Class G, Petroleum Division

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS
29 West 39th St., New York, N. Y.

METHOD FOR DETERMINING MINIMUM WAITING ON CEMENT TIME

R. Floyd Farris*
Stanolind Oil and Gas Company
Tulsa, Oklahoma

(Tulsa Meeting, October 1945)

Use This to arrive at new Std W.O.C. Time

METHOD FOR DETERMINING
MINIMUM WAITING ON CEMENT TIME

R. Floyd Farris*

ABSTRACT

A method is presented for determining minimum waiting on cement time which takes into account the differences that exist between types and brands of cements and such individual well conditions as depth, temperature, and pressure.

The basis for the method was determined by laboratory tests. Being a laboratory development, several steps were required to prove its merit. The first step consisted of laboratory tests designed to determine the minimum cement strength requirements in wells. Basis was found for setting a minimum value of 8 psi. tensile strength. Next, it was shown by laboratory tests that the time to 8 psi. tensile strength may be expressed as a function of consistometer stirring time to 100 "poises", the approximate relation being "the time to 8 psi. tensile strength equals the time to 100 "poises" times three." Next, it was shown that the time of maximum temperature development in cement slurries, due to heat of hydration, is also related to consistometer stirring time to 100 "poises" but only by a factor of approximately two. It was shown also that the shut-in casing pressure will build up after cement is placed and register a maximum pressure at approximately the same time the slurry down the hole attains maximum temperature. From this and the above relationships, the general rule was established that minimum waiting on cement time (time to 8 psi.) after casing cement jobs in any well is equal to the

* Stanolind Oil and Gas Company, Tulsa, Oklahoma

time when the shut-in casing pressure reaches a maximum, as measured from the initial mixing of cement, times a factor of 1.5.

Cement plugs drilled in the field at the time prescribed by this formula were found to drill "firm to hard", thus confirming the laboratory tests.

These tests prove that many of the present waiting on cement time regulations require longer time than is absolutely necessary. Use of the method herein proposed offers the possibility of a saving of $1200.00 per well.

INTRODUCTION

The length of time allowed for cement to set after casing cement jobs is determined either by State-wide rules, Field rules, or by self-imposed rules written into drilling contracts. In general, the time in any case is dictated by experience and common practice. However, owing to differences in opinion and differences in experience of the various groups involved, waiting on cement time practices often vary from one area to the next. For example, an operator in an area where no rules exist may drill out of surface pipe at 24 to 36 hours, while another operator in another area may wait 48 hours or more to comply with State or Field rules, although the depth of the well, hole size, type of cement, etc., are identical in each case. One will find an even greater difference in practices upon making similar comparisons with respect to oil string cement jobs. Differences in waiting on cement time practices of 36 to 48 hours are common.

Further complicating the picture is the rather common practice of allowing more waiting time for cement to set at the greater depths than is allowed at the shallow depths. This practice has existed for years in spite of the common knowledge[1,2,3] that the temperature of the earth at the usual setting depths of surface casing is much less than that at the depths at which oil strings are set and that increased temperature greatly accelerates the rate of setting and hardening of cement.

The foregoing thoughts suggest lack of a fundamental basis for determining waiting on cement time.

The minimum strength cement must develop in a well before it will secure pipe in the hole, exclude undesirable well fluids, and withstand the shock of drilling, and how long cement must stand before it attains that minimum strength are questions often discussed but never completely answered. The industry has operated to the present time without the answers to these questions simply by allowing long waiting periods for the cement to set. Thus, since experience taught that waiting periods ranging from 36 to 72 hours would give satisfactory results, these periods have become standard practice in many areas; however, it is easy to understand how a practice derived in this manner might include more time than is absolutely necessary.

Experiments conducted in the Stanolind Oil and Gas Company Research Laboratory suggested that cement in wells may set and gain adequate strength in much less time than is normally allowed for that purpose. This finding led to the development of a simple method for determining the minimum waiting on cement time which will apply to any well condition. The purpose of this paper is to describe the laboratory and field tests which contributed to the development of this method.

BASIS OF METHOD

The expression "waiting on cement time", hereinafter referred to as WOC time, simply means waiting for the cement to set and gain a given minimum strength. Thus, any logical system for determining WOC time must be based on minimum cement strength requirements in wells. Once this has been established, the time to that strength can be reasonably accurately determined.

To obtain information as to what strength cement should develop in wells before it is drilled out, laboratory tests were conducted where a correlation was made between cement tensile strength and the bonding strength of cement in an annulus. The apparatus consisted of seven pieces of 9-5/8 in. O.D. pipe five feet long into which was centered similar lengths of 5-1/2 in. O.D. pipe. Standard Portland cement slurry weighing 15.6 lbs./gal. was poured into the annulus of each unit to a height of four feet. Some of the same slurry was placed in briquette molds for tensile strength tests; also, cement slurry was placed in Vicat molds for initial and final set determinations. The cement was cured at atmospheric temperature, approximately 90° F. An end view of the cement in the annulus between the two sizes of pipe is shown in Figure 1.

The bonding strength of the cement in the annulus was determined by measuring the force which must be applied to the 5-1/2 in. pipe to break the cement bond and move it with respect to the outside or 9-5/8 in. pipe. The means of doing this is illustrated by the sketch, Figure 2. Each time the bonding strength of cement in the annulus was tested, observations were made of the corresponding cement strength and the progress toward the initial and final set.

Table I presents a summary of the test results.

TABLE I

Cement Age, Hrs.	Force to Break Bond of 4 ft. Cement, Lb.	Cement Tensile Strength, psi.	Remarks
1.83	400	0	Soft cement slurry
2.33	550	0	" " "
3.08	1,300	0	Initial set
3.66	4,000	4 est.	Cement stiffening rapidly
4.42	18,200	8 est.	Final set
5.50	20,000+	12	Could not break bond
6.50	20,000+	20	" " " "

The rate of increase in cement bonding strength is better demonstrated when these data are plotted on a graph. Figure 3 shows that cement has an enormous bonding strength at its final set.

Table II shows the calculated load each foot of cement in an annulus will support at various cement strengths, together with the length of various pipe of equivalent weight.

TABLE II

Cement Age, Hrs.	Force to Break 1 ft. Cement Bond, Lb.	Cement Tensile Strength, psi.	Length of Pipe 1 Ft. of Cement will Support, Ft.		
			5-1/2"-17#	7"-24#	13-3/8"-72#
1.83	100	0	5.8	4.1	1.3
2.33	137	0	8.0	5.7	1.9
3.08	325	0 (initial set)	19.1	13.5	4.5
3.66	1,000	4 est.	58.8	41.6	13.8
4.42	4,550	8 est. (final set)	267.5	189.6	63.1
5.50	5,000+	12	-	-	-
6.50	5,000+	20	-	-	-

Returning to the question of how much strength cement should develop in a well before it is drilled out, one can reason that it would not be safe to drill out cement before it reaches the initial set, even though the data in Table II indicate that the slurry may support the pipe, because it is not until after the initial set that the slurry passes from the fluid state into that of a solid. In fact, solidification of cement may not be called complete until it has reached the final set. Therefore, since drilling inside of casing before the cement on the outside reaches its final set could possibly reslurrify gelled cement and cause it to backflow around the shoe, it is quite obvious that cement should not be drilled out before it reaches the final set, which corresponds to a tensile strength of approximately 8 psi.

Since it has been shown that cement should not be drilled out before it attains a tensile strength of 8 psi., the next question is as to whether it would be safe to drill it out at a tensile strength of 8 psi. The foregoing data strongly suggest that it would be safe to drill out cement at that strength. At a strength of 8 psi., for example, Table II indicates that each foot of cement in the annulus should support 267 ft. of 5-1/2 in. O.D. 17-lb. pipe, and Figure 3 shows that the rate of bonding strength development is extremely rapid at that point and probably reaches even greater proportions shortly after that time. These considerations, together with the general feeling that "green" cement may be drilled with less damage to the cement in the annulus, and in view of the fact that the full weight of casing is apt to be set down on cement only in cases where the casing is cemented to the surface, prompted the tentative conclusion that the minimum cement strength requirement before drilling out the plug is approximately 8 psi.

PREDICTION OF CEMENT STRENGTH DEVELOPMENT IN WELLS - FIRST METHOD

Having determined by laboratory tests what appears to be the minimum strength requirement of cement in wells, the next step is to develop a method of determining when cement in wells will attain that strength. Cement slurry, whether in a well or in a laboratory apparatus, will remain fluid for a time after the slurry is formed, then it will stiffen, set, and start to develop strength. Also, regardless of whether or not the slurry is in a well or in a laboratory apparatus, the factors which will largely govern the time required for it to stiffen to a given consistency, reach a final set, or attain a given strength, will be water-cement ratio, temperature, and pressure. When well conditions or laboratory conditions are such as to accelerate the stiffening time of cement to a given consistency, the time to the initial set will likewise be decreased. Since both times are affected by the same factors, it appears that it should be possible to express one as a function of the other. If cement stiffening time to a given consistency is related to the time of initial set, 8 psi. tensile strength, and if laboratory tests could be conducted which would predict the actual time of stiffening of cement in wells, one could predict with approximately the same accuracy the time when cement in wells reaches the final set or a strength of 8 psi.

