INVERT MUD CUT COSTS OF DEEP DELAWARE BASIN WELLS

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ABSTRACT

Inverted emulsion (water in oil) muds have long been used for formation protection and improvement of hole stability, but slow penetration rates often offset advantages. Recently, relaxation of control of mud properties—notably fluid loss—has led to significant improvement in penetration rate. A comparison of wells drilled in the Delaware Basin shows that significant savings in total well cost can be obtained through the use of new generation invert muds.

HISTORY

In the middle 1960s it was found that incompetent Gulf Coast shales could be stabilized by an invert mud (inverted oil-water emulsion with oil as the continuous phase) having a low aqueous activity—generally a high calcium chloride content in the aqueous phase. The principle was used in West Texas' Delaware basin when Humble (Exxon) drilled the Wolfcamp-Penn section 10,500 to 16,000 ft in the Gomez field using a low-density, low-activity invert mud instead of the higher density water muds then in general use. The shale problem was solved but penetration rate was poor and the trials were abandoned.

There were a number of successful applications of invert muds, one of the more notable being in a well in Terrell County, the Mitchell No. 1. Mud weight was 9.5 to 9.7 ppg, hole made per-day averaged 58 ft, penetration rate was 3.5 ft/hr, and 112 days were required to drill a 6,530 ft section. In spite of the slow penetration rate, this well was drilled in 148 days less than the closest offset, and though it was drilled in 1970 it is still one of the better records for that area. The big difference was the absence of hole problems which plague wells drilled in that portion of the basin.

Other wells were drilled using invert muds with varying degrees of success. In most cases hole problems were eliminated, but often penetration rate was so poor there was no economic advantage in using the invert mud. A typical example is a well drilled in the ROC field in 1970.

Mud weight was run at 10.5 ppg, 3 ppg below that required for hole stability with water mud. Shales drilled at rates equal to or better than those attained with water muds; but when limes were encountered, penetration rate dropped to less than 1 ft/hr. The net effect was that the total well cost was about equal to those drills using water mud.

When the Apollo field was discovered in Winkler County, it was determined that the ratio of shale to lime to be drilled in that area was high enough to justify again trying invert muds. They worked well there and 11 wells were drilled with it. The experience gained drilling that number of wells led to a number of refinements in practice which enhanced the value of the system. It was found that softer bits could be used, bit life was better, lower mud weight could be used, greater volumes of gas could be tolerated while drilling underbalanced, and a number of lesser advantages could be obtained in contrast to drilling with water muds.

To this point all the mud employed has been formulated and maintained to meet the usual properties recommended for invert muds. Treatments were patterned for high temperature, high density application. Most notably, fluid loss was maintained at a very low value.

In 1973 Fontenot and Simpson published results

This paper is an outgrowth of the article, "Relaxed Fluid Loss Controls on Invert Muds Increases ROP," by T. B. O'Brien, J. P. Stinson, and Frank Brownson, WORLD OIL, August 1, 1977, pp. 31-34, 70.

of micro bit studies which indicated that the real culprit in the low penetration rate in lime problems was low fluid loss. A campaign was begun to relax control of fluid loss, but it was done very cautiously since everyone involved had been well indoctrinated in treating invert muds so they could be run trouble-free.

During 1974 and 1975, in addition to normal drilling, invert muds were employed in wells which had become so crooked drilling could not continue due to excessive rotating torque and vertical drag. In one case, drag was reduced from 100,000 lb to less than 25,000 and torsional drag was reduced from 13 rounds to less than 2. The systems employed there were very similar to those used for workovers since they replaced water as the drilling fluid. They were very lightly treated and had little or no fluid loss control.

