A Design for Cementing Deep Delaware Basin Wells

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INTRODUCTION

The search for oil in the Permian Basin of West Texas has resulted in new horizons in the field of petroleum engineering as well as petroleum reserves. However, one-third of the area has, so far, been elusive in yielding its secrets. This area, (See Fig. 1) is called the Delaware Basin. Prior to 1957, exploration had been in the Delaware series. Several fields have been discovered, but the larger reserves associated with Ector County, Lee County, and other Permian Basin areas have been missing.

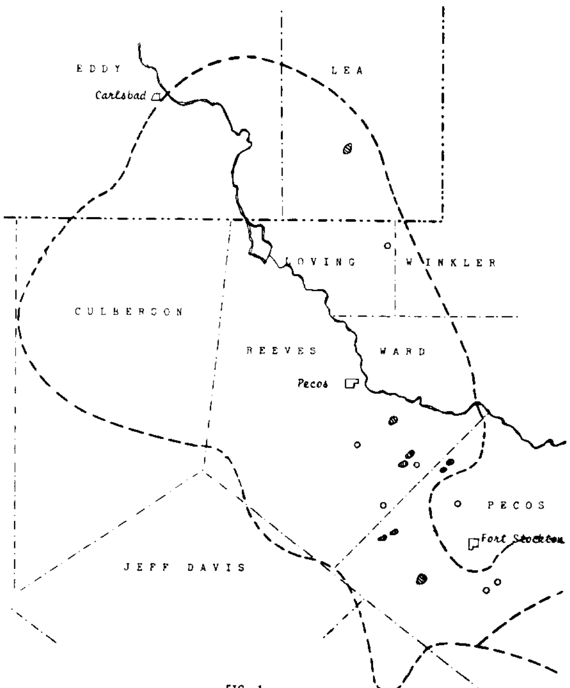


FIG. 1
DELAWARE BASIN OF WEST TEXAS AND NEW MEXICO
○ Wells below 20,000 feet
● Fields below 14,000 feet

If the hunt has produced nothing else, it has produced superlatives, "Deepest Well Drilled", "World's Deepest Production", "Deepest Drill Stem Test". Geological data indicate the search is justified and considerable exploration has been accomplished. Several wells have been drilled or are being drilled to a depth greater than 20,000 ft. One well, Pure's Tyrrell 1, has production potential below this depth. Other production is established at lesser, although still great depth, below 15,000 ft. Present indications are that the exploration will continue.

In common with other segments of the Permian Basin, many formations below the Salado are dense with permeability resulting from naturally occurring fractures. These fractures break down under excessive vertical gradients of the mud column. This requires restricting mud hydraulics to proper values to avoid lost circulation. Associated with the formations of low breakdown pressures are reservoirs of high gas pressure. Isolating these 2 factors is of prime importance.

It is, therefore, timely to consider the cementing procedures of this area. The wells are deep but anomalous temperature behaviors are being reported. The wells are hot and Phillips[1] reported a temperature of 475° F., but many of the temperatures are sub-normal for corresponding depths.

Fig. 2 is a schematic of the lithology of the area including the associated casing strings that have been used. Although this report does not constitute a recommendation, the design of casing for these wells itself constitutes an extensive study. The casing equipment associated with these strings, however, must be considered part of the cementing design. The cementing materials used in the following examples have been successfully used on jobs in the Delaware Basin. However, these specifications have not been the recommendation for any single well in the area. This approach presents the materials available and the reasons for selecting them. The selection of materials and techniques must be considered for each well. Thus, this paper presents a basic design for cementing the deep Delaware Basin wells of Texas and New Mexico.

CONDUCTOR PIPE (A, FIG. 2)

A large casing, designated as string A in Fig. 2, can be set to protect the ground water and to assist in controlling excessive washout of surface sands. The inside diameter must pass a 24 to 26 in. bit. Therefore, 26 or 30 in. casing will be necessary for use here. Class A cement with accelerator will generally satisfy requirements. Considerable excess cement, in this case, is not used. If the string is not circulated, cementing through the annulus with small tubing is easily accomplished. In fact, concrete may be used if desired.

The use of this string is arbitrary. In areas of known surface conditions, it can possibly be eliminated. However, if unexpected water flow or lost circulation is encountered it will prove extremely valuable.

