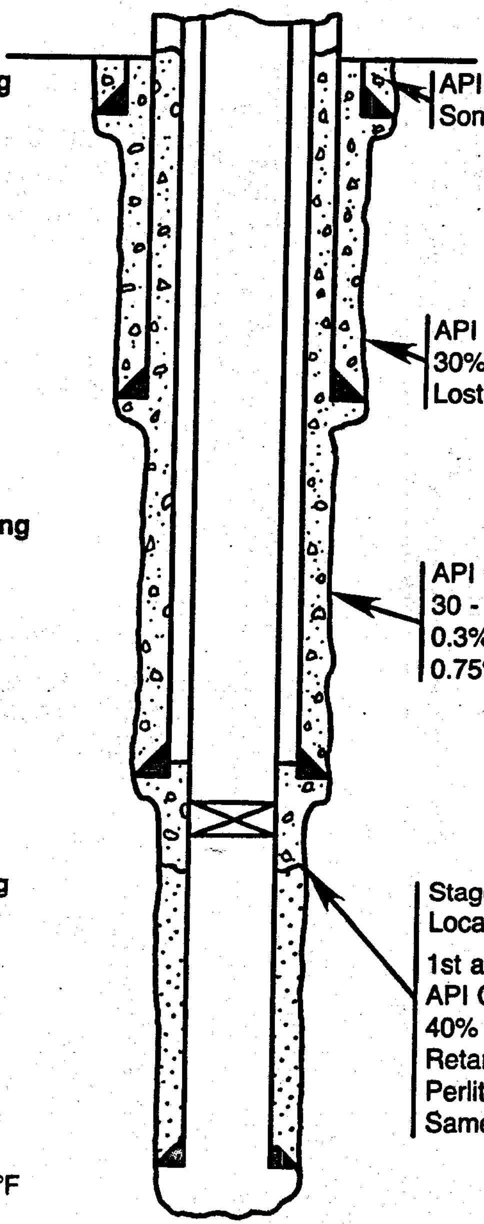
FIGURE 3



CASING BUCKLING OF UNSUPPORTED PIPE WITH HEATING[10]

FIGURE 4

Early Salton Sea Wells



Conductor Casing
55-60 Feet
20"-30" hole or
18" in 22" hole

API Class A or G Cement
Sometimes 30% Silica Flour

Surface Casing
290-300 feet
16"-22" hole or
13⅜"-17½ hole

API Class A or G Cement
30% Silica Flour
Lost Circulation Material

Intermediate Casing
1200 - 1700 feet
10¾" - 15" hole

API Class A or G Cement
30 - 40% Silica Flour
0.3% Retarder
0.75% Friction Reducer

Production Casing
4700 - 6000 feet
5½" - 9⅞" hole
7⅞" - 10⅝" hole

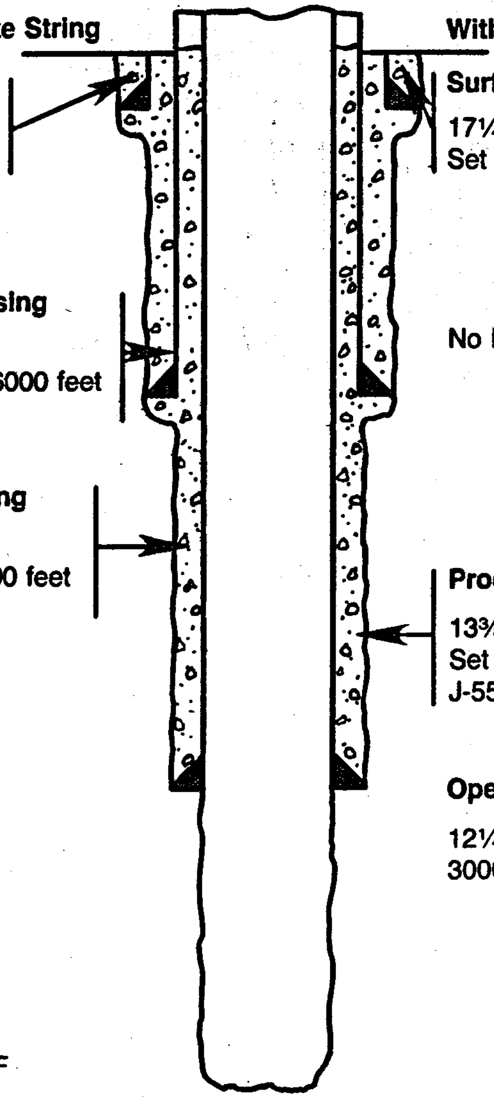
Stage Tool* - 2400 to 3000 feet
Location based on fracture gradient
1st and 2nd Stages
API Class G or E Cement
40% Silica Flour
Retarder as needed
Perlite if needed
Same material used on both stages

BHST - 500 to 700°F

*Sometimes 3 stage tool without intermediate string.