In early 1976 a normally treated drilling mud was mixed with one of those which had been employed for torque reduction. The mixture was of roughly equal parts. The combined systems were used to drill the Kyle No. 1 in Loving County. Because of a 1,000-ft-thick Atoka Reef section, there was some considerable question as to the feasibility of using an invert mud; but a substantial amount of time is often lost in that area due to hole problems, and it was concluded that even with the anticipated slow drilling through the long lime section it should at least break even cost-wise. When the lime was encountered, the penetration rate remained at least double that anticipated, and even the Mississippian lime which is normally tough to drill was drilled at 20,231 ft in 128 days with a total drilling fluid cost of $115,000. That cost includes $54,000 for surface hole mud, corrosion treatment, brine, and equipment rental, as well as $61,000 for the oil-mud section of the hole. No close offsets are available for comparison but mud costs in the general area invariably run in excess of $150,000 for mud materials alone.

The section drilled was from 12,677 to 16,943 ft or 4,266 ft. It was drilled in 837.25 rotation hours at a 5.1 ft/hr average penetration rate. The 4,266-ft interval was drilled in 38 days at a rate of 112.26 ft/day. Maximum mud weight was 11.2 ppg as compared to 15.5 ppg required for water muds throughout that area. A survey was made of mud properties and it was found that the only noticeable change was in the fluid loss. High temperature-high pressure fluid loss of an invert mud is normally maintained in the 5 cc range and no fluid is lost on an API test. Here the high temperature-high pressure fluid loss was in the order of 15 cc, and the API fluid loss was 5 to 8 cc.

Additional wells were drilled in other areas of the Delaware basin with a continuing relaxation of control of mud properties. For the Leede Oil and Gas Company, No. 1 University "18-30," the high temperature-high pressure fluid loss went as high as 80 cc and contained a substantial amount of water along with the oil. Normal high temperature-high pressure fluid loss was 30 to 40 cc and API fluid loss was 15 cc. Here there was a reduction of 30% in elapsed days on the mud drilled portion of the hole and a total savings in well costs of $175,000, about $70,000 of which was in mud costs. Figure 1 shows the location of wells reported here as well as others either presently drilling or recently drilled using the invert muds described here.

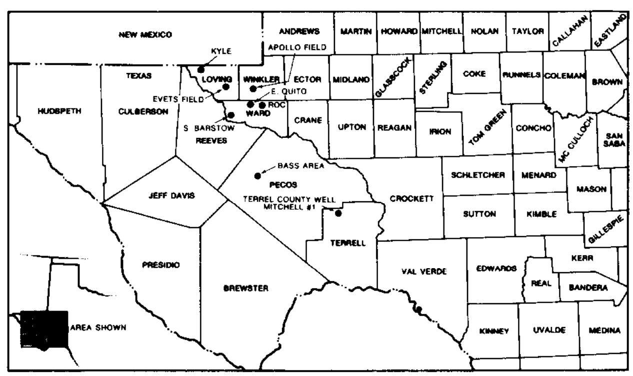

FIGURE 1—HIGH FLUID LOSS INVERT EMULSION MUDS WERE USED IN SEVERAL DELAWARE BASIN WELLS TO IMPROVE PENETRATION RATES THROUGH LIME SECTIONS (WORLD OIL).

WELL COMPARISONS

A sufficient number of wells has been drilled throughout the Delaware Basin employing inverted emulsion mud to establish its feasibility for controlling shale problems and eliminating hole trouble in the troublesome Wolfcamp-Pennsylvanian, Barnett shale sections. The recent relaxation of control on fluid properties, however, has added new value to that type system since penetration rates have been improved to the degree they now equal or surpass those attained with water muds. In three areas, wells have been drilled using invert muds with relaxed control, and offsets are available to make meaningful comparisons.

TABLE 1 EAST QUITO AREA (WORLD OIL).

Well	Section thickness, feet	Mud type	Maximum mud weight, ppg	No. of bits	No. of days	Feet per day	Rotating hours	Feet per rotating hour
A	3881	Fresh water Non-dispersed	16.2		59	65.78	1066.25	3.64
B	3529	Fresh water Non-dispersed	16.0		44	80.41	852.5	4.14
C	3995	Fresh water Non-dispersed	16.0		54	73.98	986.5	4.05
D	3910	Fresh water Non-dispersed	16.4		67	58.36	1005.0	3.89
E	3632	Invert oil high fluid loss	12.5		31	117.16	612.5	5.93

In the East Quito field area, a number of wells had been drilled with water muds and one well was drilled with an invert. Table 1 gives pertinent data to evaluate performance of the invert system. The section drilled was geologically comparable. Although gas kicks and water flows were encountered, Well E was drilled with a 12.5 ppg mud while the other wells used 16 ppg or higher weights. Well E progressed at the rate of 117.16 ft per day while the best of the rest was 80.41 ft per day, and well E's average penetration rate of 5.93 ft per hour was a 43% improvement over the best of the others.