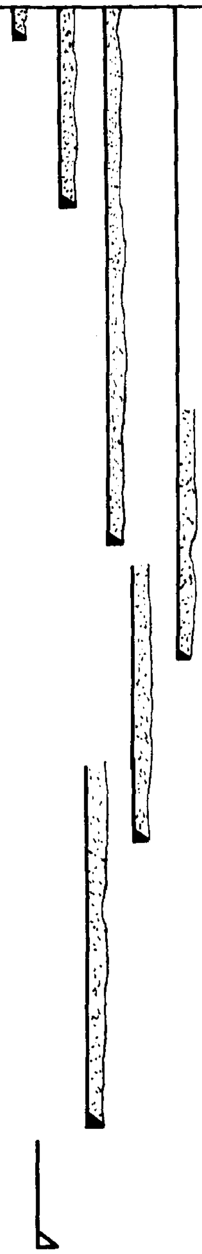
SURFACE WATER PROTECTION STRING (B - FIG 2)

The schedule for cementing surface water protection strings is shown in Table 1. The accelerator for cementing surface strings should be a water soluble chloride. The minimum amount used should result in a filtrate water with a minimum of 5000 ppm chlorides. Clay minerals are a predominate portion of shale formation and exist in various quantities below the

FIG. 2

LITHOLOGY OF DELAWARE BASIN

SYSTEM	FORMATION		TEMP. °F	FORMATION Frac.Grad. psi/ft.
Quaternary	Recient		60	
Triassic	Santa Rosa			
Permian	Dewey Lake			
	Rustler		85	0.90
	Salado			
	Castile			
	Delaware	Lamar		
		Bell Canyon		0.55
		Cherry Canyon		0.59
		Brushy Canyon		0.60
	Bone Springs		160	0.57
	Wolfcamp			0.68
	Wolfcamp Detrital			0.85
Pennsylvania	Cisco			
	Canyon		185	
	Strawn			
	Atoka			
	Morrow			0.91
Mississippian	Mississippi		250	0.73
	Kinder Hook			
	Woodford			
Devonian	Devonian			0.58
Silurian	Fusselman			0.83
Ordovician	Montoya			
	Simpson			
	Ellenburger		325	0.62
Pre-Cambrian	Bliss		475	



CASING & HOLE

A 30" x 36"

Conductor Pipe

B 20" x 24"

Surface Water Protection String

C 13-3/8" x 17-1/2"

Protective Casing

D 9-5/8" x 12-1/4"

Protective String

E 7-5/8" x 8-3/4"

Protective Liner

F 5-1/2" x 6=5/8"

Protective Liner

G

Liner

sands. The accelerator used may be sodium chloride at normal surface pipe temperature, if WOC time in excess of 18 hr. is satisfactory. Slagle and Smith[2] have presented considerable data on salt cement. Most authorities agree set cement with 500 psi compression will satisfactorily support casing. No such agreement can be found on the required safety factor which should be applied to cementing casing through which further drilling is to be conducted. It is suggested that a safety factor of 3 be applied. Average strength values are listed in published "Cementing Tables".[3]

TABLE 1

Cement: 500 cu. ft. Class A with 2% accelerator and Class C with 4% bentonite.

Casing Equipment: Float Shoe with drill pipe, seal assembly and 2 centralizers, sealing compound.

Cementing Rate: 8-10 bbl. per min.

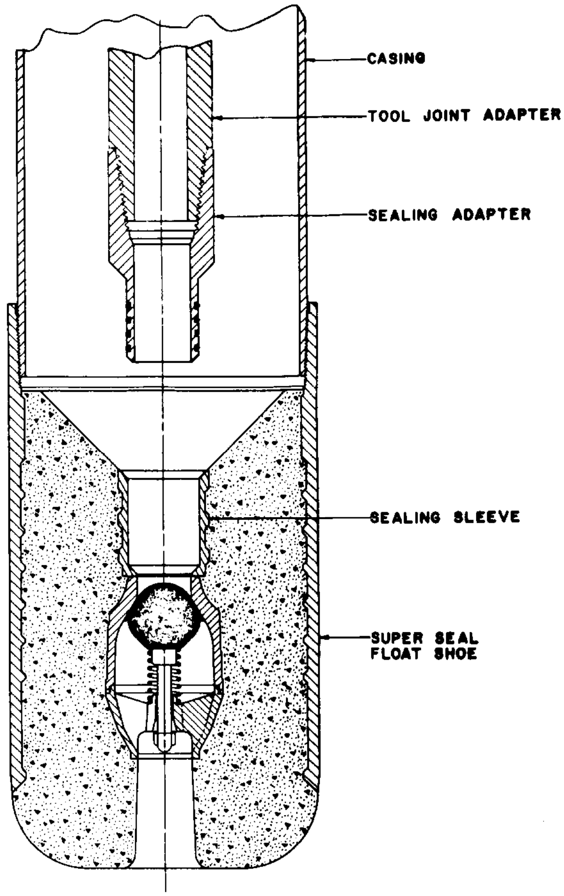
Class C cement with 4% bentonite is used to reduce hydrostatic head. It will also produce a saving in material cost. The Class C sulfate resistant cement normally used in this area is a high-water-ratio cement and will, consequently, have a greater yield per sack than Class A cement. In high-water-ratio slurries, therefore, it is often a more economical slurry. However, as sulfate resistance is obtained by eliminating the tri-calcium aluminate complex and because this complex is a prime initiator of early strength, it may not be advisable to use these cement slurries with very high water ratios where early strength is required.