FIGURE 5

Geothermal Steam Well*
Northern Italy



With Intermediate String

Surface Casing
17¼" - 20" hole
Set @ 328 feet

Intermediate Casing
13⅜" - 16" hole
Set @ 13000 - 16000 feet
J-55 - 68 ppf

Production Casing
9⅝" - 12¼" hole
Set @ 3200 - 4000 feet
J-55 - 40 ppf

Cap Rock
8½" open hole
5000 - 6000 feet

BHST 530 - 570°F

Without Intermediate String

Surface Casing
17¼" - 20" hole
Set @ 328 feet

No Intermediate String

Production String
13⅜" - 16" hole
Set @ 2600 - 3000 feet
J-55 - 68 ppf

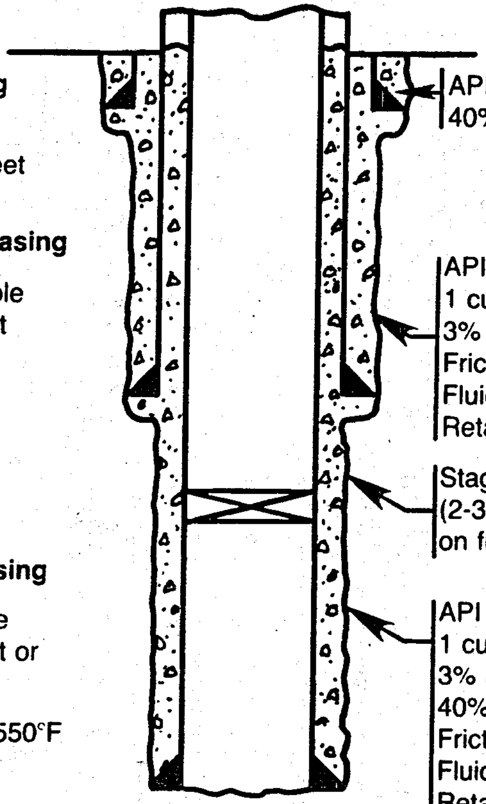
Open Hole
12¼"
3000 to 4-5000 feet

Production Casing Cement
API Class G Type
(425 Cement)
40-80% Silica Flour
plus Retarder

* From advancement in Cementation Techniques in the Italian Geothermal Wells by Cigni, Ugo, Fabbri, Fulio, Grovannoni, Anselmo - Larderello, Italy

FIGURE 6

Imperial Valley Wells
Current



Surface Casing

16" - 20" hole
Set to ± 100 feet

Intermediate Casing

13⅜" - 17½" hole
Set ± 1200 feet

Production Casing

9⅝" - 12¼" hole
Set ± 8000 feet or deeper

BHST°F 450° - 550°F

API Class G Cement
40% Silica Flour

API Class G Cement
1 cu ft Perlite
3% Bentonite
Friction Reducer
Fluid Loss Agent
Retarder

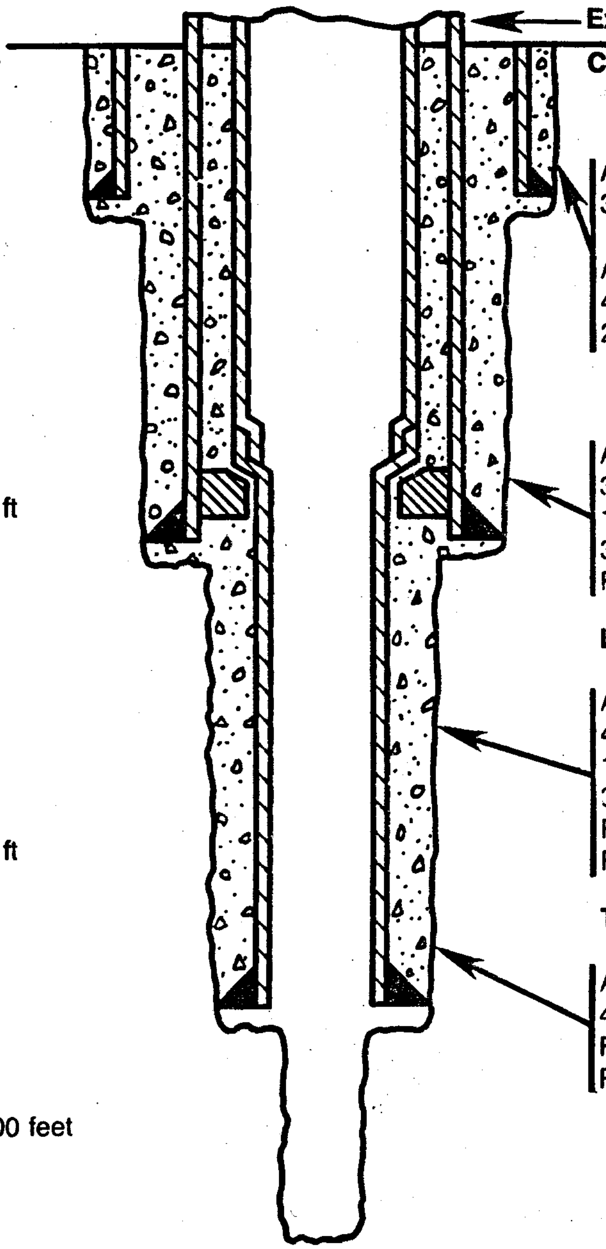
Stage Cement Tool
(2-3 stages) location based on fracture gradient