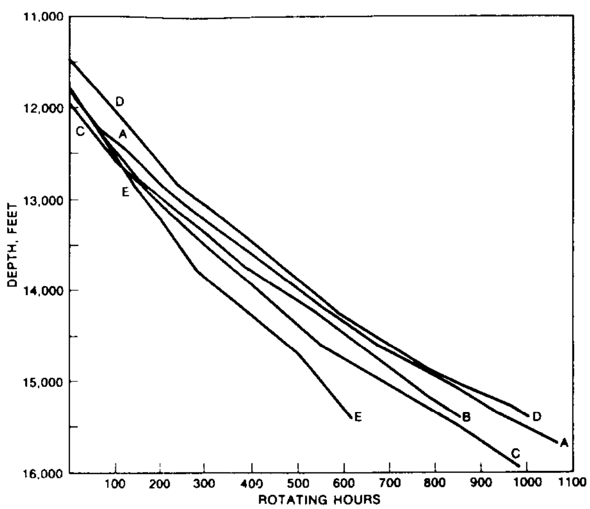

FIGURE 2—IN EAST QUITO FIELD, WARD COUNTY, TEXAS, WELLS A, B, C AND D WERE DRILLED USING WATER MUDS. WELL E WAS DRILLED AT HIGHER PENETRATION RATES BECAUSE OF THE HIGH FLUID LOSS INVERT MUD (WORLD OIL).

Figure 2 is a plot of rotating time for the comparison wells. Figure 3 is a depth vs days plot showing estimates made by two mud companies anticipating the use of water muds and the actual drilling time required to drill the well.

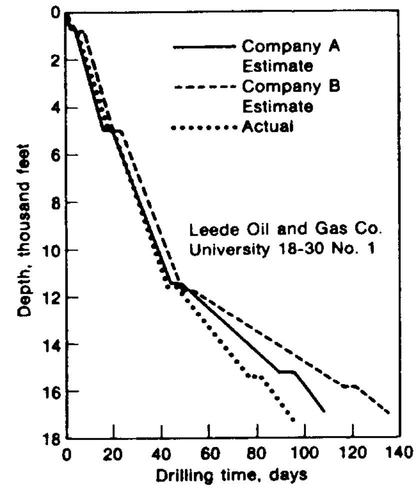

FIGURE 3—THE UNIVERSITY 18-30 NO. 1, WELL E IN THE EAST QUITO AREA, WAS DRILLED SIGNIFICANTLY FASTER THAN ANTICIPATED (WORLD OIL).

Figure 4 is a plot of estimated mud cost by the same two companies and the actual cost. The actual mud cost includes approximately $10,000 for corrosion-treating chemicals.

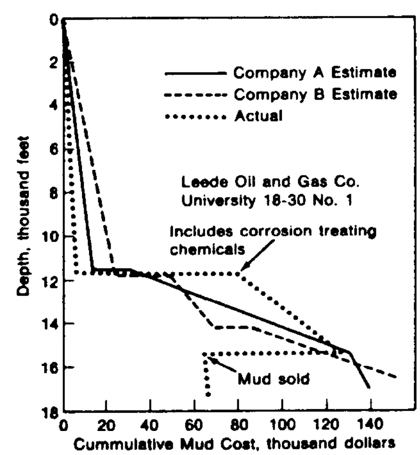

FIGURE 4—EVEN WITH CORROSION-TREATING CHEMICAL COST INCLUDED, THE MUD BILL IN THE UNIVERSITY 18-30 NO. 1 WOULD HAVE BEEN LESS THAN ANTICIPATED COST, HAD THE MUD NOT BEEN SOLD (WORLD OIL).