Lost returns likely to be encountered in this type cementing job will likely be caused by high porosity. The acceptable type material for treating this type lost returns is a fibrous type. Shreaded cellophane flakes are being used by most operators of this area. One-fourth to one-half pound per sack of cement is generally sufficient. Should a loss of mud be experienced while drilling, shreaded cellophane flakes should be added to the low density slurry.

Heads and plugs are available for 20 in. casing. However, the casing shoe with a seal assembly for a drill pipe stinger is being caused by many operators. Without this arrangement (See Fig. 3), the carefully calculated cement volume may not circulate the well, and an excess delivery can be run. With this arrangement, should cement begin to circulate before the estimated amount is used, mixing may be stopped and only the capacity of the drill pipe will be circulated out. More important, the casing stretch due to hydraulics of cementing will be reduced. This can be important when we consider that with 2000 ft. of 20 in. casing the safety factor for joint strength may have been reduced to less than 2. The overall cost, when using this tool, will be offset since large, expensive plugs are not required. The float in the float shoe may eliminate the necessity of installing a blowout preventer before the casing is cemented. A centralizer should be located at the bottom collar. Unless there is extreme hole deviation, a second centralizer located at the fourth collar from bottom will usually centralize the casing. The shoe and at least one additional joint should be bonded. One of the available epoxy "welding" compounds is recommended for this. Not only can this be done by the regular drilling or casing crew, but heat welding is usually not required. Heat welding is no longer considered essential.

If there is insufficient cement slurry to circulate the string in this stage, it will be necessary to delay operations until the cement has set and re-cement the top through the annulus with small tubing. Future drilling equipment and casings will be anchored on this string so it is necessary that it be solid. Consequently, sufficient cement slurry is quite important. The usual method is to calculate annular volume from data available in the "cementing tables" or other sources. To this theoretical amount, a field correction factor is applied based on experience in the area. This correction factor will vary from 50% to possibly 300%. A fluid volume survey is available and reliable. Another volume survey is the independent actuating arm type caliper survey. This type survey with a constant integration device will deliver data marked in ft. per 100 cu. ft. hole volume.

The string, designated as B in Fig. 2, is to be set to isolate potable waters from contamination. Water in areas receiving less than 20 in. average rainfall should be considered. Even brackish source waters demand adequate protection. Besides ground water, the Santa Rosa and Rustler formations are locally used as water sources. The Castile may also produce a useable water. Some operators prefer to protect the ground waters with this stage and protect other water sources the next stage. However, most prefer to set below the Rustler. Not only does this help protect 2 important water sources, it also helps isolate future mud systems



FLOAT SHOE SEAL ASSEMBLY
AND
DRILL PIPE ADAPTER
FIG 3

from lost circulation conditions in the Rustler as well as excessive washout of surface sands and gravel. Lost circulation of the Rustler has not been considered a great problem in the immediate area of exploration. However, correction of lost circulation in the Rustler has been extremely difficult in some areas.

When setting this string it is most important that the casing seat be carefully selected. If a poor seat is selected and a good cement bond is not obtained, the drill pipe will possibly break off a bottom joint. It is also believed that if an unconsolidated formation is used for a seat, a washout will occur behind the cement and casing. This is another cause of failure of protective strings. Failure of protective strings causes considerable extra expense and possible loss of the hole drilled. To hold the casing firmly while drilling continues, neat cement has been selected for placement on the bottom.