API Class G Cement
1 cu ft Perlite
3% Bentonite
40% Silica Flour
Friction Reducer
Fluid Loss Agent
Retarder
(Basic cementing composition used on both stages of production string)

Note - All slurries should be mixed with 0% free water.

FIGURE 7

Northern California Geysers Area



Conductor Casing

20" - 26" hole
Set at 100-150 feet

Surface Casing

13⅜" - 17½" hole
Buttress thread
Set at 2000 - 2500 ft
K-55 - 61 ppf

Production Liner

9⅝" - 12¼" hole
Buttress thread
36 - 40 ppf
Set at 5000 - 5800 ft

Open Hole

8¾ to 7000 - 10,000 feet
BHST 450-525°F

Expanding Well Head

Cement

Surface

API Class G
3% Calcium Chloride

API Class G
40% Silica Flour
2% Calcium Chloride

Intermediate

API Class G Cement
35% Silica Flour
1 cu ft Perlite
3% Bentonite
Friction Reducer

Liner - Lead Slurry

API Class G Cement
40% Silica Flour
1 cu ft Perlite
3% Bentonite
Friction Reducer
Retarder

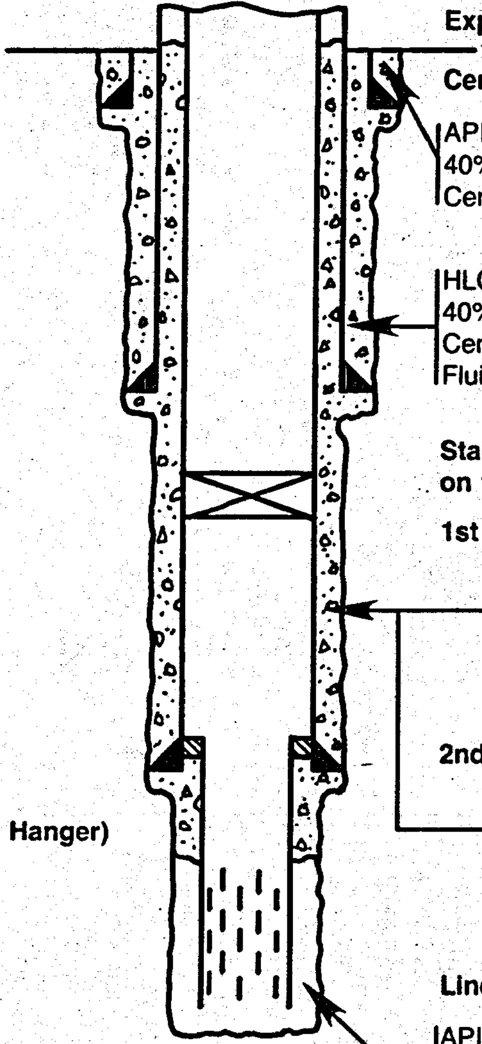
Tail In Slurry

API Class G Cement
40% Silica Flour
Friction Reducer
Retarder

Note - Liner top sometimes squeezed tie back string usually 10¾".
All slurries mixed with 0% free water.
Preflushes used on all strings.