In 1941, Stanolind Oil and Gas Company developed a method [1] of testing cements where temperatures and pressures are varied to correspond with the increasing temperatures and pressures imposed upon cement slurries as they are pumped from surface to bottom hole conditions of wells of various depths. The results obtained from these tests are called cement stirring time tests to 100 "poises" at simulated well depths. Field tests have shown that this method of evaluating cements describes reasonably accurately the actual performance of cement slurries in wells. Table III is a tabulation of stirring time tests to 100 "poises" at various simulated well depths, the time to 8 psi. tensile strength (assumed to be equivalent to the time of final set), and the ratio of these times.

TABLE III

Type of Cement	Well Depth Simulated, Feet	Stirring Time to 100 "poises" Hours	Time to 8 psi. Tensile Strength Hours	Time to 8 psi. / Time to 100 "poises"
Standard Portland	2000	3.5	5.4	1.54
	4000	3.0	3.8	1.27
	6000	2.5	2.9	1.16
Slow Set A	8000	4.0	8.5	2.12
	10000	3.4	8.0	2.35
	12000	3.0	7.9	2.63
Slow Set B	6000	3.7	10.6	2.86
	8000	3.1	9.3	3.0
	10000	2.5	7.5	3.0
Slow Set C	6000	4.0	10.1	2.52
	8000	3.1	8.8	2.84
	10000	2.6	7.8	3.00
Slow Set D	6000	3.7	6.5	1.75
	8000	3.3	5.2	1.57
	10000	4.4	5.4	1.23

Data under the column heading "Time to 8 psi. Tensile Strength, Hours" in Table III, were obtained from time-versus-strength data by extrapolation from actual test points in the neighborhood of 20 to 30 psi. tensile strength. For that reason, and also because the strength tests were made at atmospheric pressure, the data under this heading do not exactly describe the time to 8 psi. tensile strength in a well. The times are a little longer than that which would be found in actual practice, and thus become an added safety factor to the method herein proposed. But, in spite of the fact that the test data in Table III are not perfectly representative, the ratio of the time to 8 psi. strength to the time to 100 "poises" is surprisingly constant. The average ratio multiplied by the time to 100 "poises" would quite accurately predict when cement in the average well attains a strength of 8 psi. However, since it is desirable that cement in all wells, not just in the average well, reach a strength of 8 psi. before it is drilled out, the largest ratio, or three, must be used. In general, therefore, cement in wells will attain a tensile strength of at least 8 psi., the minimum strength requirement in wells, at a time corresponding to three times the time required for the cement to reach a consistency of 100 "poises" at well conditions of temperature and pressure. Or, for practical purposes,

$$\text{Minimum WOC time} = T_{8\text{ psi.}} = T_{100\text{ "poises"}} \times 3$$

Where: $T_{8\text{ psi.}}$ = time to a tensile strength of 8 psi.

$T_{100\text{ "poises"}} \times 3$ = Well simulation stirring time tests to consistency of 100 "poises"

It will be shown later that this method of predicting cement strength development in wells is actually more accurate than one is inclined to believe at this point. However, since the method involves several assumptions, thought was turned to the development of a more simple, more accurate method of determining strength development in wells.

PREDICTION OF CEMENT STRENGTH DEVELOPMENT IN WELLS - SECOND METHOD

When water is added to dry cement, chemical reactions occur which give off heat. It is this behavior of cement slurry that permits one to run a recording temperature instrument into a well after a casing cement job and locate the top of cement behind the pipe. It has been found that the temperature of cement behind casing may remain higher than the temperature of the adjacent formation for as long as 60 to 70 hours after pumping the cement into the well. Field tests have shown also that temperature surveys made at 24 hours or less after cement jobs show the tops of cement more distinctly, suggesting that sometime after cement is placed in a well the temperature increases to some maximum value above the surrounding strata then slowly decreases to the normal temperature at that depth. Laboratory tests were made to determine the time of maximum or peak temperature of cement slurries at various pressures and temperatures in simulation of various well depths.

An example of maximum temperature development in a standard portland cement slurry at three simulated well depths is shown in Figure 4. It will be observed that the greater the depth the quicker the cement reaches the maximum temperature. Viewing this behavior brings to mind the fact that the greater the depth the quicker cement stiffens and sets. That thought, in turn, suggests that the time to maximum temperature development in a well may be related to stirring time to 100 "poises". A number of tests were made on standard portland and slow set cements to throw some light on this subject.

A plot of the stirring time of various cements at various conditions of temperature and pressure, corresponding to wells of various depths, versus the time to the peak or maximum temperature development, Figure 5, suggests that these factors may be reasonably closely related to each other.

In other words, knowing the stirring time to 100 "poises", one can multiply that time by a factor (K) which is more than one but less than two and predict the approximate time when cement in wells will reach the peak temperature. Figure 5 indicates that the average K factor is somewhere between 1.5 and 2.0.

Field tests were then made to determine when cements in wells actually reach peak temperature and to determine how it is related to laboratory tests of stirring time to 100 "poises". The first test was run in a well in North Cowden Field, Ector County, Texas where 5-1/2 in. O.D. casing was set at 4624 ft. and cemented with 125 sacks of a standard portland cement. Immediately after pumping the cement down, a recording temperature element was lowered into the casing to a point well below the estimated top of the cement and was left at that point for approximately 24 hours. The temperature recorded during this time is plotted on Figure 6. The ratio of the time to the peak temperature in this well to the stirring time to 100 "poises", as determined by a laboratory well simulation test on the same cement, is 2.2, or slightly higher than the K factor indicated by previous laboratory tests.

Since the maximum temperature recorded in this well was so very much greater than the normal static formation temperature, approximately 94° F., at that depth, the thought occurred that perhaps if the casing being cemented is closed in after the cement is pumped down, expansion of the fluid in the casing should cause an increase in the shut-in casing pressure which would reach a maximum at approximately the same time the cement down the hole reaches its maximum temperature. This thought was investigated in the next field test.

In the next field tests, the test procedure used on the previous well was followed, except hourly readings of the shut-in casing pressure were taken. This well was located in Tri-Cities Field, Texas where 5-1/2 in. O.D. casing was set at 7681 ft. and cemented with 600 sacks of a slow set cement. Figure 7 shows the results of these tests. It will be observed that the pressure built up with temperature to approximately the peak, but unfortunately, the pressure on the casing was lost, bled off, at that time. Ratio of the time to peak temperature to the time to 100 "poises" was found to be 2.6.

Another test was run in Tri-Cities Field to obtain a record of the pressure build-up on the casing since readings were not taken to the maximum pressure on the previous well. In this test, 5-1/2 in. O.D. casing was set at 7612 ft. and was cemented with the same type and amount of cement. The results, shown on Figure 8, confirmed the thought that pressure on the casing after placing cement, reflects heat of hydration of cement in a well. The ratio of time to peak pressure to stirring time to 100 "poises" was 2.82 in this case. Why the peak temperature occurred in one well at 9 hours and 28 minutes and the peak pressure occurred at 12 hours and 16 minutes in another well of approximately the same depth is understandable after one considers the fact that the cement showed different setting time characteristics, although the same brand was used in both cases. Also another possible difference between these wells is the fact that the latter well was cemented during a season of the year when the atmospheric temperature was probably less than that at the time of cementing the first well. It is a well known fact that mud pit temperatures are affected by atmospheric temperature which, in turn, affect the bottom hole temperatures and therefore, the setting time of cement placed therein.

A pressure build-up test was made on a well in West Edmond Field, Oklahoma where 7-inch O.D. casing was set at 7028 ft. and cemented with 700 sacks of a special experimental oil well cement. Figure 9 shows that the ratio of peak pressure to 100 "poises" was 2.4.

Surface pipe, 10-3/4 in., was set at 649 ft. in a well in Sour Lake Field, Texas and cemented to the surface with 500 sacks of a standard portland cement. Figure 10 shows that the ratio of peak pressure to 100 "poises" was 2.1. Pressure was bled down once to permit installation of a recording pressure gage. Pressure was bled down at first to avoid subsequent high pressure on the casing. When the peak pressure was reached, a transit was set up some distance from the well and trained to a mark on the pipe to observe any settling of the pipe when the strain was released. The weight of the pipe was set down on the cement, but no movement was observed.

Earlier in the discussion it was shown by laboratory tests, that the ratio of the time to maximum temperature development in cement to the stirring time to 100 "poises" is equal to a factor (K) slightly less than 2 but more than 1.5. All field tests show that the ratio is slightly more than 2 but less than 3. Since the difference between laboratory tests and field tests is small, one might strike a compromise with the statement or conclusion that cements in wells reach peak or maximum temperatures at a time corresponding to approximately equal to twice the time required for the cement to attain a consistency of 100 "poises", under the particular laboratory consistometer test conditions used in this case. This relationship, along with others pointed to throughout the discussion, may be written as equations as follows:

laboratory predictions hold true in field practice is quite another matter. Field tests were made to check the correctness of these hypotheses.

FIELD TESTS

If the trends indicated by laboratory tests are fundamentally correct, the equation for predicting minimum WOC time will apply to all portland type cements in any well at any depth. Therefore, exceptions to Field rules were obtained where necessary to permit drilling out of cement as early as might be required to check laboratory tests. Wells were selected in various areas and at various stages of drilling in order to obtain data on jobs at various depths and with different types and brands of cements. Each job differed from normal practice only in the time of drilling out of the plug. Field men were instructed to take hourly readings of the shut-in casing pressure until it reached a maximum, release pressure at that point, run the bit into the hole, and to start drilling the plug at a time equal to the time to the maximum pressure times 1.5. Incidentally, field men were advised to bleed off the pressure at intervals if it reached dangerous proportions. The criterion is not necessarily the magnitude of the pressure, but, rather, is the point when the fluids inside the casing stop expanding as a result of an increase in temperature.