PROTECTIVE CASING (C - FIG. 2)

The schedule used for cementing protective casing is shown in Table 2. The cement selected for this type job is of special manufacture. The silica content of this material is greater than normally associated with portland cement. It has the quality of having a wide range of maximum to minimum water-cement ratio. In this particular type of job a 90% ratio was selected to obtain a density of 12.6 lbs. per gal. To obtain a flow rate in excess of that required for fluid turbulence, a special dispersant with a minimum retarding effect was used. The Class C cement will usually give adequate high strength to firm the bottom joints for further drilling. On the upper stage it is still desirable to have high annular flow turbulence; however, a higher breakdown pressure is allowed. As a tail-in above the stage collar, the water ratio in the cement will be reduced in the mixing process. The dispersant used will allow this to be done to a degree so the cement will have early strength equivalent to Class C cements.

Table 2

Cement: First Stage - Special high silica cement plus 0.75% friction reducer (CFR-2) tailed in with 100 sacks Class C cement.

Second Stage - Special high silica cement plus 0.5% friction reducer.

Casing Equipment: Down-jet float shoe, float collar, differential fill collar, stage collar, nine centralizers, thread seal.

Pump Rate: 7-8 bbl. per min.

Slagle has presented a series of rheological calculations which have proven practical, through field usage, in designing a cementing system[4]. A relatively simple laboratory method using standard laboratory and viscometric equipment was suggested for determining the rheological properties of slurries. A criterion of divergence from laminar-flow characteristics was proposed. This proposal was based on the work and theoretical equation of Metzner and his associates. The particular advantage of this equation is that it does not require identification of the fluid, i.e. non-newtonian, Bingham plastic, etc., before its application.

The advantages of high displacement rate in cementing have long been recognized. Even before Howard and Clark[5] published their classical work, field personnel knew the advantage of "getting after it" when cementing. These investigators recommended pumping in turbulence to remove over 90% of circulatable mud. It is now suggested that a flow velocity in the annulus be 1.5 times the value calculated as the rate necessary to achieve turbulence. However, as many drilling foremen know, in certain areas fast pumping is associated with lost returns.

By use of the above method of calculations, dynamic pressures in the hole may be used to select conditions of rate and fill up. These calculations can be accomplished by simple slide-rule manipulations. They are also well adapted to computer programming. If the breakdown pressures of the formations to be covered are known or can be reasonably assumed, the safe height of the cement column can be estimated. This is the position, less a reasonable factor for excess hole enlargement, for placing the stage tool. Fig. 2 lists formation fracture gradients observed in association with permeability in the accompanying formation. These gradients, while reliable, should only be used in the absence of more reliable data.

Recently, laboratory tests have proven certain compounds will lower the velocity at which turbulence may be obtained with cement slurries. The more effective of these materials are organic compounds. Organic compounds generally cause excessive retardation in cementing materials. However, certain select materials do not materially affect the set time with similar water-ratio slurries.

Casing shoes for long strings of large casing may be supplied with side ports below the float valves as shown in Fig. 4. The purpose of these ports is to relieve fluid if the bottom port becomes sealed on the bottom. This may happen due to the excessive strain required to lift the pipe from the bottom after bottom has been found. Stretch of the casing while pumping cement may become severe. This may account for the guide shoe sealing on bottom. The added load of the cement slurry to be lifted may make the lifting of the casing prohibitive. It has also been considered by some that the dynamic load could exceed the strength of the collars. It is quite common for the weight gauge to increase several thousand pounds before cement reaches bottom. For this reason, some operators pick the pipe up a short distance or apply tension on the pipe although not enough to actually raise the casing.

The "ram effect" of lowering casing in the hole is well known. The resulting loss of returns is a recognized field experience. The differential fill valve (Fig. 5) is designed to relieve this detrimental pressure surge. It has the added value of not requiring shut-down to fill the casing. The side port design includes a pressure balanced valve on the inside of the casing. This allows pumping around the shoe in the normal manner. Should it be necessary to clear the hole while running casing, this may be done without altering the differential effect. It is possible that due to weight limitations, it will be necessary to float the casing to bottom. The differential valve can be shut by dropping a ball and applying pressure. Casing should be lowered more slowly after this operation.