Figure 5 shows the estimated and actual mud weight requirements for the well.

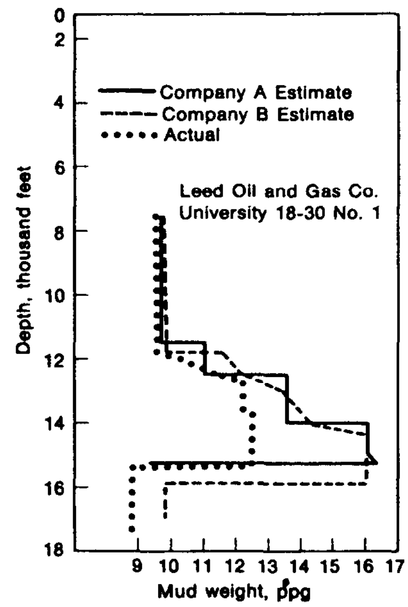

FIGURE 5—ANOTHER ADVANTAGE OF INVERT EMULSION MUDS IS THEIR ABILITY TO MAINTAIN HOLE STABILITY AT MUD WEIGHTS BELOW THOSE REQUIRED FOR FRESH WATER SYSTEMS (WORLD OIL).

Mud cost estimates were for $140,000 or more, which is less than actual expenditures on other wells. The reason for the reduction in mud cost of Well E at 15,410 ft is that the mud, when no longer needed, was sold to another operator for 75% of its purchase price.

Table 2 gives comparative data for wells drilled in the ROC field area. In this field, only the lower Pennsylvanian and Barnett shale must be drilled with mud; the Wolfcamp is drilled with 10 ppg brine. In this instance the comparison includes a conventional invert mud, i.e., one which had its fluid loss rigidly controlled. The effect of increased fluid loss is apparent. Here the ability to maintain hole stability is not shown because the invert mud when purchased weighed 12.2 ppg, and the cost of reducing its weight with oil additions was not considered justified. Still, the high fluid loss invert outperformed other muds. Figure 6 is a plot of days vs

TABLE 2—ROC AREA (WORLD OIL).

Well	Section thickness, feet	Mud type	Maximum mud weight, ppg	No. of bits	No. of days	Feet per day	Rotating hours	Feet per rotating hour
F	2090	Invert sat. 10 ppg brine and NaCl conventional	13.4	5	22	95	348.50	6.00
	1069	Oil mud	13.4	3	16	66.81	270.00	3.98
G	1751	Invert sat. 10 ppg brine and NaCl conventional	11.0	8	20	87.55	365.25	4.79
	884	Oil Mud	11.0	4	14	63.14	332.00	2.66
H	1871	10 ppg brine & brine mud	12.7	4	13	143.92	274.00	6.83
	1141	Brine mud	12.7	3	10	114.10	206.00	5.54
I	1830	Brine & invert high fluid loss	12.1	3	12	152.5	229.00	7.99
	937	Invert high fluid loss	12.1	2	8	117.3	149.5	6.27

depth for the comparison wells. The top of the Mississippian Lime is noted. Since one of the primary objections to the use of invert muds has been the slow penetration rates attained in drilling lime, a good comparison can be made here. Table 3 shows ft per day and ft per hour for drilling the Mississippian Lime in the four comparison wells.

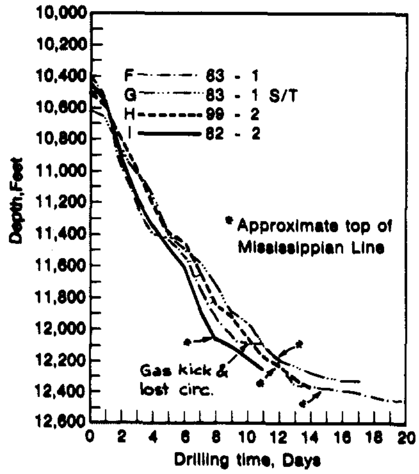

FIGURE 6—IN THE ROC AREA, WARD COUNTY, TEXAS, HIGH FLUID LOSS INVERT MUDS USED TO DRILL WELL I PROVIDED PENETRATION RATES HIGHER THAN THOSE OBTAINED USING OTHER SYSTEMS (WORLD OIL).