Table IV presents a summary of eight field tests where attempts were made to drill out cement at the minimum WOC time indicated by laboratory tests.

DISCUSSION

The field tests summarized in Table IV show by the drilling rates that the cement in each well had passed the final set, and therefore

$$T_{8\ psi.} = T_{Min.\ WOC} \tag{1}$$

$$T_{Min.\ WOC} = T_{100\ "poises"} \times 3 \tag{2}$$

$$T_{Max.\ Temp.} = T_{Max.\ csg.\ press.} \tag{3}$$

$$T_{Max.\ csg.\ press.} = T_{100\ "poises"} \times 2 \tag{4}$$

Therefore,

$$T_{Min.\ WOC} = T_{Max.\ csg.\ press.} \times 1.5 \tag{5}$$

where:

$T_{8\ psi.}$ = Time from mixing cement to a tensile strength of 8 psi.

$T_{Min.\ WOC}$ = Minimum waiting on cement time

$T_{100\ "poises"}$ = Cement well simulation stirring time test to 100 "poises" (Pressure consistometer; Stanolind test procedure)

$T_{Max.\ Temp.}$ = Time to maximum temperature development in cement.

$T_{Max.\ csg.\ press.}$ = Time to maximum shut-in pressure on casing.

Equation 5, which expresses the second method for predicting cement strength development in wells, simply means that all one has to do to determine the minimum WOC time in any well is read the shut-in casing pressure after landing the cement until it reaches a maximum, then multiply the time to that point, as measured from the time of mixing the first sack of cement, by a factor of 1.5. This method is much simpler than the first method and is much more accurate as it will reflect differences in well conditions and differences in cement behavior.

The foregoing equations describe relationships which laboratory tests indicate to be true, or approximately true, in wells with respect to minimum strength requirements and minimum WOC times. Whether or not the

ILLEGIBLE

had attained a tensile strength of at least 8 psi. as predicted by laboratory tests. It is also interesting to note the reasonably close agreement between the time to maximum pressure on the casing and laboratory stirring time to 100 "poises" x 2. These data show that cement tests can be made in the laboratory which will predict the approximate stiffening time of cement in wells. In three field tests unforeseen events delayed drilling of the plug to a time which approached the usual drilling out time and thus rendered those tests practically useless insofar as the subject experiment was concerned. The only information of significance obtained from those tests was that no slurry backflowed into the casing when the pressure was released. Many believe that releasing the pressure after it reaches the maximum is a more critical test than the test of drilling the shoe. They reason that if the cement is soft it will back up into the casing when pressure is released, especially if the common type of float equipment is not used as was the case in two of the wells tested.

The writer is of the opinion that the tests conducted on the surface pipe cement job at Sour Lake were more severe than those at any other location. The cement was apt to have been much more "green" when it was drilled than at any other test location, owing to the low curing (formation) temperature and pressure. Immediately after releasing the pressure, which, as stated before, may be a critical test of whether or not the cement has set, the master valve and blow-out preventer for 10-3/4 inch casing were set down on the casing. The cement not only supported the full weight of the casing at that point but held the very large weight of that equipment. Then after drilling the wooden plug and float collar and four or five feet of cement, the driller stopped rotation and set all the weight of the drill

TABLE IV

WOC FIELD TESTS

	Casing		Cement		Elapsed Time, Hrs., To							
Field	Size In.	Depth Ft.	Type	Sacks	Max. Csg. Pressure	Stirring Time 100 "poises" x 2	Release of Csg. Press.	Plug Drilled at Hrs.	Time to Max. Csg. Press. x 1.5, Hrs.	Drilling Rate Min. Ft.	Wt. on Bit M#s	R.P.M.
Fullerton, Texas	7-5/8	3771	Common	2000	≠	6.16	7.38	12.25	9.24	5	5	55
Fullerton, Texas	7-5/8	3805	"	1800	7.25	7.23	8.0	16.0	10.87	5	2	50
Fullerton, Texas	7-5/8	3785	"	1900	7.05	6.16	7.20	11.2	10.57	2.4	2	50
Fullerton, Texas	5-1/2	6765	Slow Set	350	≠	8.0	7.07	26.2	12.0*	2.0	3	50
Sittner, Kansas	5-1/2	3612	Common	150	≠	8.5	9.53	16.2	12.75*	3	3	50
W. Edmond, Okla.	7	7005	"	700	≠	5.33	6.92	**	8.0*	-	-	-
Sour Lake, Tex.	10-3/4	647	"	500	14.77	14.0	14.77	24.27	22.15	0.5	6	100
Riverside, Texas	5-1/2	6415	Slow Set	750	10.12	8.8	11.0	**	15.16	-	-	-
High Island, Texas	7	5704	" "	750	15.67	11.10	15.67	**	23.5	-	-	-
Elk Basin, Wyoming	7	5300	Common	300	8.00	7.40	8.0	24.3	12.0	2.5	6	90

* T to 100 "poises" x 3
** Not drilled early
≠ Head leaked

pipe, kelley, and swivel (8 points) down on the cement, then increased the pump speed to a relatively high rate to see if the cement could be washed out. The weight indicator had picked up no weight after circulating six minutes. The driller termed the cement as drilling "firm to hard."

The cement in all the tests where the plug was drilled reasonably soon after the specified time drilled firm to hard inside the pipe and gave no evidence of backflow into the casing after the shoe was drilled. Also, in no case was the cement sufficiently soft to be circulated out.

These data indicate that basing WOC time on the time to maximum casing pressure times a factor is fundamentally sound and applicable to field practice. It would appear that such a system as this would be particularly attractive as a basis for State or Field rules since the time to maximum shut-in casing pressure reflects individual conditions of the well as they affect the particular type of cement used in that well. The multiplier 1.5 merely sets the time back to allow a minimum strength to be developed. Unless further field experience proves that the multiplier 1.5 is too low, there is little reason for suggesting that a waiting period longer than that prescribed by the formula should be used. These tests indicate that few will be the cases where rig operations will permit cement to be drilled out at the minimum time. This suggests that the phrase "waiting on cement time" should be deleted from our vocabulary since it has been found that the cement usually waits on the drilling crew.

Much must be done before full advantage can be taken of the indicated savings in time. Aside from the fact that certain regulations will have to be modified, certain of the routine of rigging up and handling of rig operations may have to be shifted. For example, much of the rigging up or repair around a rig which now is deferred until WOC time may be handled by extra roustabout help or may be done by the rig crew during slack time while drilling. Also, much time is now spent in changing rams on blowout preventers and in the installation of the master valve and the blowout preventer after setting surface pipe. If this equipment were made up in a shop ready to be flanged onto the surface pipe, it appears that it could be installed as a unit with a great deal more efficiency.

As an example of the saving which might be effected by reducing WOC time, the over-all average WOC time on Stanolind Oil and Gas Company properties is approximately 51 hours per casing cement job. This figure is lower than might be expected because it includes practices in areas where no regulations exist. The over-all average WOC time indicated by the method proposed in this paper is estimated to be approximately 15 hours per casing cement job. This suggests a saving of 36 hours per job. However, practical considerations teach that few would be the cases where the crew would be able to start drilling on the plug that early. It has been estimated that, at least until the present rig routine is appropriately modified, the plug cannot easily be drilled out before an average time of approximately 21 hours after cementing casing. Therefore, it appears that an average of 30 hours per cement job might be saved without much difficulty.

Translating rig time into dollars at $20.00/hr., an average of $600.00 per casing cement job or at least $1200.00 per well, assuming two cement jobs per well, should be saved. Realizing that over 24,000 wells were drilled in the United States during 1944, one can appreciate how reducing WOC time might benefit the industry.

SUMMARY

It has been shown that the minimum waiting on cement time in wells can be reasonably accurately predicted by laboratory well simulation tests, but can be more simply determined by observing the shut-in pressure on the casing to a maximum value then multiplying the time from initial mixing to the time maximum pressure is reached by a factor of 1.5. Field tests show that the cement has ample strength to support the pipe and withstand the shock of drilling at that time.

A great deal of waiting on cement time may be eliminated if regulations are relaxed and if rigging up and drilling routine is adjusted to fit in with minimum cement waiting time requirements.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Stanolind Oil and Gas Company for permission to prepare and publish this paper; to S. C. Oliphant and D. D. Burrows for suggestions which encouraged the development of this method; to J. B. Clark for helpful suggestions and criticisms; to C. R. Fast for his assistance in conducting both the laboratory and field tests; and to Stanolind Oil and Gas Company's Division and Field personnel for arranging and conducting the field tests.

BIBLIOGRAPHY

1. R. Floyd Farris: "A Practical Evaluation of Cements for Oil Wells", Drilling and Production Practice, American Petroleum Institute, New York, 1941.
2. N. Healey and S. L. Pease: "Hardening Times for Casing Cementation", Journal of the Institute of Petroleum, Volume 28, 1942.
3. R. W. French: "Geothermal Gradients in California Oil Wells", Drilling and Production Practice, A.P.I., New York, 1939.