This string, designated as C in Fig. 2, is considered the most critical in the well, if the proposed depth is to be reached with accompanying production. In fact, this can be said to be the key to successful exploitation of the deep Delaware Basin. The fracture gradients of these sections, as can be seen in Fig. 2, are quite low. Beaupre[6] has reported a bottom hole pressure gradient of 0.55 psi/ft. in the Delaware and a gradient

FIG. 4

Down Jet Super Seal
Float Shoe

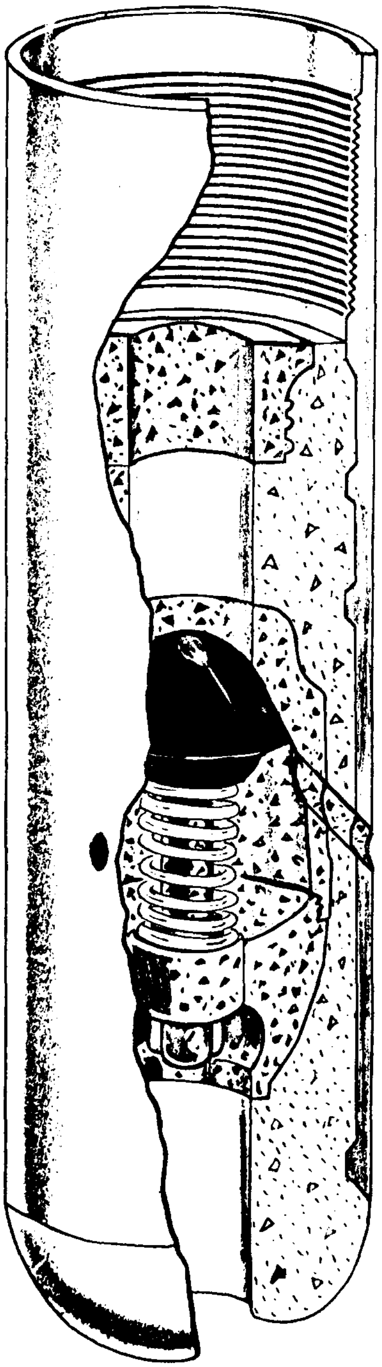
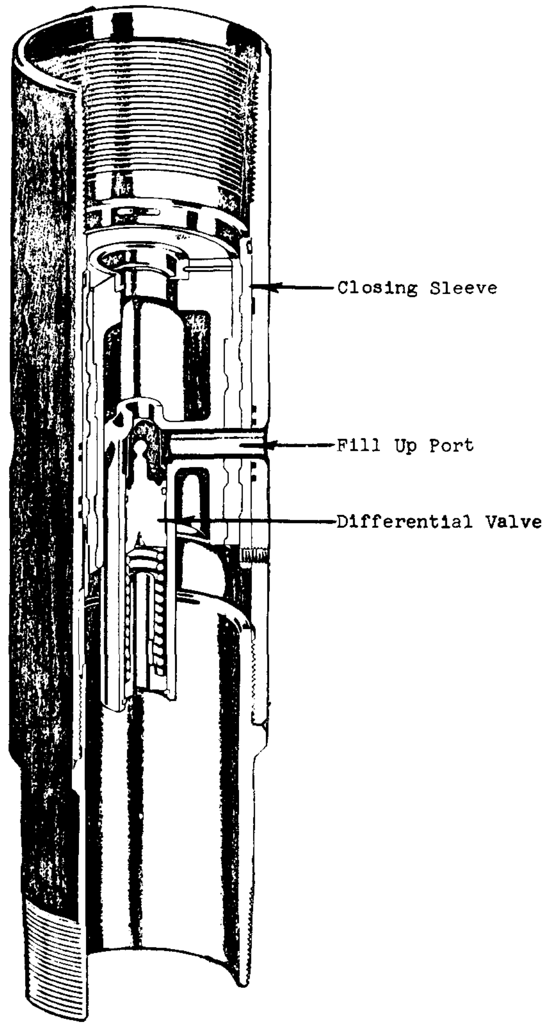


FIG. 5

Self-Fill Differential Collar



of 0.62 psi/ft. in the Wolfcamp. It becomes necessary then to run this casing through permeable sections in the Bone Springs, which is thought of as associated with the Delaware. Great care must be taken with the hydraulics of drilling, however. Gas and oil is associated with the Delaware, especially in the Bell Canyon and the Cherry Canyon formations. Older production in the basin has been from these zones. Lost circulation may become hazardous as well as difficult. On the other hand, the operator must be prepared to handle Wolfcamp gas. A dense lime streak has appeared in the bottom of the Bone Spring. This is the desired casing point.