TABLE 3—ROC AREA, MISSISSIPPI LIME DRILLING (WORLD OIL).

Well	Footage	Days	Hours	Feet per day	Feet per hour
F/83-1	93	5	90.00	18.6	1.03
G/83-1 S/T	141	5	93.75	28.0	1.49
H/99-2	139	2	41.00	69.5	3.39
I/82-2	206	3	64.5	68.7	3.20

Table 4 compares five wells in the South Barstow area. Two used non-dispersed fresh water muds, one used a conventional invert, and two used high fluid-loss inverts. (The same system was moved from Well J to Well N.) The higher mud weight in Well N was required to control a gas flow too great to allow drilling with it flowing. Here again penetration rate with the high fluid-loss invert is substantially higher than with the conventional invert and about 20% higher than with water muds. The number of bits used was reduced by one-half. Here also progress per day is significantly improved due to almost total elimination of hole instability.

The system that has become known as high fluid-loss invert mud has now begun to see use in a wide variety of geologic provinces. Included are South Texas, Mississippi, the Anadarko Basin, the Over-

TABLE 4—SOUTH BARSTOW AREA (WORLD OIL).

Well	Section thickness, feet	Mud type	Maximum mud weight, ppg	No. of bits	No. of days	Feet per day	Rotating hours	Feet per rotating hour
J	4745	Invert high fluid loss	12.2	5	43	110.35	845.00	5.6
K	4730	Fresh water non-dispersed	15.3	11	53	89.25	1087.75	4.3
L	4850	Fresh water non-dispersed	16.4	11	50	97.00	916.75	5.3
M	6600	Invert conventional	13.3	10	80	82.63	1701.00	3.9
N	4653	Invert high fluid loss	13.8	5	28	166.2	729.00	6.4

thrust Belt of the Northern Rockies, Colombia, and Algeria. Much of this use is recent and collecting usable data is difficult. However, in one area in Zapata enough wells have been drilled to offer a fair comparison. Two of these rigs used both types of mud.

Figure 7 depicts drilling days vs depth for the comparative section. Here as in the Delaware Basin a reduction of 30% or more is attained in overall time for the interval. Not all of the improvement is due to increased penetration rate because lost time due to hole trouble is virtually eliminated. Additionally, probably because of absence of hole enlargement, hole deviation problems have also been eliminated. In fact, it is now possible to drill there without drill-collar stabilization.

Bit types have been changed again going to softer bits—even going from tungsten-carbide insert bits to milled cutter bits for lower cost per ft. Another benefit of gage hole provided by the invert mud is a substantial improvement in quality of cement jobs on production liners. Experience with completions here, as was also found in the Anadarko Basin, is that treatments—acid or frac jobs—are confined to the zone of interest, whereas in out-of-gage holes drilled with water muds, treating fluids very often go out of zone.

MUD PROPERTIES

Typically, invert muds show no loss of fluid on the API filtration test and on high temperature and pressure—250° F and 500 psi—fluid loss is normally less than 8 cc. Filtrate is 100% oil. Any measurable water in the filtrate is considered a sure sign of impending disaster. But it has been found that much of what is considered essential in oil mud control is not truly necessary for many applications. Oil muds were originally designed to prevent damage to some producing zones by preclusion of any fluid loss.