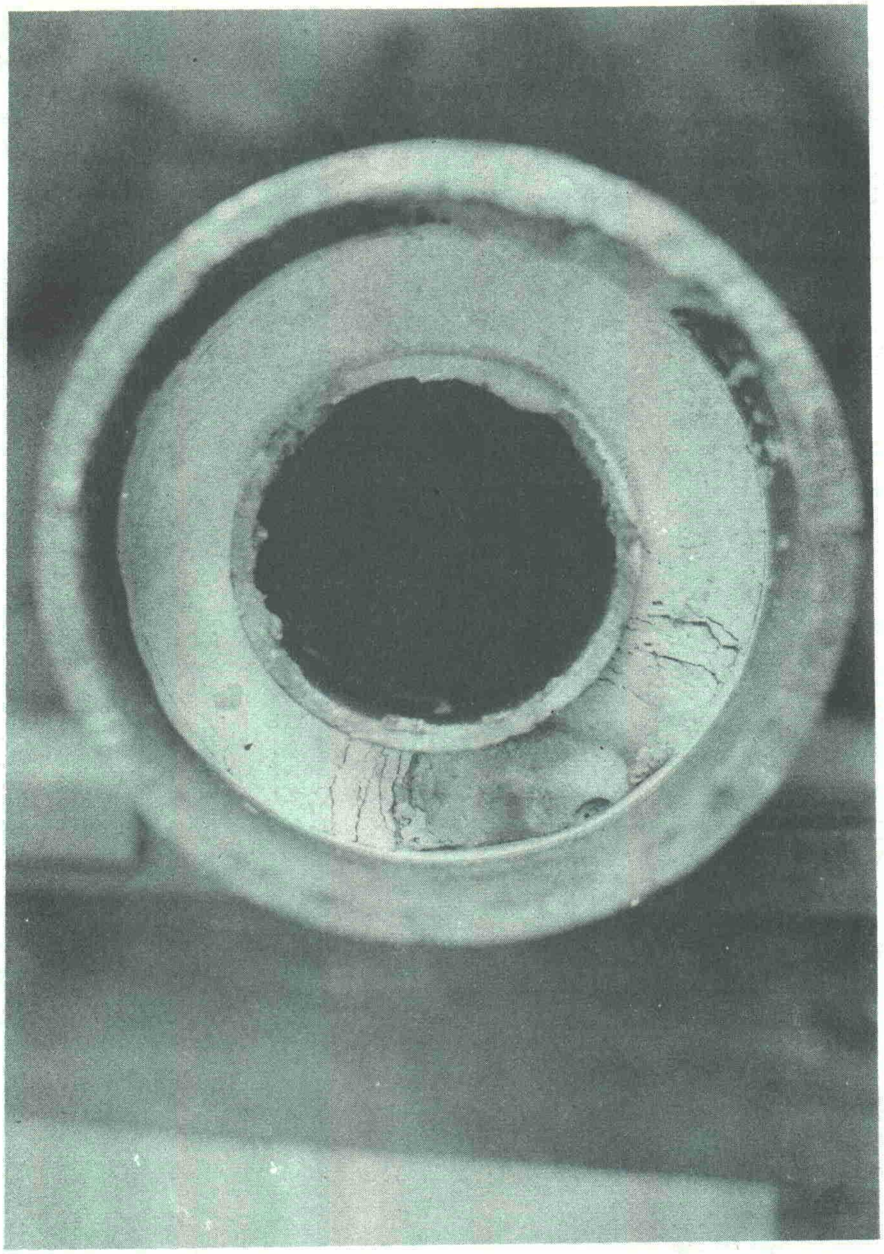


Figure 1

End view of 5-1/2 in. O.D. casing inside 9-5/8 in. O.D. casing showing cement in the annulus.

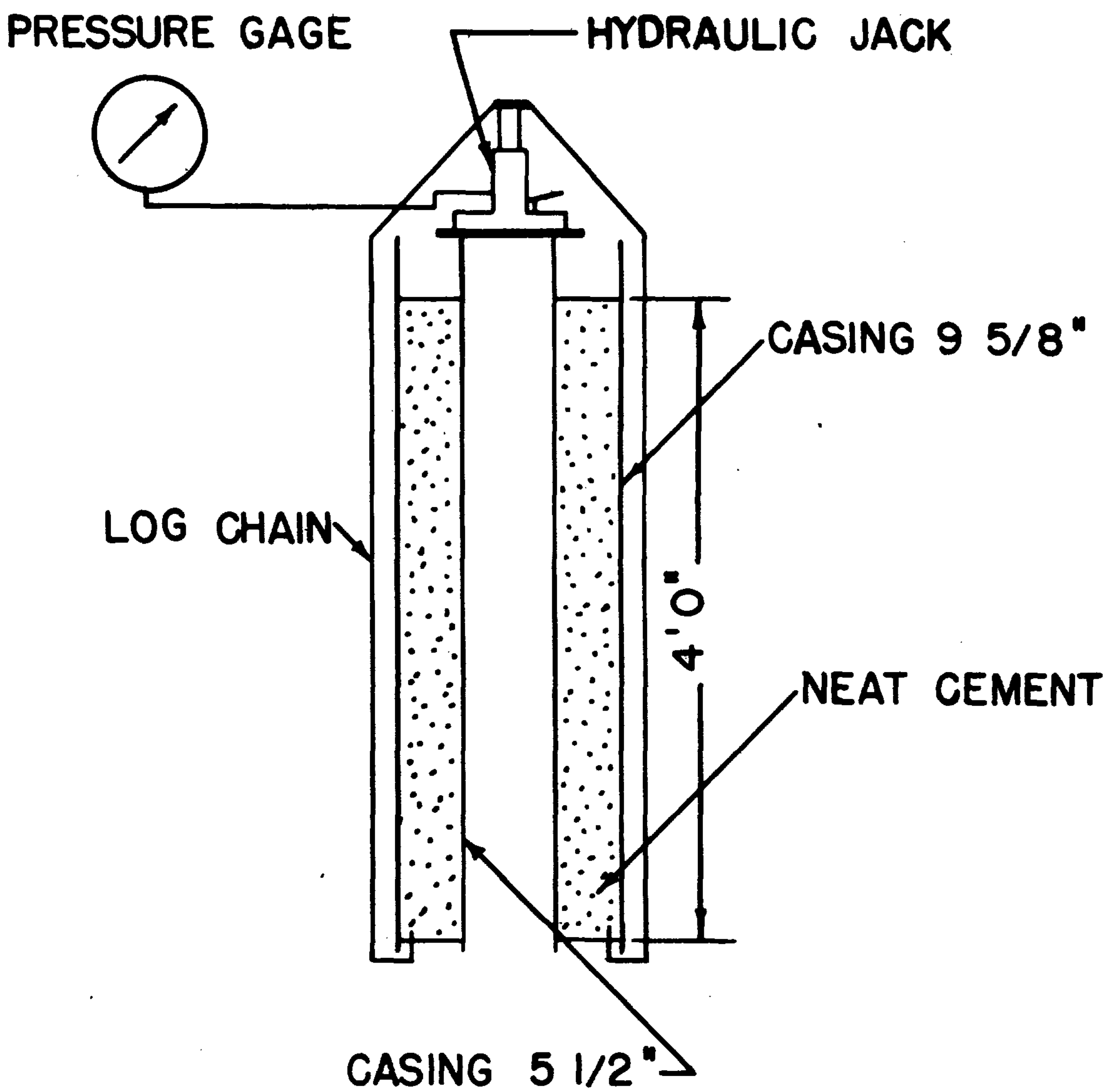
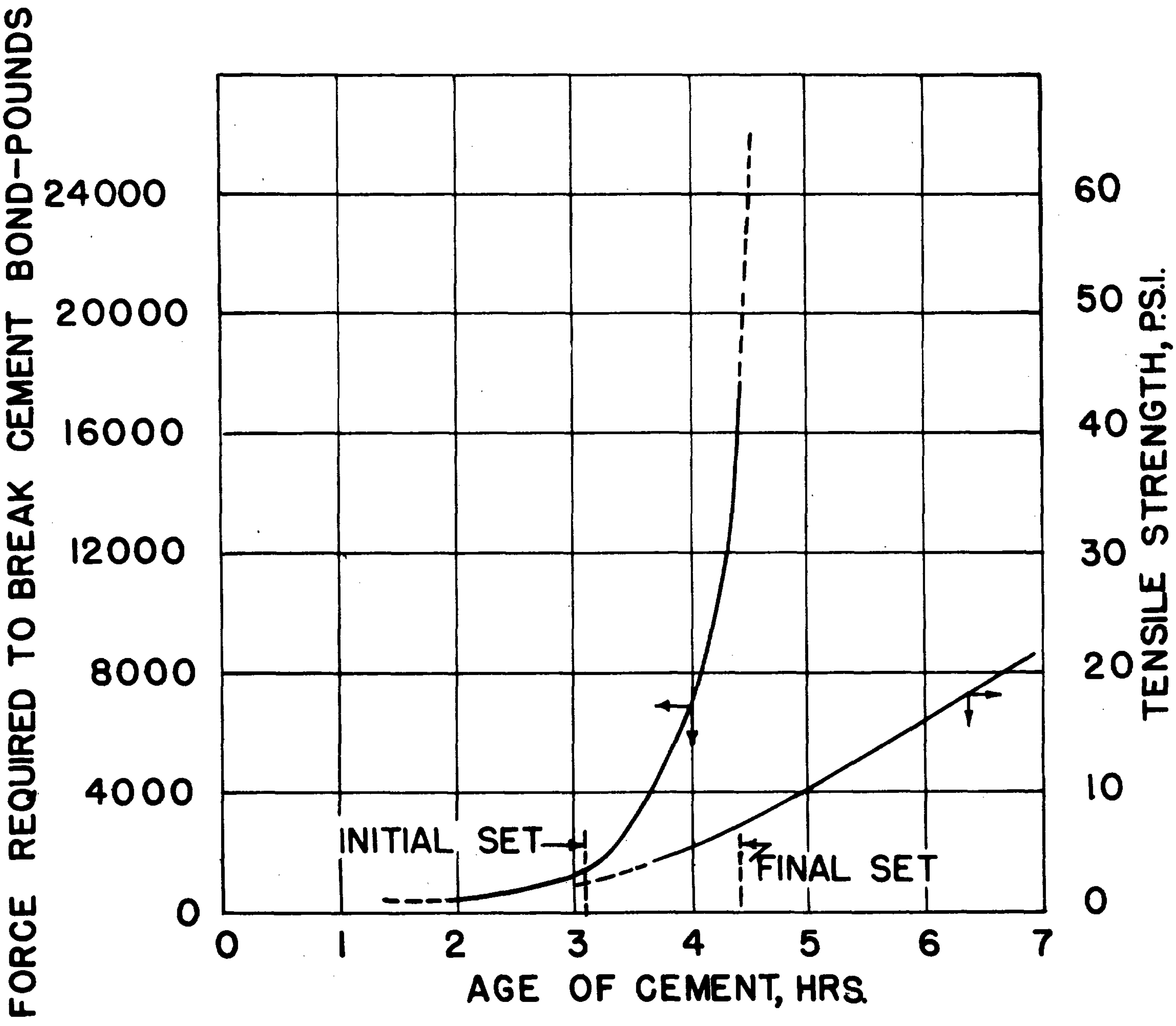