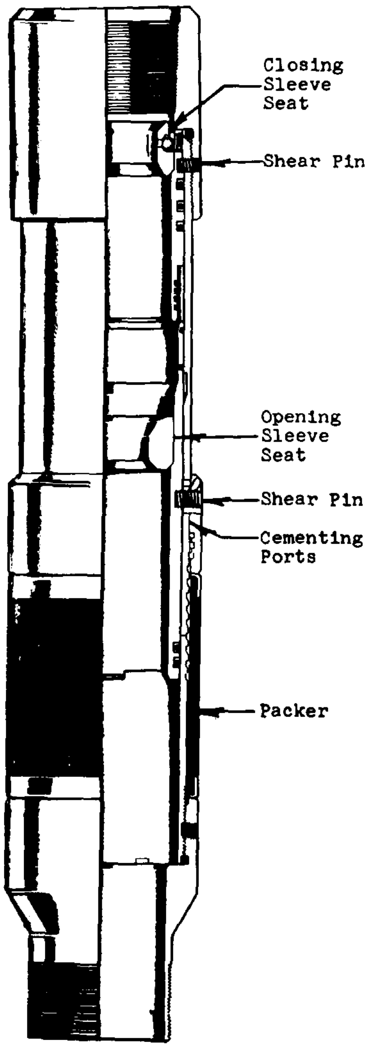
Salt is streaked and variable but when associated with possible water it becomes necessary to cover it. Therefore, prudence dictates cement be circulated back into the B string (Fig. 2). It is possible to bring cement back to the surface by using the stage cementing technique. Considering the consequences of Rustler breakdown this procedure has been designed with this section already covered although as previously stated, a shorter surface-water string is also used. Should this be desired, a three-stage technique may be required.

PROTECTIVE STRING (D - FIG. 2)

The schedule for cementing a protective string is shown in Table 3. Previously discussed criteria for casing equipment are valid here. The stage collar selected here is shown in Fig. 6. The packer incorporated with this tool permits a greater hydrostatic pressure and a greater column on the second stage. A

FIG. 6

DV Packer Cementing Collar



sound hole of true dimensions is needed for the packer. Centralizers again should be spaced according to hole deviation starting with the bottom joint. However, it is anticipated more would be required at the depth of this casing. Centralizers should be placed on each side of the stage tools. Centralizers are of definite value and, as can be seen, they are recommended on every casing string. This number can be calculated from a minimum desired cement sheath, hole size and hole deviation. Centralizers may cause eddies which contain unmoved mud; they may also cause increased pressures due to hole restriction which may be increased to a danger point if large amounts of lost circulation materials are present as they probably may be when drilling this section. Therefore, only a minimum number should be used. One of the uses of centralizers is to prevent high bearing loads on the casing. As suggested for placing centralizers adjacent to the stage tool, increased lateral loads on the collars will cause distortion of the collar. A small distortion may cause a stage tool to become inoperative. Regular pipe collars may not be noticeably damaged; but, the maximum load may be reduced and the probability of leaking increased. The damage due to distortion is increased with integral type connections used for deep wells. To reduce pipe or collar distortion, only spring type centralizers should be used. Rigid type centralizers will increase the probability of damage due to side loading. Also, the rigid type centralizer is difficult to install because the heat treated casing used for these strings should not be welded with field equipment.

Table 3

Cement: First Stage - Class A - possolan (50-50 blend) 2% bentonite, 0.3% diacel LWL, 12.5 lbs. Gilsonite per sack added.

Second Stage - Class C - pozzolan (50-50 blend) 6% bentonite, 12.5 lbs. per sack Gilsonite added. Follows with Class C - pozzolan (50-50 blend) 2% bentonite, 12.5 lbs. per sack Gilsonite added.

Casing Equipment: Down-jet float shoe, float collar, stage packer collar, 20 centralizers and 10 cans epoxy cement.

Pump Rate: 29.7 bbl. per min.

It is required to circulate cement on this stage back into the previous casing string with several hundred feet tie-in. The stage tool will be set in accordance with a hydraulic analysis of formations and cementing fluids. However, it will probably be just below Wolfcamp productive zones. The analysis should include a salt water pre-flush ahead of the cement. This pre-flush can be adjusted for desirable weight by varying the salt concentration. Salt concentration need only be sufficient to prevent formation damage to fresh water sensitive clays. Since these formations are marine sedimentations, it is likely that 5% or greater salt concentration will not affect exposed silicates. The chloride content of the mud may be used as a guide for the minimum required salt content in the cement. The water pre-flush will remove much of the mud from the hole as it is practically impossible to pump water below turbulent flow conditions. If oil has been added to the system a surfactant should be added to the pre-flush to render the casing and formation water-wet. The surfactant should be such that emulsions which may have formed are removed. Chemical thinning materials should only be used if the mud system will tolerate thinning. Salt clays and starches are not thinned by these chemicals; consequently, this type of pre-flush additive is of small value.