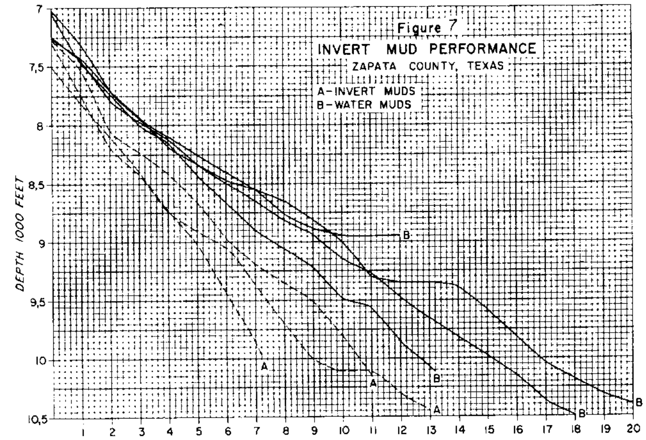

FIGURE 7

Later, as wells were drilled to greater depths where bottom hole temperatures exceeded 350° F, it was found that no water muds then available could operate successfully at such extreme conditions. Oil muds were developed to operate there and even at much higher temperature. But the highly treated, sophisticated oil muds used for extreme conditions were then applied generally. Only relatively recently (Fontenot & Simpson 1973) was work done to investigate means of improving penetration rate. As a result of that work, slightly higher fluid losses were allowed with minimal improvement in penetration rate, but when essentially all control of fluid loss was removed and the muds treated only to the least degree possible, substantial improvement in penetration rate was obtained.

Table 5 presents typical mud properties for four wells. The mud system from Well 1 was used later on Well 2, and the mud from Well 3 was moved to Well 4. The data presented here are from field tests.

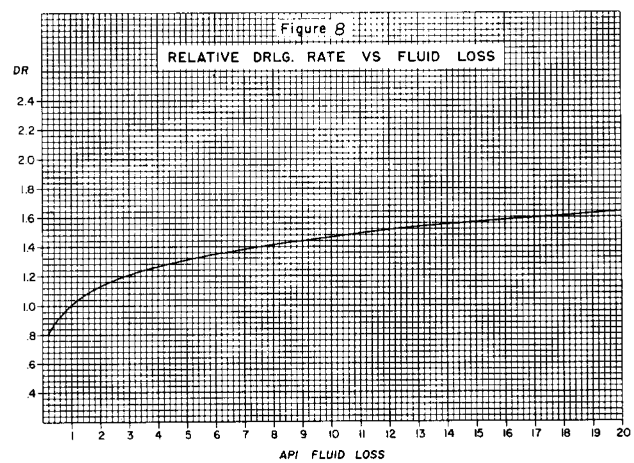

FIGURE 8

TABLE 5--TYPICAL INVERT MUD PROPERTIES (WORLD OIL).

Company	Well	Mud weight, ppg	Funnel viscosity	YP	PV	Gels initial/10 min	Fluid loss H.T.	Fluid loss API	Cake 1/32"	Oil %	Cl ppm x100	Solids %	O/W Ratio	Elec Stability
1. HNG	Kyle	11.2	68	18	25	7/18	....	5	1	62	350	12	80/20	...
		11	58	17	20	6/15	....	4.8	1	67	378	15	79/21	...
		11	56	18	20	7/14	13.6	5.2	1	68	374	15	80/20	...
		11.5	56	19	24	10/19	15.2	5.4	1	67	374	17	81/19	...
2. HNG	Lee	12.0	55	13	25	5/11	....	4.3	2	61	320	21	78/22	...
		11.1	47	8	18	3/5	14.0	5.6	1	69	376	18	84/16	...
		13.6	52	12	22	4/6	28.0	10.4	2	63	350	28	87/13	...
		13.8	50	12	24	4/6	....	11.0	1	62	345	30	89/11	...
3. Leede Oil & Gas	University	9.8	45	5	7	4/7	22.4	5.2	1	70	200	12	79/21	700
		12.6	57	13	17	10/21	28	6.0	1	68	350	19	85/15	500
		12.6	61	16	21	12/24	84	12.8	1	61	240	19	75/25	300
		12.5	59	7	16	4/15	39.8	6.0	1	71	320	14	83/17	500
4. HNG	Caprito	12.2	100	19	30	5/19	36	....	1	54	307	16	66/34	...
		12.2	75	8	27	5/14	26	....	2	56	307	20	70/30	...
		12.0	80	9	27	5/8	18	4	..	60	307	18	76/24	...
		12.1	80	9	28	9/17	35	9.2	..	58	304	17	66/34	...