FIGURE 8

Baja California, Mexico
Cerro Prieto Field
Geothermal Completion



Conductor Casing

20" - 26" hole
H-40 - 94 ppf
Set 100 - 300 feet

Surface Casing

13⅜" - 17½" hole
K-55 - 61 ppf
Buttress thread
Set @ 3000 - 3200 feet

Intermediate Casing

9⅝" - 12¼" hole
N-80 - 43.5 ppf
Hydril SEU
Set @ 6000 - 6500 feet

Production Liner (Mech. Hanger)

7" set in 8½" hole
Hydril SEU
9780 feet

BHST - 600-650°F

Expanding Well Head

Cement

API Class G Cement
40% Silica Flour
Cement Friction Reducer

HLC Cement
40% Silica Flour
Cement Friction Reducer
Fluid Loss Agent - Retarder

Stage Tool - Location based on fracture gradient

1st Stage - API Class G Cement
40% Silica Flour
Filler Additive
Friction Reducer
Bentonite
Fluid Loss Agent

2nd Stage - API Class G Cement
1 cu ft Perlite
Bentonite
Friction Reducer
Fluid Loss Agent
Retarder

Liner

API Class G Cement
40% Silica Flour
Filler Additive
Friction Reducer
Bentonite
Fluid Loss Agent

Note - Flushes ahead of cement slurry on surface and intermediate strings.

MODULUS OF ELASTICITY OF CASING
VERSUS
TEMPERATURE

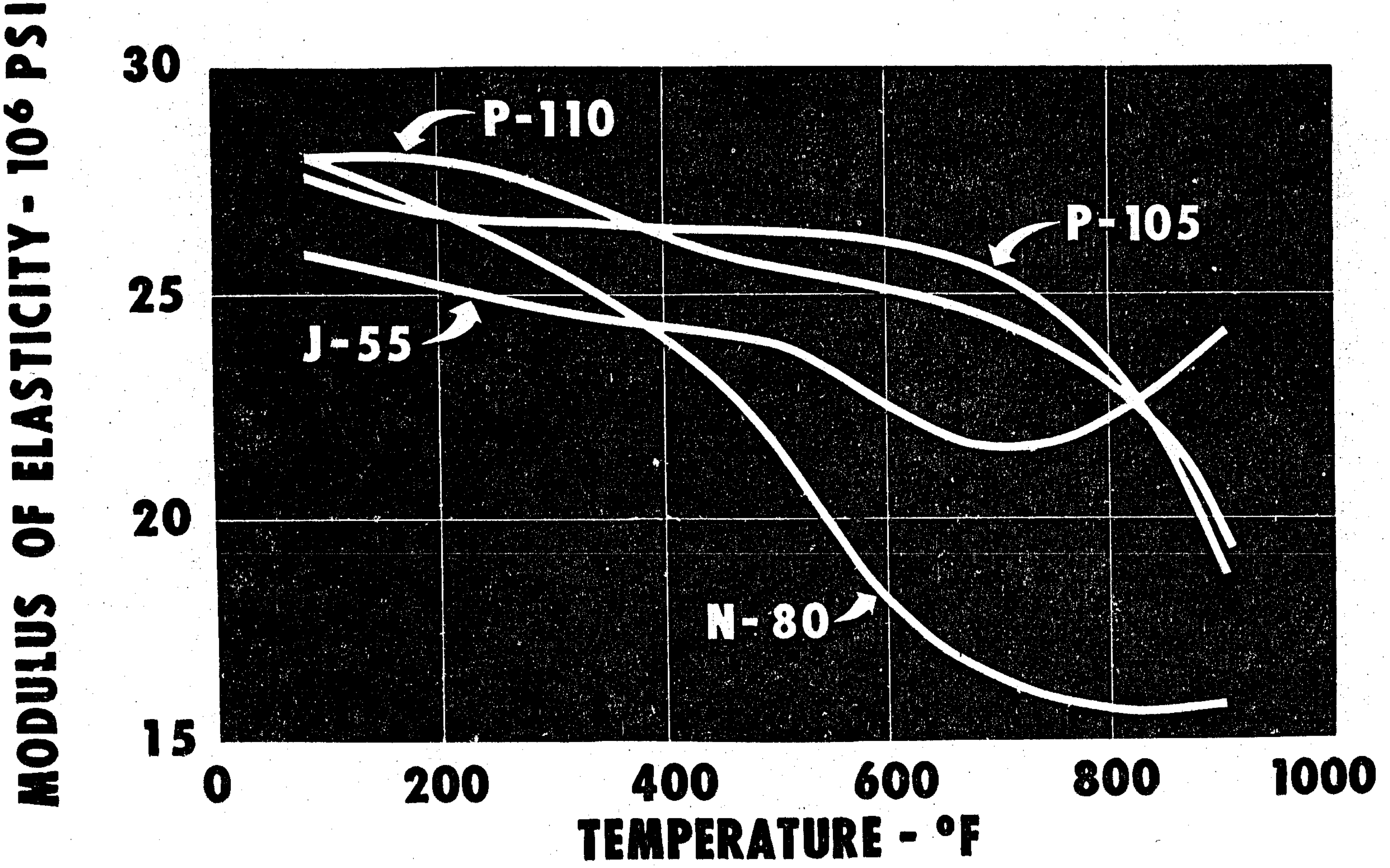
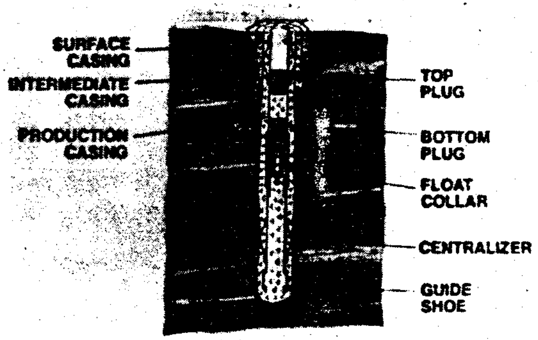