Because of the temperature at this depth it will be necessary to have some retardation of the Class A cement in the lower stage cement. The selection of this retardation is an example of multiple effect which can be obtained from the proper chemical additive. Moderate filter loss control reduces excessive fluid damage to productive formations. In extreme cases, filtrate loss to permeable formations may cause dehydration and a "flash set". However, filtrate loss will more often appear as insufficient fill-up or formation breakdown due to increased fluid density and thickness. Improved flow characteristics are also obtained by the selected chemical additive.

A pozzolan additive is used to reduce slurry density and improve resistance to corrosive water. Pozzolans vary in their chemical activity. To be effective as a cementing material, a pozzolanic material should have relatively high cementitious ability. Portland cement-pozzolan mixtures may equal or exceed the strength of Portland alone with curing. Their slower hydration rate increases the resonance of the cement. In earlier stages of drilling out and while large diameter drill collars are in the casing this is an important asset. Adequate strength is developed for a reasonable WOC time. Class A cement was used on the first stage due to its better response to the chemical additive.

For the temperature and pressure encountered in the upper stages, class C cement slurries have satisfactory flow properties without an additive. It also has a more economical yield factor. By using 6% bentonite, a reduced density cement was obtained which would have an adequate (although reduced) strength factor. The reduction of the gel percentage to 2% increases the cement strength factor over likely productive zones. The reason for the stage tool below the productive section was to increase the scouring time of cement. The cement isolating zones will also be less likely to be contaminated by drilling fluid materials.

Laboratory data and field practice have shown that lost returns due to fractured permeability are best controlled by a granular type material. For best results, a uniform particle size distribution is used. Equal amounts of coarse and fine particles are used. A medium grade product is used to allow maximum pump performance. This grade has also been found to cause the least amount of interference with casing equipment. Gilsonite, a naturally occurring mineral, has proven superior for this use. Due to its low density the slurry density will be lowered. This can be accomplished without the loss of strength normally associated with light weight materials. The reason for this is because most materials used to reduce slurry density absorb water. This will increase water ratio and decrease ultimate strength. Gilsonite does not absorb water and only sufficient water to wet the surface need be added.

The Wolfcamp section being drilled during this interval contains gas with a relatively high driving force although sometimes of limited reservoir volume. This will require a 10-11 lbs. per gal. mud for control. Even so, considerable gas cutting has been experienced. The detrital section of the lower Wolfcamp may possibly cause problems of lost returns. The extent of this section is quite difficult to predict. In fact, the top Pennsylvanian series may be missing in many places. The detrital section must be isolated in this operation because of the value of the Pennsylvanian gas found in this section. This gas, if present, will have the greatest pressure gradient of the entire area. Sixteen or seventeen lbs. per gal. mud may be required to hold it. Therefore, this casing, designated as D in Fig. 2, should be anchored in Pennsylvanian strata.

PROTECTIVE LINER (E - FIG. 2)

For cement to remain static until "final set" has occurred, it should weigh more than the mud being used. Even slight aeration, which with mud can be handled with degasers, will be detrimental to cement. Migration of fluids between strata is a cause of communication which causes so much difficulty in attempting completion requirements. The amount of weighting material used will depend upon the weight of the mud necessary.

Table 4

Cement: Class E cement, 30% silica flour, 10 lbs. Hi-Dense #2 per sack, 0.2% HR-12.

Casing Equipment: Float shoe, float collar, liner hanger, centralizers.

Pump Rate: 13-14 bbl. per min.

Laboratory evaluation of materials to be used on the job is helpful. Under critical conditions, variation of materials manufactured at different times may result in a variation of previously tested components. For setting liners an appropriate API casing schedule is used.[7] Pumping time sufficient for placement should be estimated for a reasonable margin of error. However, excessive pumping time is not desired. As pointed out above, migration of formation fluids can be quite detrimental while cement is setting. For this reason over-retardation should be minimized. For more consistant results and to help eliminate the need for using an excessive amount of retarder, a modified lignin retarder may be used. High temperature retarders are generally compatible with the retarders already present in Class E cements.