PRESSURE GAGE
HYDRAULIC JACK
CASING 9 5/8"
LOG CHAIN
4'0"
NEAT CEMENT
CASING 5 1/2"

FIG. 2



FORCE REQUIRED TO BREAK CEMENT BOND-POUNDS
24000
20000
16000
12000
8000
4000
0
TENSILE STRENGTH, P.S.I.
60
50
40
30
20
10
0
INITIAL SET
FINAL SET
0
1
2
3
4
5
6
7
AGE OF CEMENT, HRS.

FIG. 3

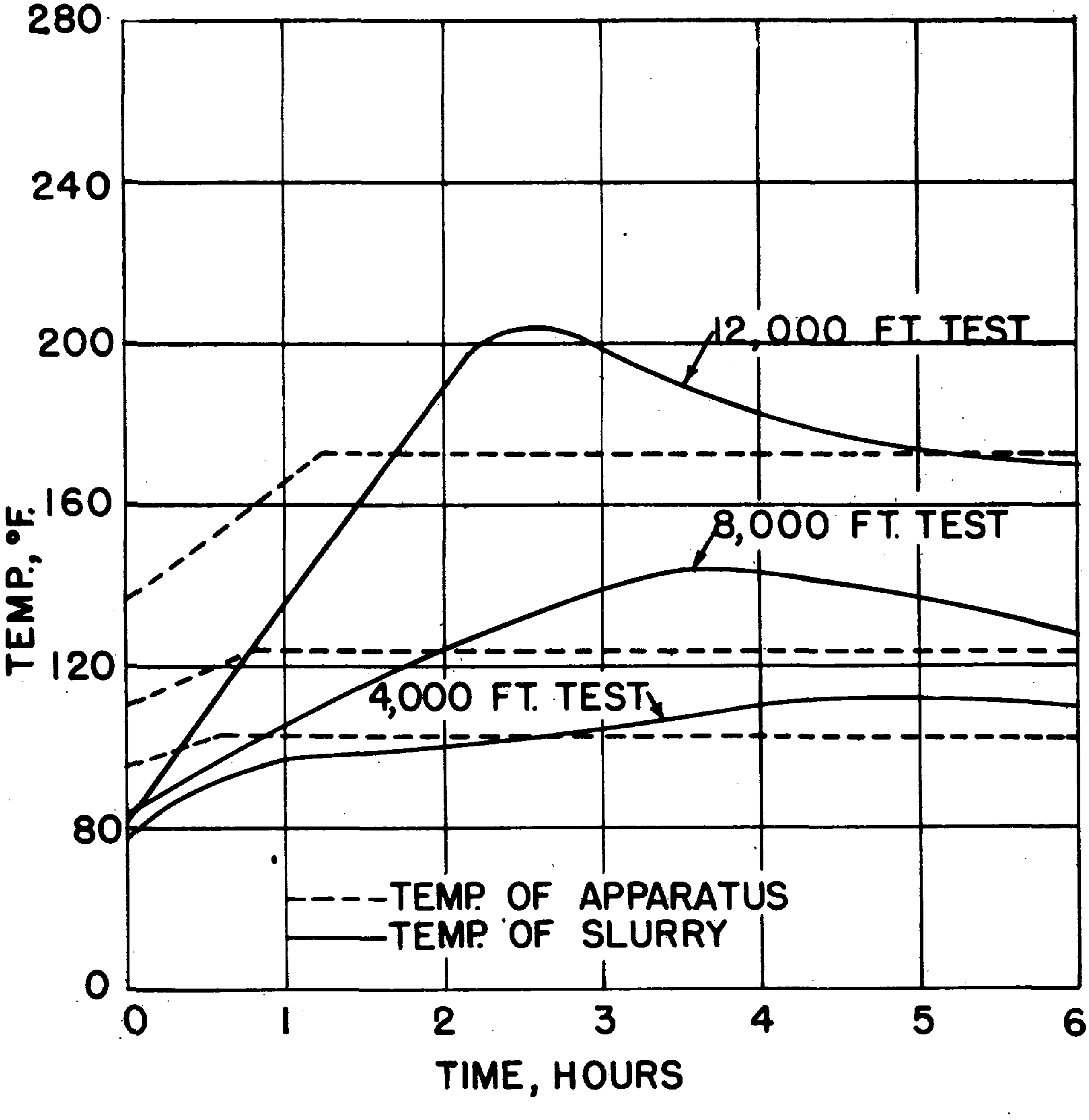

280
240
200
160
120
80
0
TEMP., °F.
0
1
2
3
4
5
6
TIME, HOURS
12,000 FT. TEST
8,000 FT. TEST
4,000 FT. TEST
TEMP. OF APPARATUS
TEMP. OF SLURRY