FIGURE 9

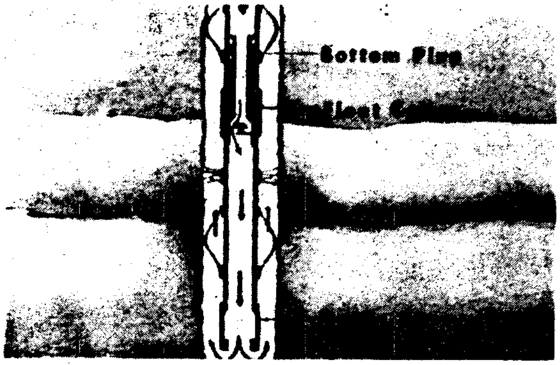
FIGURE 10

CASING EQUIPMENT

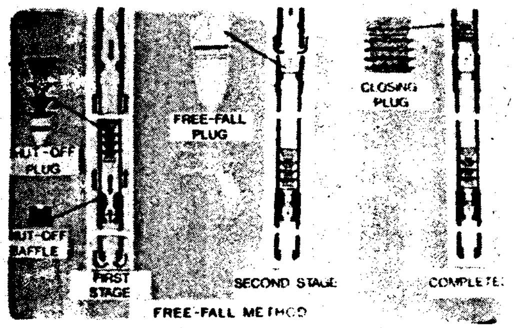
NORMAL DISPLACEMENT METHOD



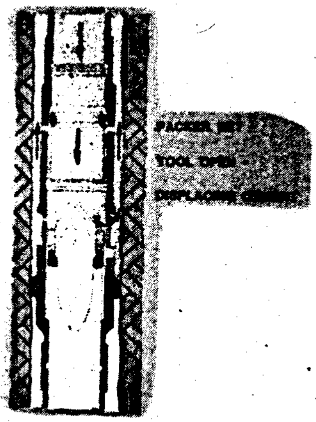
CEMENTED CASING STRINGS



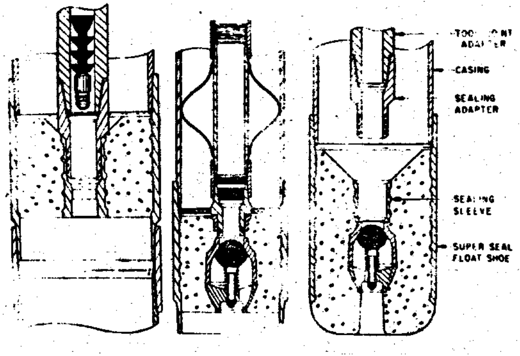
CASING CENTRALIZERS
AND SCRATCHERS



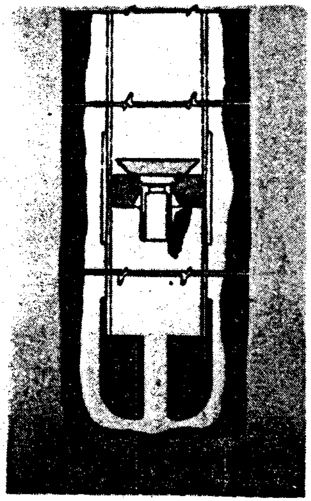
STAGE CEMENTING



STAGE CEMENTING COLLAR
AND PACKER COLLAR



STAB IN FLOATING EQUIPMENT



AUTOMATIC FILL UP EQUIPMENT