The use of silica flour under these temperatures should be considered. Some authorities consider strength retrogression at these temperatures not significant. There has been no documented report of failure due to cement deterioration at elevated temperatures. However, available experimental data indicate the advisability of using silica flour. Patchen[8] states, "It is demonstrated that addition of fine-ground silica in proper proportion results in a hydrated cement with superior properties above 230° F., i.e., early compressive strengths are higher and increase with additional curing, permeabilities are significantly lower and thickening times are increased". Carter and Smith[9] report, "Loss in strength occurs in many of the cementing compositions used in high temperatures. The critical temperature range appears to begin at 230° F while the more severe range seems to be at temperatures above 260° F. As the temperature increases above 260° F. this retrogression phenomenon progresses more rapidly. In general, very little retrogression in strength was noted between 7 and 90 day strength at 290° F and 320 F. Permeabilities of the set cement followed a similar trend to the compressive strength and were the greatest where strength retrogression was the severest".

Packer seal type liner hangers are generally not suggested for this protective string, designated as E in Fig. 2. Relief of hydrostatic head may allow seepage of formation fluid into the cement slurry. This will result in an unconsolidated set cement. Excess cement should be left in place, allowed to set and then drilled out. The top of the liner should be pressure tested. If leakage is evident, the top of the liner will need to be squeeze cemented. This is another reason for not using a packer liner hanger. If the packer leaks, it would be necessary to perforate before squeezing.

A tie-back string will probably be run from the top of this liner to the surface. This will give added strength for high pressure gas production. This will allow use of large diameter tubing for gas production. The string will probably be run prior to running the next protective liner. This will facilitate entry into the liner by the liner tools of the next string. However, until the next section is drilled, both the hydraulics and mechanics of the operations will be improved if it is not run until after the hole is made.

Production, from this section, will be sought from Pennsylvanian lime in the Atoka and Morrow formations. Mud weights in the range of 17 lbs. per gal. will be required to control this gas. Gas from Mississippi sections can be controlled with lesser weights and the formation breakdown strengths are not sufficient to maintain the mud column. Kinderhook and Woodford sections are mostly shales; but a satisfactory casing point should be found at the top of the Mississippi lime. Formation breakdown pressures in this section are relatively high. However, due to the narrow annular space the placement rate of the cement is critical. The necessity of obtaining a good fill and sound cement dictates a rate as high as possible. Mathematical analysis of the hydraulics of this system should be studied as suggested in the preceding discussion.

PROTECTIVE LINER (F - FIG 2)

Diatomaceous earth will give a degree of retrogression prevention. Ostroot and Walker[10] maintain, "High concentrations of diatomaceous earth inhibit retrogression, but do not attain the high ultimate strength obtained as when silica flour is used, due to the high water ratio of the diatomaceous earth". In this placement a reduced density is suggested. The use of diatomaceous earth will allow placement of a 13.5 lbs. per gal. slurry. In this string, designated as F in Fig. 2, formation breakdown pressures will again need consideration. Fracture gradients will be in the range of 0.7 psi per foot. The narrow annulus requires reduced turbulent rates. The friction reducer selected is very efficient; however, it is a strong retarder. In this case this property can be used to advantage. Hydraulic analysis of this system should be evident. Laboratory evaluation of the materials used in cementing this string is important.

Table 5

Cement: Class E, 20% Diacel D, 0.2% CFR-1.
Casing Equipment: Float shoe, float collar, liner hanger, slim hole centralizers.
Pump Rate: 9-10 bbl. per minute.

The Devonian section is an important source of gas development. Fractured porosity is again evident, so it could not be penetrated with the mud system used for Pennsylvanian. Silurian and upper Ordovician formations are also objects of exploration. These systems also contain fractured permeability. The Ellenburger of earlier Ordovician and Pre-Cambrian origin is the object of exploration. Just how much of this has been penetrated is hard to say. Production is associated with vugular type porosity. This may be subject to damage by mud and cement loss. If this can be penetrated to the base, no additional casing will be necessary. However, this is a question which remains to be answered.

LINER (G - FIG. 2)

Cementing recommendations for this stage remain to be determined. Production may or may not be worth the effort. Temperatures will surely be much higher. Phillips, as stated, has reported a temperature of 472° F. However, it is believed cementing materials are available to meet these conditions. The techniques to use these materials have been presented here.

ACKNOWLEDGEMENT

The author is grateful to the personnel of the Halliburton Company and others for their help in preparing this paper and to the Halliburton Company for permission to present this paper.

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