FIG. 4

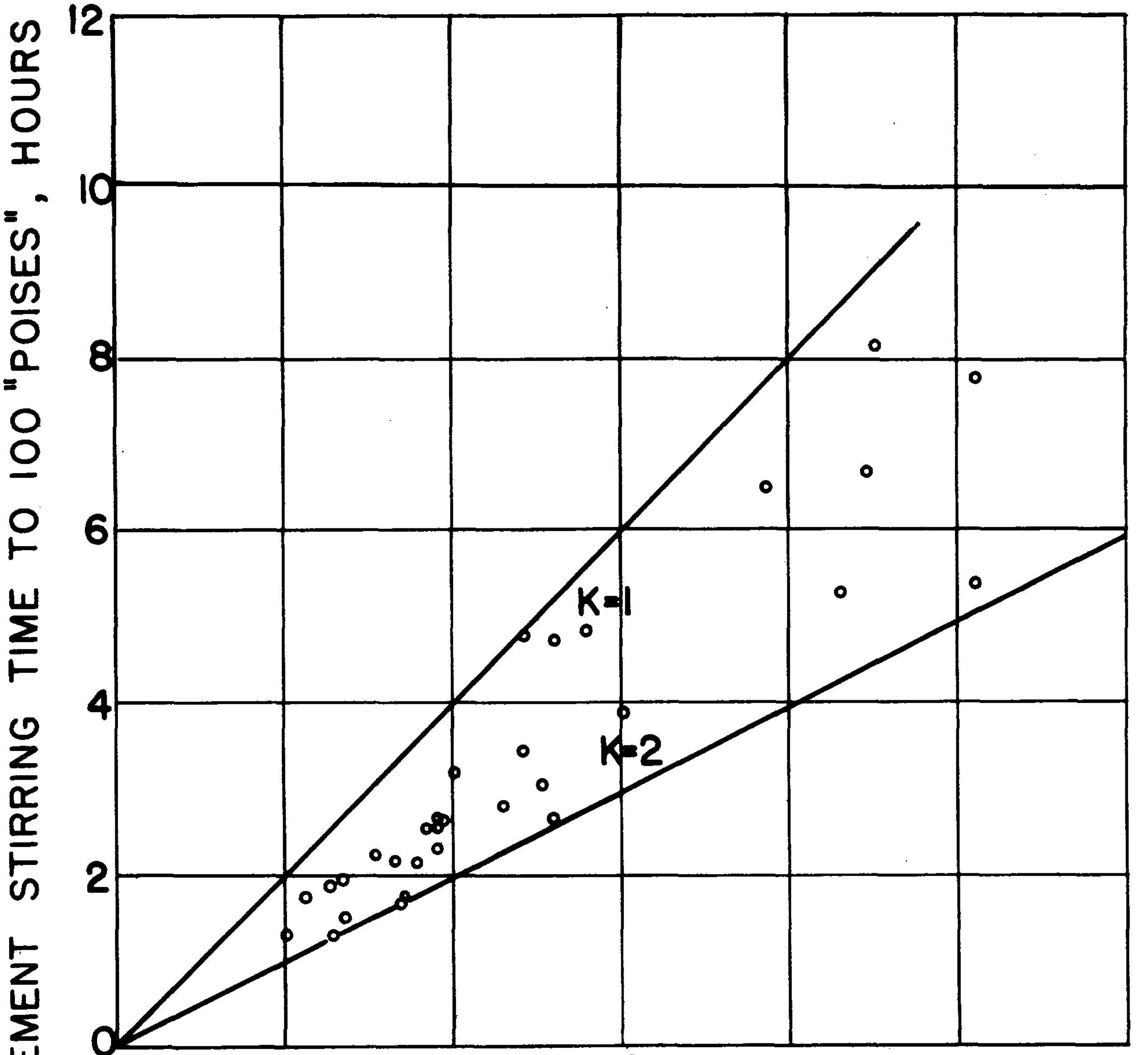

CEMENT STIRRING TIME TO 100 "POISES", HOURS
TIME TO PEAK TEMPERATURE, HOURS
K=1
K=2
0
2
4
6
8
10
12

FIG. 5

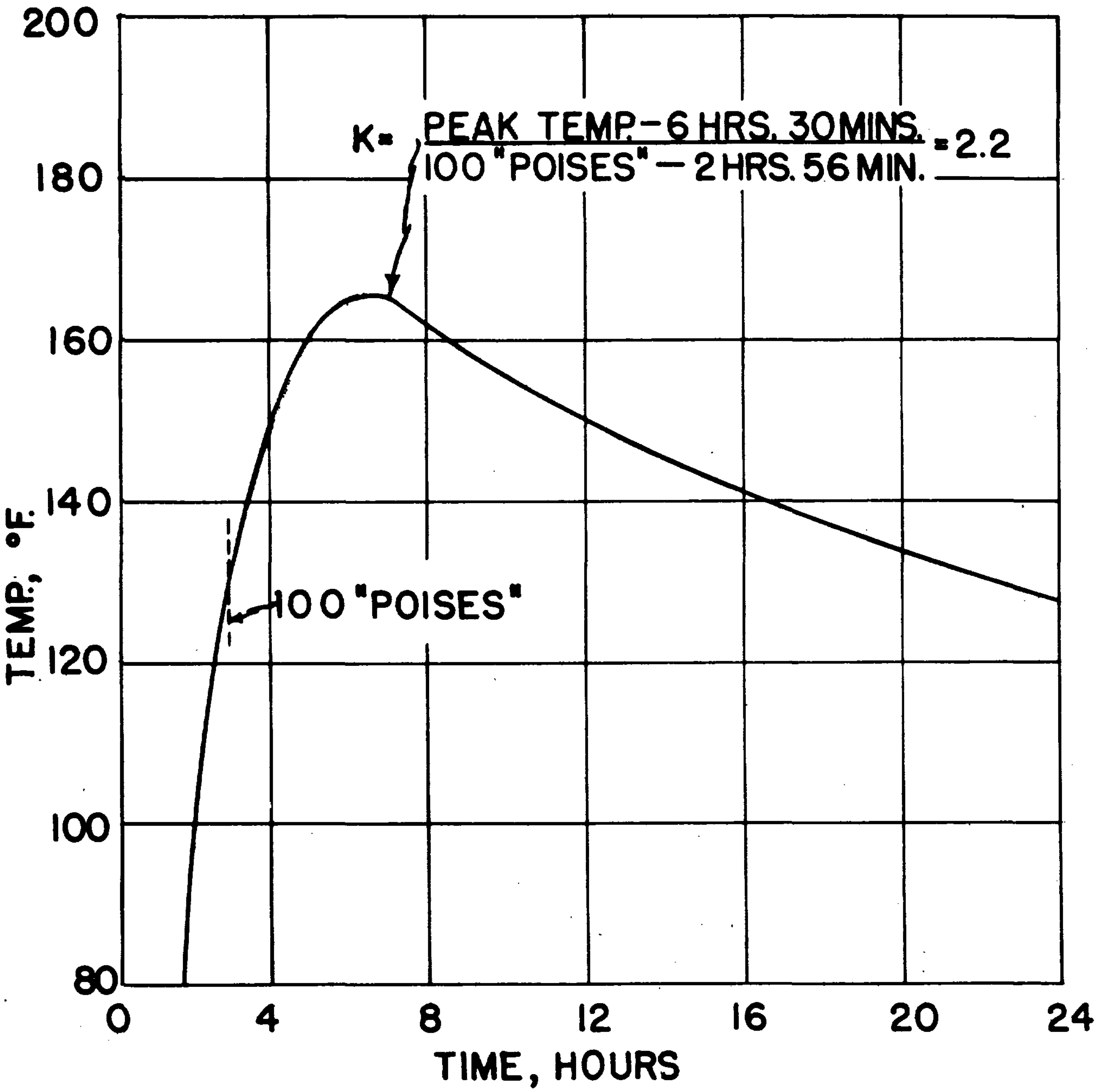
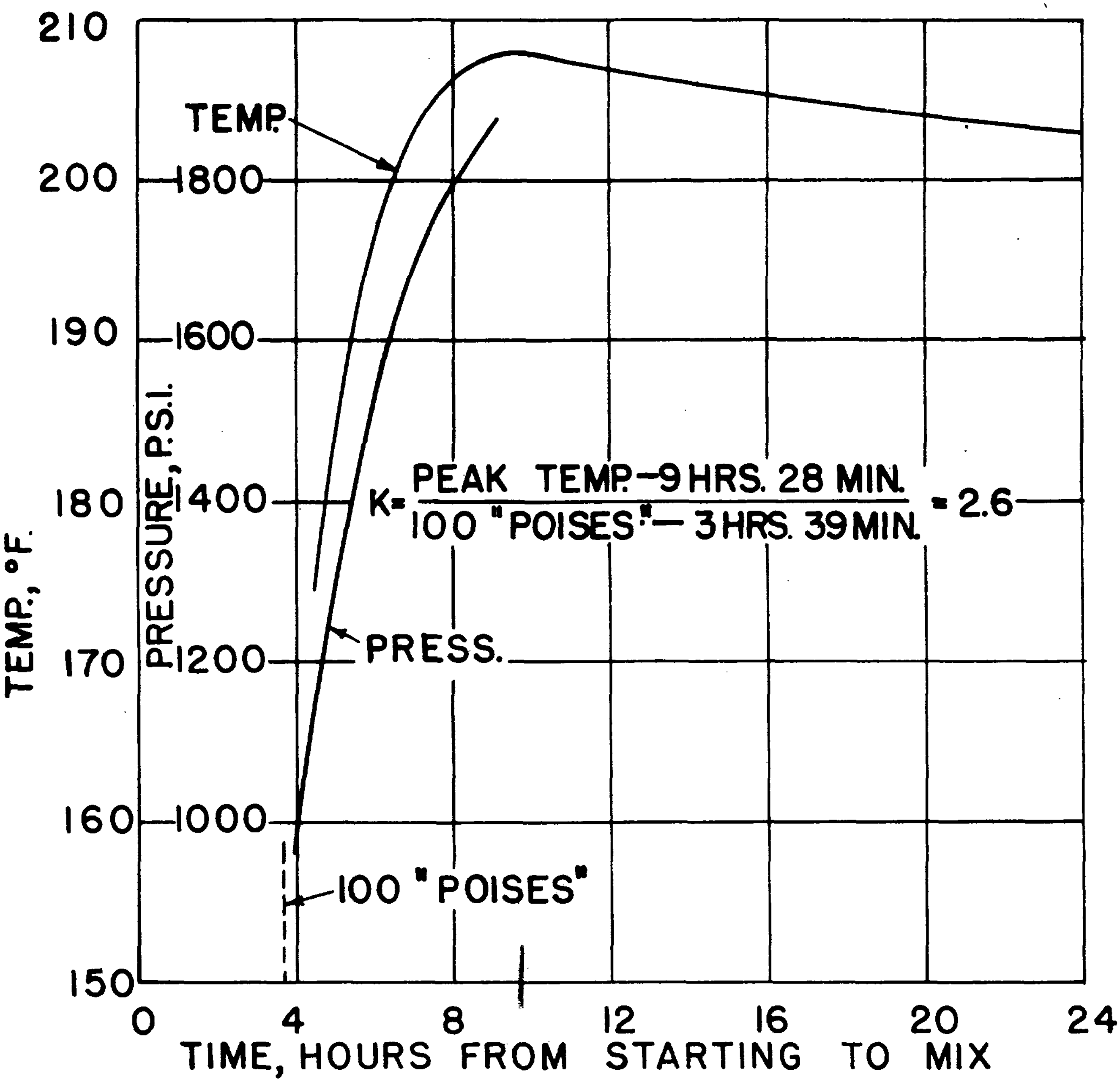

K= PEAK TEMP.−6 HRS. 30 MINS. / 100 "POISES" − 2 HRS. 56 MIN. = 2.2
100 "POISES"
TEMP., °F.
200
180
160
140
120
100
80
0
4
8
12
16
20
24
TIME, HOURS

FIG. 6



210
200
190
180
170
160
150
1800
1600
1400
1200
1000
TEMP., °F.
PRESSURE, P.S.I.
TEMP.
PRESS.
K= PEAK TEMP.—9 HRS. 28 MIN. / 100 "POISES"— 3 HRS. 39 MIN. = 2.6
100 "POISES"
0
4
8
12
16
20
24
TIME, HOURS FROM STARTING TO MIX