CONCLUSIONS

The superior ability of invert emulsion muds to maintain hole stability is firmly established. Mud weights have been reduced 3.5 ppg to 4 ppg in the absence of substantial gas or water flows without loss of hole stability. Probably the nagnitude of the reduction may vary depending on the nature of particular shales, but there is no doubt that no over-balance is required to maintain hole stability.

It has been shown previously and confirmed here that a low-activity water phase of the emulsion is desirable. Hole stability, i.e., hole gage and shale sloughing, improves with increased salt concentration in the water phase. In a few instances saturated sodium chloride brine is adequate, but in many instances it is not; and in no case has excess salt concentration been found to be detrimental. Therefore, calcium chloride in concentrations greater than 300,000 ppm, usually 350,000 ppm, has been used.

No upper limit has been set on fluid loss. API fluid loss as high as 80 cc has been tolerated without loss of hole stability. With any other mud (if there is a positive wellbore-to-formation pressure differential and a permeable section is open) wall sticking can occur. There are several cases of this kind on record. In each case the fluid density was reduced and the pipe came loose. But some practical limit must be set.

Figure 8 is a plot of Relative Drilling Rate vs API Fluid Loss for Invert Muds, representing the best curve fit for several hundred data points. The primary increase in drilling rate occurs at low fluid-loss values.

Generally 8.5 to 14 ppg invert muds, after a few days drilling, attain a fluid loss in the range of 5 to 10 cc without specific treatment. As a result, that is the range in which most muds are run. The absolute value of emulsion stability is not considered important, but when it begins to change, treatment is required.

Invert muds can maintain hole stability at as much as 5 ppg mud density below that required for fresh water muds. Often this reduction will be equal to actual pressure underbalance. The degree of underbalance that can be tolerated varies with shales and with the same shale in different areas. In every case, when hole stability alone has been the concern, a differential of at least 3 ppg has been satisfactory. Occasionally, sufficient gas volume has been encountered to require increases in mud density. Figure 9 contains data from a number of fields in the Delaware basin and shows the effect of reduction in mud weight on drilling rate, and Figure 10 consolidates that data to show an average effect for the area. This shows that the improved performance indicated here is the result both of the ability to reduce mud weight without loss of hole stability and improvement resulting from higher fluid loss.

Handling gas either from a kick or from trip gas is easier with invert muds than with water muds. In most cases the need for a degasser is eliminated. Mud goes through a mud-gas separator directly to the circulating system. Trip gas comes up as a single bubble and is gone. No long period is required to circulate gas-cut mud. Kicks are more easily killed because gas is more easily disposed of at the surface. However, to one who is accustomed to the pressure volume reaction of water muds when drilling a kick, the reaction of an invert mud may seem strange. Since gas is soluble in oil and the solubility varies with temperature and pressure, a constantly changing condition exists and the pattern of casing pressure and pit-volume change may not be constant from well to well.

Additionally, the incidence of stuck drill pipe while killing a well is much reduced with invert muds. But when high fluid losses are used, pipe can become wall stuck. On the one occasion when wall sticking is known to have occurred, the hydrostatic head was reduced by circulating diesel oil. The well flowed, the pipe came loose and was run to the bottom before the well was killed again.

Mud costs have been reduced by 30 to 50% and drilling time for the interval of use has been reduced by about 30%. Well cost reduction, as compared to water mud drilled offsets, of $150,000 to $200,000, is common.