FIG. 7

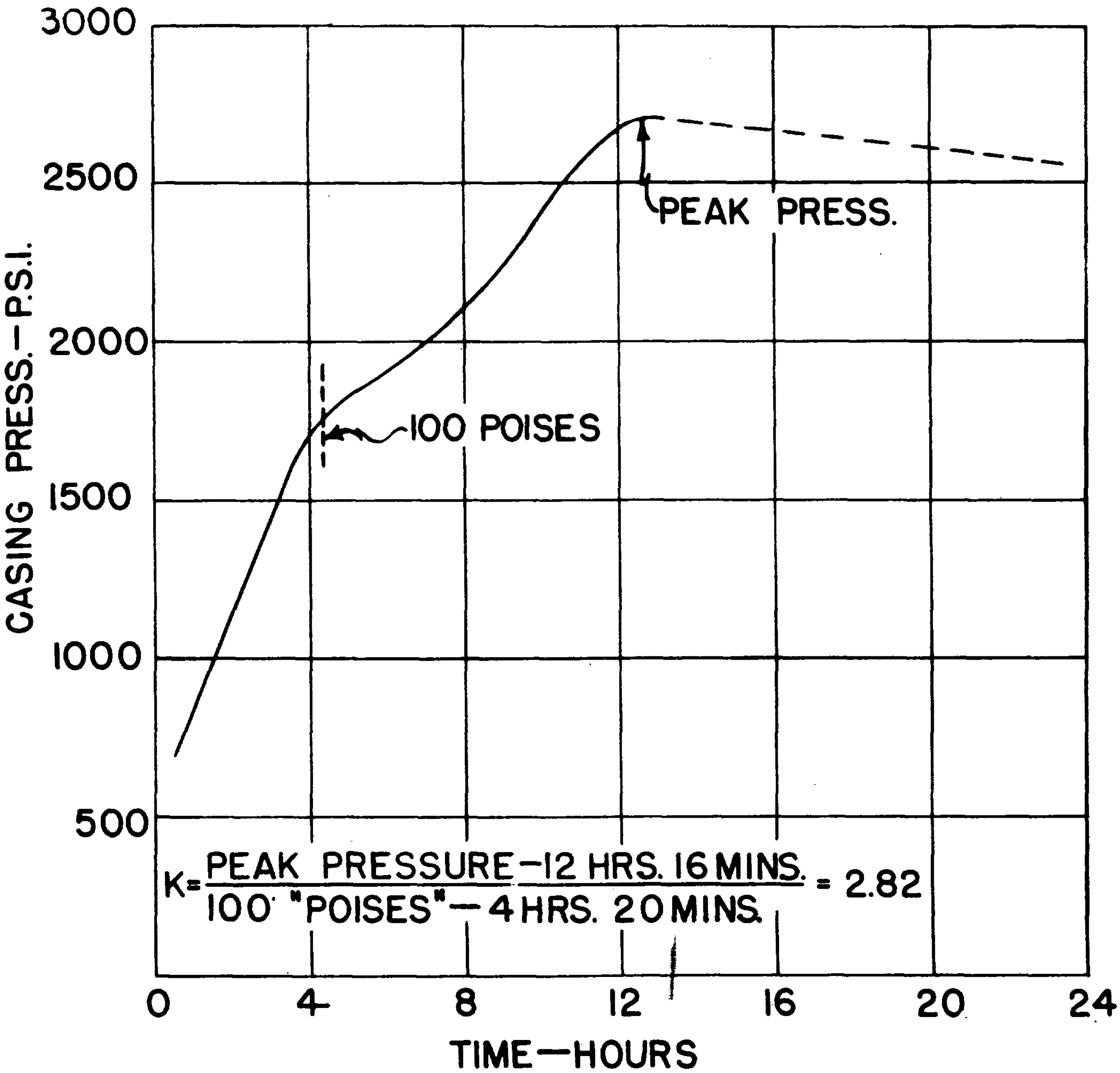
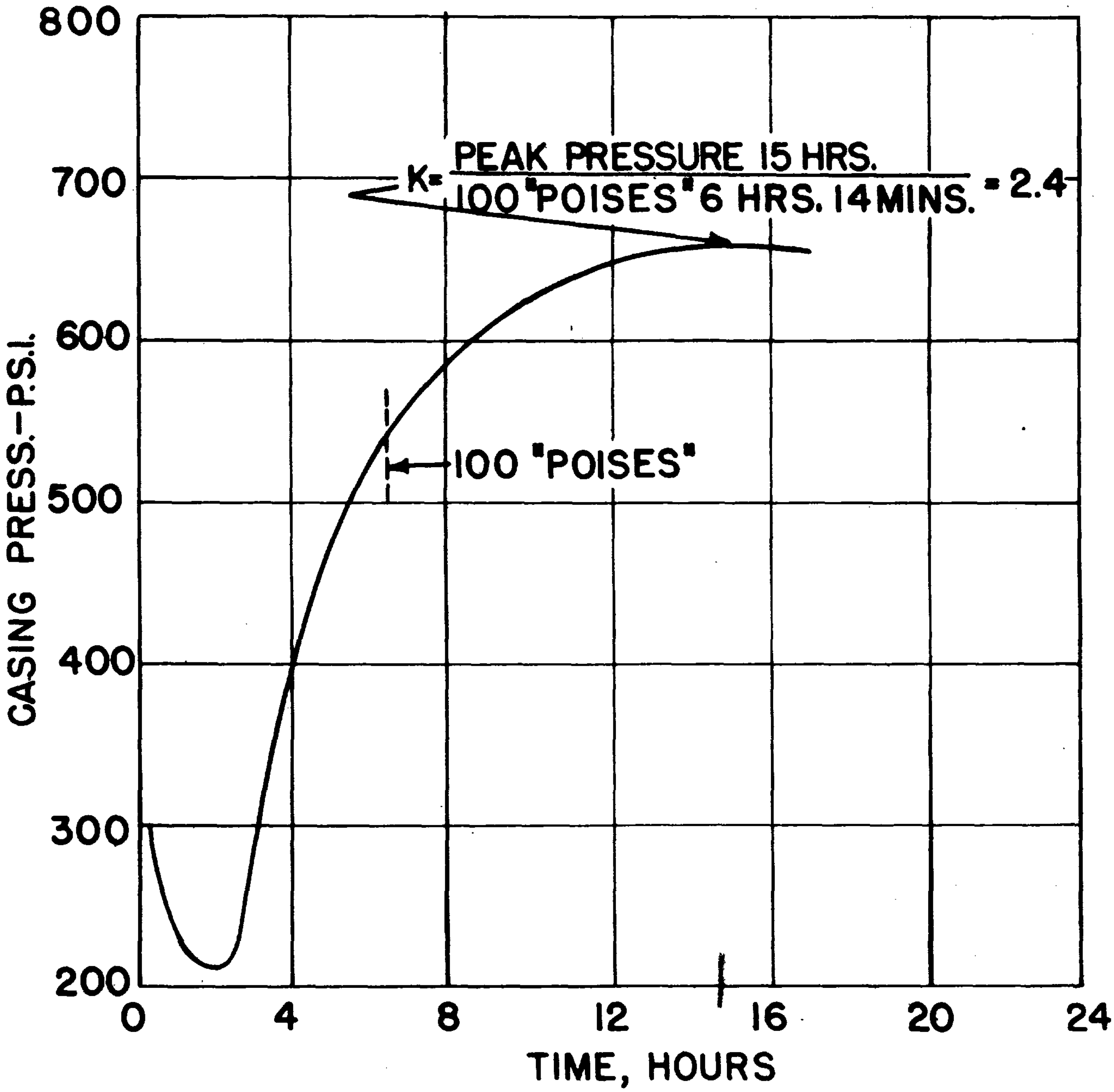

3000
2500
2000
1500
1000
500
CASING PRESS.—P.S.I.
PEAK PRESS.
100 POISES
K= PEAK PRESSURE—12 HRS. 16 MINS. / 100 "POISES"—4 HRS. 20 MINS. = 2.82
0
4
8
12
16
20
24
TIME—HOURS

FIG. 8



800
700
600
500
400
300
200
CASING PRESS.-P.S.I.
0
4
8
12
16
20
24
TIME, HOURS
K= PEAK PRESSURE 15 HRS. / 100 "POISES" 6 HRS. 14 MINS. = 2.4
100 "POISES"

FIG. 9

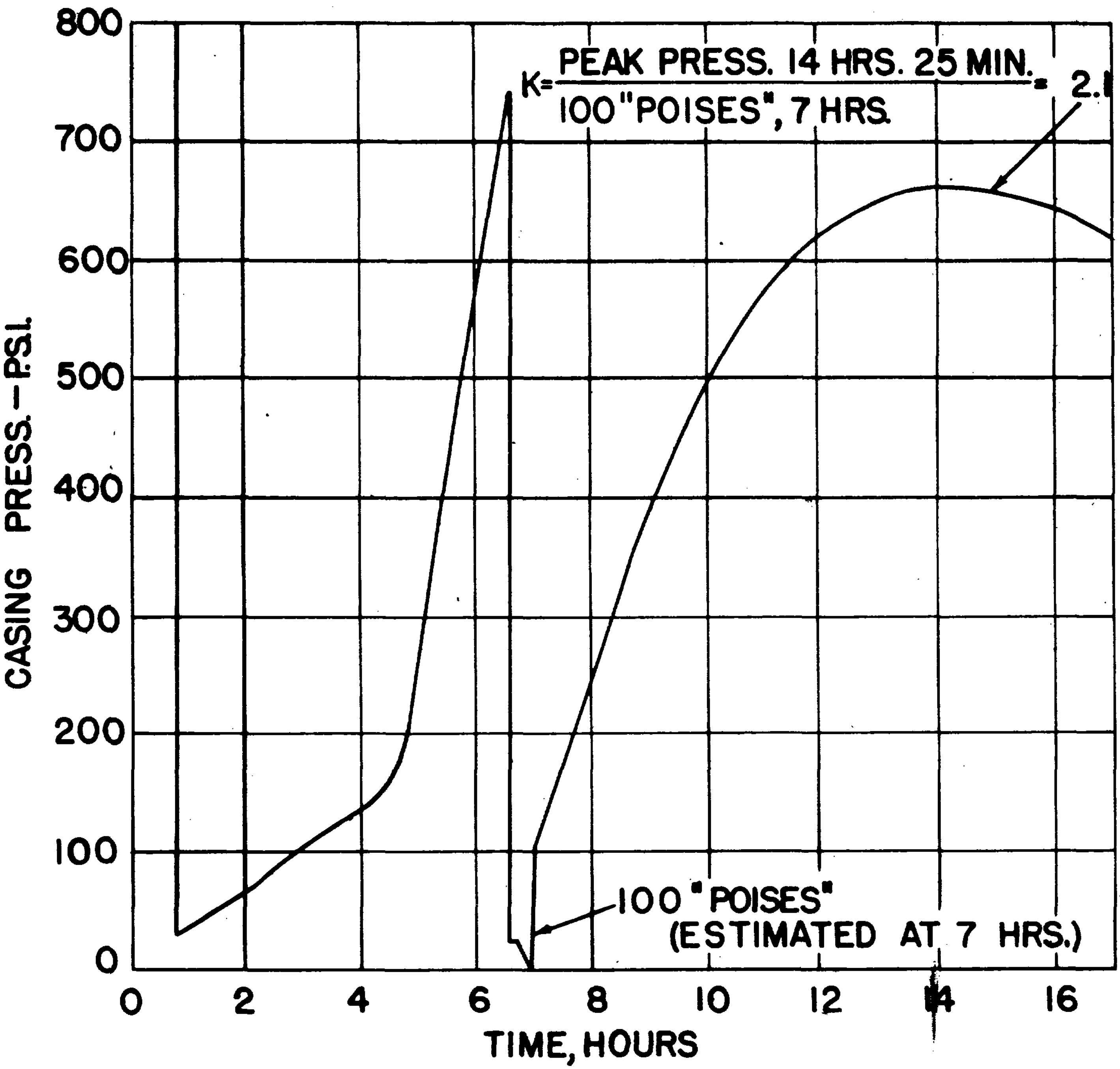

K= PEAK PRESS. 14 HRS. 25 MIN. / 100 "POISES", 7 HRS. = 2.1
100 "POISES" (ESTIMATED AT 7 HRS.)
CASING PRESS. – P.S.I.
TIME, HOURS
0
100
200
300
400
500
600
700
800
0
2
4
6
8
10
12
14
16

FIG. 10

TO ALL OPERATORS

PLEASE FIND ATTACHED COMMISSION ORDERS # 698 & 699

GLENN STALEY

LEA COUNTY OPERATORS COMMITTEE
HOBBS, NEW MEXICO
APRIL 14, 1947

FORE THE OIL CONSERVATION COMMI ION
OF THE STATE OF NEW MEXICO

IN THE MATTER OF THE HEARING CALLED BY THE OIL CONSERVATION COMMISSION OF THE STATE OF NEW MEXICO FOR THE PURPOSE OF CONSIDERING:

CASE NO. 90

ORDER NO. 698

THE APPLICATION OF STANOLIND OIL AND GAS COMPANY FOR MODIFICATION OF THE RULES AND REGULATIONS OF THE COMMISSION WITH RESPECT TO THE PERIODS PRESCRIBED FOR WAITING ON CEMENT IN CONNECTION WITH THE CEMENTING OF CASING.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at ten o'clock A.M. January 10, 1947 at Santa Fe, New Mexico before the Oil Conservation Commission of New Mexico, hereinafter referred to as the "Commission".

NOW, on this 8 day of April, 1947, the Commission having before it for consideration the testimony adduced at the hearing of said case, and being fully advised in the premises;

IT IS THEREFORE ORDERED THAT:

SECTION 1. That part of Order 52(Lea County Rules), captioned "Casing Tests for all Fields" be and the same is hereby amended to read as follows:

The surface casing string shall be tested after drilling plug by bailing the hole dry. The hole shall remain dry for one hour to constitute satisfactory proof of a water shut-off. The surface casing shall stand cemented for at least 24 hours before drilling plug. The conductor string of one to three joints need not be tested after cementing.

The intermediate string shall stand cemented not less than 30 hours before testing pipe and cement. Tests of pipe and cement shall consist of building up a pressure of 1,000 pounds, closing valves, and allowing to stand 30 minutes. If the pressure does not drop more than 100 pounds during that period, the test shall be considered satisfactory. This test shall be made both before and after drilling plug.

The production string shall stand cemented not less than 30 hours before testing casing. This test shall be made by building up a pressure of 1,000 pounds, closing valves, and allowing to stand 30 minutes. If the pressure does not drop more than 100 pounds during that period, the test shall be considered satisfactory.

All cementing shall be done by the pump and plug method, except that this method shall be optional for a conductor of one to three joints.

Bailing tests may be used on all casing and cement tests and drill stem tests may be used on cement tests, in lieu of pressure tests. In making bailing tests, the well shall be bailed dry and remain approximately dry for 30 minutes.

If any string of casing fails while being tested by pressure or by bailing test, herein required, it shall be recemented and retested, or an additional string of casing shall be run and cemented. If an additional string is used, the same tests shall be made as outlined for the original string. In submitting Form C-101, "Notice of Intention to Drill", the number of sacks of cement to be used on each string of casing shall be stated.

Done at Santa Fe, New Mexico as of the day and year hereinabove designated.

OIL CONSERVATION COMMISSION

THOMAS J. MABRY, CHAIRMAN

JOHN E. MILES, MEMBER

R. R. SPURRIER, SECRETARY

LEA COUNTY OPERATORS COMMITTEE
HOBBS, NEW MEXICO
April 14, 1947

FORE THE OIL CONSERVATION COMMI ION
OF THE STATE OF NEW MEXICO

IN THE MATTER OF THE HEARING CALLED BY THE OIL CONSERVATION COMMISSION OF THE STATE OF NEW MEXICO FOR THE PURPOSE OF CONSIDERING:

CASE NO. 91

ORDER NO. 699

THE APPLICATION OF GULF OIL CORPORATION FOR THE PROMULGATION OF AN ORDER REVISING RULE 15, GENERAL ORDER NO. 4 "OIL TANKS AND FIRE WALLS".

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at ten o'clock A.M. January 10, 1947 at Santa Fe New Mexico befor the Oil Conservation Commission of New Mexico, hereinafter referre to as the "Commission".

NOW, on this 8 day of April, 1947, the Commission having before it for consideration the testimony adduced at the hearing of said case, and being fully advised in the premises;

IT IS THEREFORE ORDERED THAT:

SECTION 1. That part of Order 4 of the Commission (General Rules), captioned "Rule 15. Oil Tanks and Fire Walls", be and the same is hereby amended to read as follows:

Oil shall not be stored or retained in earthen reservoirs, or in open receptacles. All lease, stock and oil storage tanks shall be protected by a proper fire wall, which wall shall form a reservoir having a capacity one-third larger than the capacity of the enclosed tank or tanks in the following cases:

Where any such tanks are within the corporate limits of any city, town or village; or where such tanks are closer than 500 feet to any highway or inhabited dwelling or closor than 1000 feet to any school or church; or where any such tanks are so located as to be deemed an objectionable hazard within the discretion of the Commission. Such tanks shall not be erected, enclosed or maintained closer than 150 feet to the nearest producing well.

Done at Santa Fe, New Mexico as of the day and year hereinabove designated.

OIL CONSERVATION COMMISSION

THOMAS J. MABRY, CHAIRMAN

JOHN E. MILES, MEMBER

R. R. SPURRIER, SECRETARY

LEA COUNTY OPERATORS COMMITTEE
HOBBS, NEW MEXICO
April 14, 1947

SUMMARY OF MINIMUM W.O.C. EXPERIMENTS - LEA CO., N. M.

Well	Size Pipe	Depth	Sacks Cement	Type Cement	Elapsed Time To- Max. Csg. Press.	Max. Press. X 1.5	Pressure Released	Start Drlg. Plug	Drlg. Time Min./Ft.	Wt. on Bit M#	Rev. Per Min.	Pump Press.
Rowan-Elliott B-15 #2	9-5/8"	1165	650	Incor High-Early			21.3	50.2 hrs.	.67	Full	90	500
	7"	5350	500	Incor High-Early	8 hrs.	12 hrs.	?	43	.29	4	57	900
Rowan-Elliott B-9 #3	5½"	8189	750 700	Common Incor-H.E.	8	12						
Anderson-Prichard Parcell 1	9-5/8"	3003	1150	Common			10 hrs.	17.5	1.1*	18		700
Rowan-Elliott B-9 #2	5"	5514	400	Incor High-Early	3.85	5.77	4.5	26.5	2.0	3	60	?

*Cement Cored.

	Remarks
Rowan-Elliott B-15 #2	No Pressure Build-up. Did not bump float collar.
Rowan-Elliott B-15 #2	Mud Temp. 79° F. Rig repairs delayed early drilling of plug.
Rowan-Elliott B-9 #3	Pipe was set through pay. No cement was drilled.
Anderson-Prichard Parcell 1	No pressure build-up. Did not bump float collar. 11' of cement was cored and 2' was recovered at surface 22.5 hours after first cement mixed. Core was hard and firm.
Rowan-Elliott B-9 #2	1278 feet of cement left in pipe, as cement circulation stopped. Cement drilled firm.