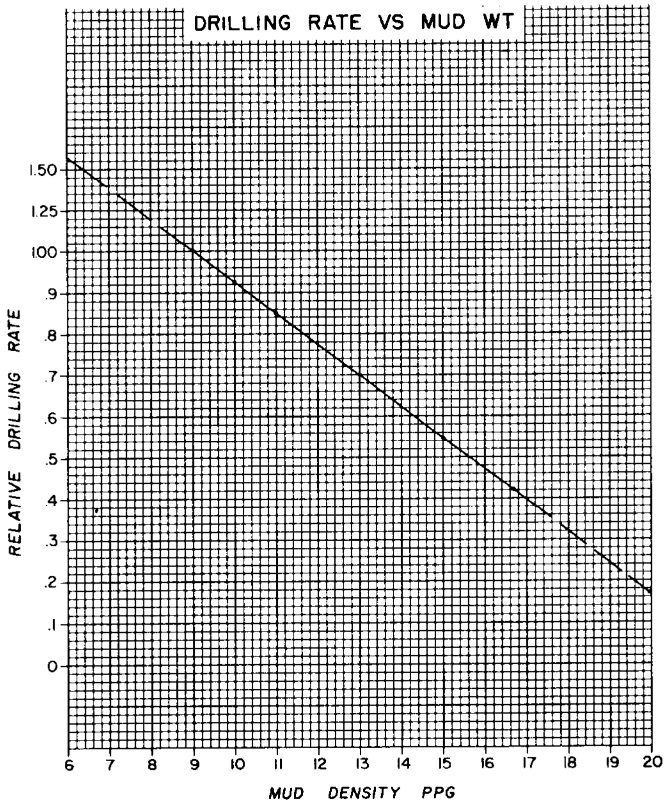

FIGURE 10

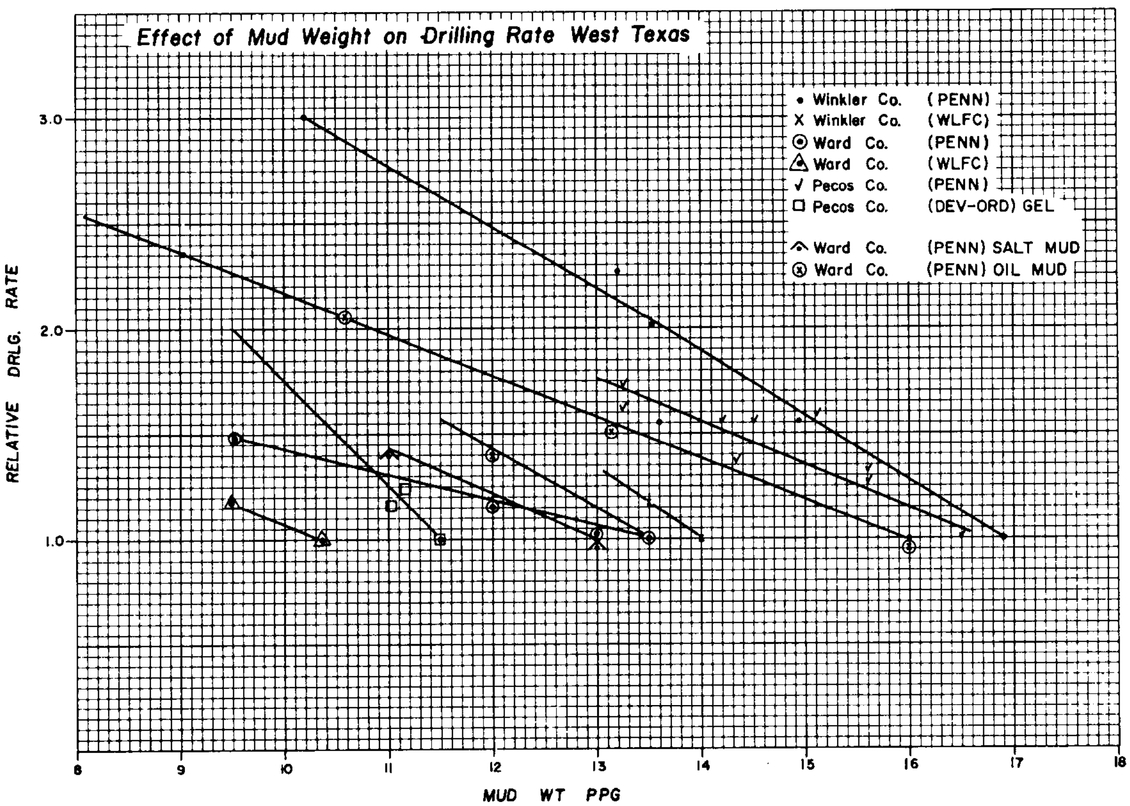

FIGURE 9